Examining the Spring Discontinuity in Daily Temperature Ranges

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ABSTRACT

The atmosphere and biosphere both change rapidly throughout midlatitude spring. Many weather variables are modified during this season, including the diurnal temperature range (DTR). The mean DTR trend displays a discontinuity at the onset of spring characterized by a rapid increase for several weeks, followed by an abrupt leveling off. The trend then remains essentially flat throughout the remainder of the warm season. These DTR changes reflect the interactive role many weather variables play with surface-layer processes. Thus, diagnosing the causes of these variations may provide background information for numerous global change analyses, as daily temperature data become increasingly available worldwide. The results of this study suggest that several factors (snow cover loss, more frequent southerly winds, and increased ceiling heights) are responsible for the initial rapid increase in the DTR. The second half of the discontinuity (subsequent leveling off) is connected with increased atmospheric moisture and coincides with the onset of plant transpiration.

1. Introduction

This short study will define and examine a spring season discontinuity in the annual cycle of the diurnal temperature range (DTR). During the onset of spring the DTR rapidly increases for several weeks, followed by an abrupt leveling off. These abrupt DTR variations provide an opportunity to employ empirical data for investigating surface layer—energy interactions. As daily temperatures become commonly available across the globe, the DTR will be an important indicator of climate change (Karl et al. 1993). A better understanding of the spring DTR discontinuity may help distinguish natural climate variations from possible human-induced effects in global DTR trend analyses.

Several papers have examined abrupt modifications in surface conditions during the winter—spring transition. Ruschy et al. (1991; Schwartz 1992; Schwartz and Karl 1990). Ruschy et al. (1991) concentrated on changes in the DTR due to seasonal variations in snow and cloud cover. Whenever snow is present, latent heat of the ice water phase change and high albedo suppress daily temperature variations (Oke 1987). Snow cover disappearance subsequently leads to rapid decreases in surface albedo and increased net radiation. Considering these energy-balance effects, it appears that snow cover removal is connected with the sudden DTR increase observed prior to spring’s onset.

Cloud cover ceiling height and percent coverage may also play a role (Karl et al. 1993). Of equal interest is the abrupt “leveling off” of this upward trend after several weeks. Ruschy et al. (1991) showed that net radiation continues to slowly increase during the spring and early summer seasons. Meanwhile, cloud cover decreases throughout the remainder of spring, only starting to increase again in early summer. These changes should induce a slow increase in DTR over the spring to early summer period. Since this does not occur, another compensating factor would seem to come into play—halting the increase in DTR several weeks after its initiation in the spring.

In this paper I examine the hypothesis that this compensating factor is plant transpiration. Satellite NDVI data and surface observations show that the midlatitude onset of greenness (“green up,” start of plant photosynthetic activity) often occurs abruptly in early spring, and then greenness gradually increases to a maximum in midsummer (Reed et al. 1994; Schwartz 1994; Lolland et al. 1991). This is just the pattern that would be expected if increased greenness is important in leveling the DTR trend. To verify this connection, the processes behind satellite-observed changes must be determined. Schwartz and Karl (1990) showed that significant changes in lower atmospheric changes occur relative to spring green up (based on the first appearance of leaves in the lilac Syringa chinensis) but only speculated on the causes of this relationship. Schwartz (1992) examined variations in surface weather variables across the time of spring green up and found that many change at this time—all in a fashion consistent with the expected influence of transpiration on the lower atmosphere. When plants produce foliage in the
spring, near-infrared reflection and transpiration rapidly increase (Dorman and Sellers 1989; Oke 1987; Kaufmann 1984). These effects contribute to greater levels of near-surface atmospheric moisture and slightly reduced net radiation, which should lead to changes in temperature and DTR. Schwartz (1992) did not pursue the significance of the moisture-temperature change connection or explore alternative reasons for the observed effects.

Therefore, a study is needed that evaluates the significance of spring atmospheric moisture changes and the DTR in the context of surface-layer processes. One way of doing this is to develop multiple regression models and to observe the sign and magnitude of component variables. Karl et al. (1993) constructed an annual DTR model using this method. In this study I will produce a similar model but restrict the data period to the several weeks encompassing the spring DTR discontinuity. This methodology will yield a statistical verification of the discontinuity, as well as identify those variables associated with its appearance.

