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SHORT COMMUNICATION

CHANGES IN NORTH AMERICAN SPRING

MARK D. SCHWARTZ* and BERNHARD E. REITER
Department of Geography, P.O. Box 413, University of Wisconsin-Milwaukee, Milwaukee, WI 53201 0413, USA

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ABSTRACT

Onset of the growing season in mid-latitudes is a period of rapid transition, which includes heightened interaction between living organisms and the lower atmosphere. Phenological events (seasonal plant and animal activity driven by environmental factors), such as first leaf appearance or flower bloom in plants, can serve as convenient markers to monitor the progression of this yearly shift, and assess longer-term change resulting from climate variations. We examined spring seasons across North America over the 1900–1997 period using modelled and actual lilac phenological data. Regional differences were detected, as well as an average 5–6 day advance toward earlier springs, over a 35-year period from 1959–1993. Driven by seasonally warmer temperatures, this modification agrees with earlier bird nesting times, and corresponds to a comparable advance of spring plant phenology described in Europe. These results also align with trends towards longer growing seasons, reported by recent carbon dioxide and satellite studies. North American spring warming is strongest regionally in the northwest and northeast portions. Meanwhile, slight autumn cooling is apparent in the central USA. Copyright © 2000 Royal Meteorological Society.

KEY WORDS: phenology; climate change; global change; spring; North America; modelling

1. INTRODUCTION

Plants in mid-latitudes are adapted to a seasonal climate that includes cold–warm phases and fluctuations in light. Timing of phenological events (seasonal plant and animal activity driven by environmental factors, such as first leaf appearance or flower bloom in plants) can be influenced by various local and genetic factors, permitting plants to serve as effective indicators of environmental change (Schwartz, 1997, 1998; Menzel and Fabian, 1999; Sparks and Crick, 1999). Vegetation is particularly responsive to temperature variations in the spring season. Thus, spring plant phenology data are extremely useful for monitoring the impact of climate variations (Running and Hunt, 1993; Myneni *et al.*, 1997; Schwartz, 1999).

We were intrigued by the shift towards an earlier onset of phenological spring reported in Europe over the 1959–1993 period (Menzel and Fabian, 1999), and wished to replicate and expand upon that study in North America, if possible. Unlike Europe, long-term geographically-dispersed phenological records are limited to a few indicator shrub species in North America, with most station inventories shorter than 20 years (Caprio, 1993; Schwartz, 1997). Fortunately, proxy phenology measures—the spring index first leaf, first bloom and affiliated model output—have proven effective in generating accurate simulations of genera *Syringa* and *Lonicera* (lilac and honeysuckle) indicator phenology from commonly available daily maximum–minimum temperature series. These spring index models have also been successfully linked to broader multi-species springtime vegetation growth and development across eastern North America (Schwartz, 1997, 1998; Schwartz and Reed, 1999). Application of these techniques to the entire continent is a practical extension of previous work, and will allow for the assessment of regional change patterns.

* Correspondence to: Department of Geography, P.O. Box 413, University of Wisconsin-Milwaukee, Milwaukee, WI 53201 0413, USA; tel.: +1 414 229 3740; fax: +1 414 229 3981; e-mail: mds@uwm.edu

2. DATA

North American phenological data included in this study were common lilac (*Syringa vulgaris*) first leaf and first bloom dates observed at multiple western USA sites, and the same events recorded for cloned lilac *(Synnga chinensis* 'Red Rothomagensis') plants at station locations in the eastern portion of the continent, both from 1959–1993 (Caprio, 1993; Schwartz, 1994, 1997; Plate 1). Honeysuckle data were not used because of one species' limited availability in the eastern USA (*Lonicera tatarica* 'Arnold Red'), and another's unavailability in the western USA *(L. korolkowii* 'Zabeli'). Daily maximum temperatures observed at selected sites (as input for the spring index models) came from the USA Daily Historical Climatology Network[1] (HCN) up to 1995, with 1996 and 1997 data obtained from yearly COOP Network[2] updates. Comparable Canadian climate data[3] were also acquired up to 1997. The year 1900 was selected as the starting point for analysis, given that few stations (less than 100) are available before that time (Schwartz, 1998). The number of available stations in the network increases steadily over the 1900–1950 period, and then remains stable, at roughly 700–800 locations from that time onward. Climate stations were selected for inclusion in this study only if they had maximum–minimum temperature data available for at least 25 years during the 1961–1990 period (this ensures that a representative 30-year normal is used in annual departure-from-normal calculations). Lastly, far southern stations were removed because of insufficient winter chilling, and far northern stations because of inadequate summer warmth for proper indicator (lilac and honeysuckle) development (Plate 2).

3. METHODS

As extensive multi-species phenological data, comparable with the European study (Menzel and Fabian, 1999), do not exist for North America, an alternate mixed methodology was employed. All available lilac first leaf and first bloom station records totalling at least 20 years within the 1959–1993 period were evaluated for a linear temporal trend (regression analysis, F-test), as in the European study (Plate 1). Simulated (spring index model) first leaf and first bloom dates, and other related measures (Schwartz, 1997), were also produced and evaluated for this period at stations in the high-quality climate network (Plate 2; see Schwartz, 1997, 1998 for observed versus modelled phenology comparisons). Using this combination, our limited lilac phenology data fortified the veracity of geographical patterns revealed by the simulated phenological events. Further, the spring index suite of measures (see below) facilitates a comprehensive analysis of temperature related climate variations and their impact on spring plant development (Schwartz, 1998).