2. Data

The database for this project was the same as used by Schwartz (1992). Selected station pairs are the only ones in eastern North America that combine a comprehensive set of surface meteorological variable observations with abundant phenological data (Fig. 1). The phenological data consist of first leaf emergence dates for clones of the lilac cultivar Syringa chinensis "Red Rothomagensis" (a specific genetic type), which were collected as part of several regional Agricultural Experiment Station projects over the 1961–1986 period (Schwartz 1994). This lilac was selected because of its easily distinguished phenological phases (first leaf, first bloom, etc.) and broad distributional range (Hopp et al. 1969, 1973). Cloned plants standardize the response to environmental conditions. The first leaf event (defined as when the widest part of the new leaf moves past the winter bud scale) was chosen to measure green up, since previous studies have established it as a functional indicator of lower atmospheric change (Schwartz 1992; Schwartz and Karl 1990).

The meteorological data consist of daily maximum and minimum temperature, snow depth on the ground (SOG), mean temperature, mean ceiling height, mean relative humidity, mean sky cover, and mean U and V wind components for the period 1961–1986—provided by the Global Climate Laboratory of the National Climatic Data Center in Asheville, North Carolina. Mean daily water vapor pressures were calculated from the temperature and relative humidity values. Daily potential solar radiation values were determined from station latitude and solar declination data.

3. Methodology

As a first step, daily DTRs were calculated by taking the difference of the maximum and minimum temperatures each day and converting these values to degrees Celsius (original data are in Fahrenheit). Also, for each station-year, daily SOG values were examined to determine the last day that measurable SOG (2.5 cm or more, as data are originally recorded as whole inches)

Fig. 1. Phenological (open symbols) and meteorological (filled symbols) locations.
was recorded, and the date of this occurrence was termed the last snow date for that particular station-year. Next, in order to effectively combine the information from this large number of different stations and years, the time variable was transformed from calendar date into days relative to the first leaf date (or last snow date) for each station-year (Schwartz and Karl 1990). For example, suppose that a selected station-year has a first leaf date of day 100 and a last snow of day 85 (these are calendar dates rendered in days beginning on 1 January). To convert these dates into relative first leaf days, the difference between the calendar date and first leaf date would be determined for each day, such that day 90 would become $-10$, day 100 would be zero, day 110 would be +10, and so on. Similarly, in this case, to transform the time variable to days after last snow date, day 90 would become +5, day 100 would be +15, etc. The database developed with this approach included 242 station-years of information. As an initial analysis, the average DTR trend relative to first leaf date was plotted at four stations for visual comparison (Fig. 2).

A complicating aspect of examining mean spring plant–atmosphere changes is that while SOG typically disappears before first leaf (about two weeks before on average), in some situations additional snow falls after the initial green up has occurred (Schwartz 1992). When this happens, it can be problematic to separate
the effects of these two factors on springtime temperature trends. Therefore, to address this issue, two subsets of the original database were created for use in subsequent analyses. The first (leaf set) included only those station-years in which first leaf date occurred at least 14 days after last snow date (the average difference in these dates over the whole dataset). Graphs of the average DTR relative to first leaf date and last snow date were prepared for this data subset (which consisted of 150 station-years, 62% of the original data, Figs. 3 and 4). The second data subset (snow set) include only those cases where the last freeze date was at least 14 days after the last snow date (187 cases, 77% of the original data). This subset was created to assess the impact of last freeze date on the DTR trend, through a graph showing the average DTR relative to last 0°C freeze date (Fig. 5).

In order to assign statistical significance to these observed DTR changes, two procedures were carried out using the entire dataset (242 station-years). First, mean values of the DTR and related variables (cf. Karl et al. 1993) were calculated during three periods: 1) the time just before mean last snow date (−42 to −29 days after first leaf), 2) the time immediately after first leaf (0 to +13 days), and 3) several months later (+42 to +55 days). Variables included in this set were (among others—see Table 1) mean day to day temperature difference and mean snow cover, both calculated as by Karl et al. (1993). Between the last two periods (+14 to +41 days) the initial results suggest that the DTR does not change (Fig. 3). A random sample of 100 days was drawn from each period (0 to +13 days and +42 to +55 days after first leaf), and the standard t test was used to assign statistical significance to the differences in sample variable means between these periods (Table 1).