Eight model-related measures from Schwartz (1997, 1998) were initially calculated for each station year, and evaluated at each climate station for significant trends ($\alpha \leq 0.05$) over the 1959–1993 period:

1. first -2.2°C frost date in autumn,
2. composite chill date–average date when winter cold requirements among the three indicator plants (lilac and two honeysuckle species) has been satisfied, meaning they are ready to respond to spring warmth,
3. spring index first leaf date—'early spring' average date among the three indicator plants that leaves grow beyond their winter bud tips, related to a general onset of growth in grasses and shrubs,
4. spring index first bloom date—'late spring' average date among the three indicator plants that flowers start to open, related to a general onset of growth in dominant forest vegetation,
5. last -2.2°C frost date in spring,
6. frost period, the number of days from first frost date in autumn to last frost date in spring,
7. damage index value, the difference in days between the first leaf date and last frost date, indicative of the relative internal timing of spring and potential for plant damage in a given year,
8. average annual temperature, and all twelve average monthly temperatures for comparative purposes

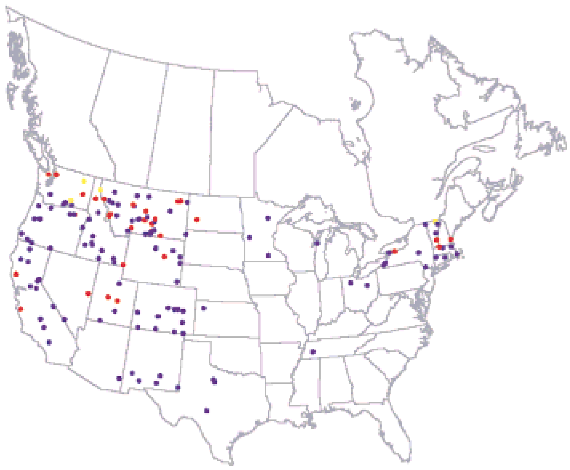

Plate 1

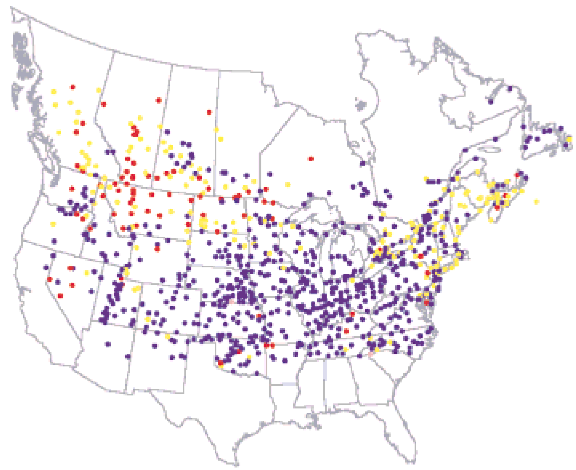

Plate 2

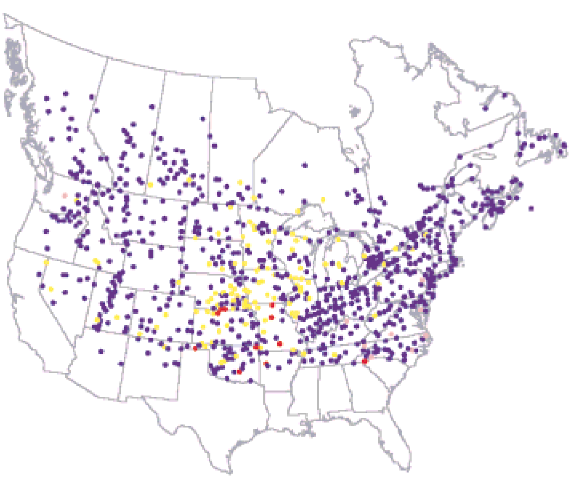

Plate 3

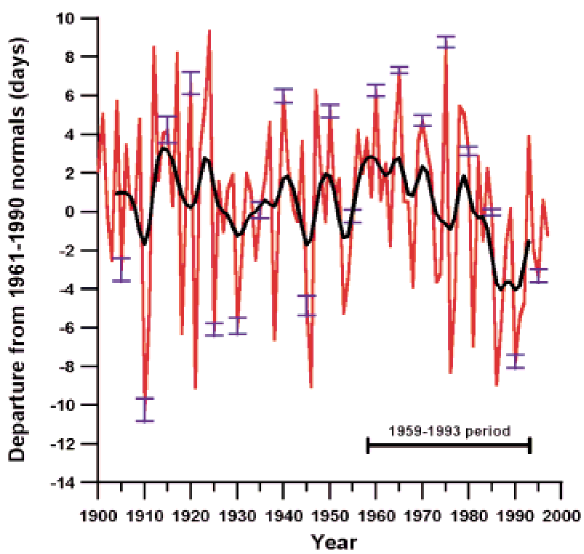

Plate 4

Plate 1. Lilac first bloom date linear trends. Data are from stations with long data series (20 years or more) during the 1959–1993 period. Red dots, significant at the 5% level, and trends < -0.3 days/year; yellow dots, significant at the 5% level, and trends between -0.3 days/year and 0 days/year; pink dots, significant at the 5% level, and trends greater than 0 days/year; blue dots, not significant at the 5% level; *F*-test

Plate 2. Spring index first bloom date linear trends. Data period and stations symbols as in Plate 1

Plate 3. Spring index composite chill date linear trends. Data period and stations symbols as in Plate 1

Plate 4. North American departures from the mean of spring index first leaf date, 1900–1997, with ± 1 standard error bars, and smoothed trend produced by a 9-year, moving average normal curve filter (heavy black line)

All variables were also transformed into departures from the appropriate 1961–1990 station normals, and then averaged by year to produce annual continental departures.

4. RESULTS AND DISCUSSION

Spring index first bloom dates showed the strongest regional patterns of advancement toward earlier arrival, primarily in northwestern USA–southwestern Canada, with a secondary concentration in the northeast USA—Canadian Atlantic provinces (Plate 2). Monthly average temperatures show that western regional changes are being driven by warmer temperatures throughout March–May, while the eastern region appears to be responding to warmer Aprils only.

Spring index first leaf dates are also progressing in these same two regions, as well as another area in the central USA (Nebraska–Kansas), with more complex interactions (not shown). The central USA is experiencing earlier chill dates, which could contribute to accelerated spring plant development, by allowing earlier response to spring warmth (Plate 3). Earlier chill dates might be caused by a colder winter, earlier cold temperatures in autumn, or some combination of the two. In this case, monthly average temperatures show that colder autumns (especially October), and associated earlier first frost dates (not shown), are the likely proximate causes of this change.

Other results indicate that the last frost dates, frost period, and damage index values did not show strong regional patterns (not shown). Confirming previous findings (Chapman and Walsh, 1993), January temperatures are rapidly warming in the Canadian prairie provinces (Alberta, Saskatchewan, Manitoba), and to a lesser extent in the northern USA great plains (Minnesota and the Dakotas). Reflecting the various monthly temperature patterns, average annual temperatures showed a high degree of spatial variability (not shown).

Significant linear trends ($\alpha \leq 0.05$) over the 1959–1993 period were detected for spring index first leaf date (-0.18 days per year, equivalent to an advance of 5.4 days towards earlier arrival over 30 years, Plate 4), spring index first bloom date (-0.14 days per year, equivalent to an advance of 4.2 days towards earlier arrival over 30 years), and last frost date (-0.15 days per year, equivalent to an advance of 4.5 days towards earlier arrival over 30 years, supporting results from an earlier study in the northeast USA: Cooter and Leduc, 1995). These modifications agree with advancing North American tree swallow *(Tachycineta bicolor)* nesting times for a comparable period (Dunn and Winkler, 1999), and align overall with trends toward longer growing seasons, reported by recent carbon dioxide (Keeling *et al*., 1996) and satellite (Myneni *et al*., 1997) studies. They also compare favourably with the 6.0-day advance recorded in Europe (Menzel and Fabian, 1999). All these results suggest that spring changes for this period are broadly synchronous in at least two major continental areas. The lack of autumn phenology data makes direct comparison with the European results difficult in that season. However, North America does not seem to be getting warmer in autumn. Rather, some areas are cooling and enduring earlier frosts. Thus, overall increases in growing season length are ambiguous, with weak regional spatial patterns across the continent.

Ascribing the cause of these spring advances to century-scale global warming is indeterminate. Year-to-year variability is quite high in all the indices (e.g. Plate 4), and before 1959, long-term trends are suggested only for last frost date. Last frost events progress toward earlier dates throughout the 20th century in North America, but in a highly variable, and non-linear fashion. Nevertheless, recent lilac phenology data from parts of eastern North America suggest that Spring has continued to advance towards earlier arrival, at the same pace, up to 1999 (limited 1998 and 1999 first leaf dates scattered across that region were on average 16 and 12 day earlier, respectively, than average values for the 1994–1997 period). Thus, these trends merit careful watching for future developments. Our results underline the utility of phenological data and models for regional, continental and global change studies, as well as the critical need for global-scale surface observation networks to complement satellite sensor-derived data (Myneni *et al*., 1997; Schwartz, 1998, 1999; Schwartz and Reed, 1999; White *et al*., 2000).

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NOTES

1. Includes period-of-record station data up to 1995, provided via FTP by the Environmental Services Division, Carbon Dioxide Information and Analysis Center, Oak Ridge National Laboratory, Tennessee, USA.
2. Provided by the National Climatic Data Center, Asheville, NC, USA, on CD-ROM.
3. Provided by Environment Canada, Downsview, Ontario, Canada, on CD-ROM.

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