Lastly, a stepwise multiple regression equation was developed to predict the square root of the DTR (de-
dependent variable) in terms of related variables. Without the square-root transformation, nonnormal residuals make it more difficult to interpret the results of a regression analysis (Karl et al. 1993). Daily potential solar radiation was not included as an independent variable because of its high positive correlation with mean water vapor pressure \( (r = .68) \), and neither mean sky cover \( (r = -.83) \) nor mean relative humidity \( (r = -.62) \) were included because of their high negative correlation with mean ceiling height. High correlations among independent variables (multicollinearity) violate the assumptions of regression analysis. Significant variables \( (\alpha = 0.00005 \text{ level}) \) in the equation were recorded along with their partial correlation coefficients (Table 2). Such a high significance level helps protect against inflated \( p \) values due to the multiple comparison selection process of stepwise regression. Among the variables included in the independent set were "phenological" variables covering seven-day ranges starting from \(-56 \) to \(-50 \) days after first leaf until \(+55 \) days after first leaf. These variables take on zero values when outside the designated day ranges and assume a value equal to the number of days after first leaf when inside the designated ranges (Schwartz and Karl 1990). This allows the regression equation to determine times when there are significant changes in the DTR trend relative to first leaf date. In the final multiple regression equation phenological variables with overlapping standard error ranges were combined.

4. Results and discussion

Visual examination of the DTR trends at four sample stations showed considerable variations but in all cases a level or decline in magnitude after first leaf date (Fig. 2). It was assumed for subsequent analyses that the station's responses were not significantly different and could be effectively combined. This interpretation may be subject to debate but is consistent with results from previous work and will not be pursued in this paper (Schwartz and Karl 1990). The graphs of average DTR relative to first leaf date and last snow date (Figs. 3 and 4) reveal the general nature of the proposed effects of green up and snow cover. Since the two graphs include only those station-years with first leaf date at least \(14 \) days after the last snow date, observed DTR changes relative to these two events can be temporally distinguished. Viewed on the first leaf timescale, the DTR rises from \(4-5 \) weeks before up until the time of first leaf and then levels off or even declines over the next eight weeks (Fig. 3). In contrast, changes in DTR relative to the last snow date show a strong discontinuity—a rapid (less than one week) \(2^\circ C\) rise in the DTR—immediately after the date of last snow and little increase subsequently (Fig. 4). The sharp dip around the time of last snow date is likely associated with this final "snow blanket," producing a dramatic but short-lived reduction in DTR, since stations are of-

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**Table 1.** Changes relative to first leaf date.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean 0–13 days after</th>
<th>Mean 42–55 days after</th>
<th>Sign of change</th>
<th>(t)-Statistic for difference between sample means</th>
<th>Significance of (t)-statistic (1-tail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ceiling (CIG, m)</td>
<td>16565</td>
<td>17479</td>
<td>+</td>
<td>5.43</td>
<td>&lt;0.00005</td>
</tr>
<tr>
<td>Mean day to day temperature differences ( (</td>
<td>\text{TMP}<em>0 - \text{TMP}</em>{-1}</td>
<td>+</td>
<td>\text{TMP}<em>0 - \text{TMP}</em>{+1}</td>
<td>) ) ( (\Delta\text{TMP}, ^{\circ} \text{C}) )</td>
<td>5.96</td>
</tr>
<tr>
<td>Mean relative humidity (RH, %)</td>
<td>64.01</td>
<td>68.24</td>
<td>+</td>
<td>17.13</td>
<td>&lt;0.00005</td>
</tr>
<tr>
<td>Mean sky cover (SKY, %)</td>
<td>51.72</td>
<td>61.02</td>
<td>-</td>
<td>2.91</td>
<td>0.005</td>
</tr>
<tr>
<td>Mean snow cover (binary, if snow depth ( \geq 2.54 \text{ cm} )</td>
<td>(SNOW))</td>
<td>0.01</td>
<td>0.00</td>
<td>-</td>
<td>19.90</td>
</tr>
<tr>
<td>Mean diurnal temperature range (daily max – daily min) ( (\text{DTR}, ^{\circ} \text{C}) )</td>
<td>11.87</td>
<td>11.69</td>
<td>-</td>
<td>2.16</td>
<td>0.025</td>
</tr>
<tr>
<td>Mean U-wind component (UWIN, kt.)</td>
<td>1.07</td>
<td>0.80</td>
<td>-</td>
<td>12.61</td>
<td>&lt;0.00005</td>
</tr>
<tr>
<td>Mean V-wind component (VWIN, kt.)</td>
<td>0.73</td>
<td>1.71</td>
<td>+</td>
<td>15.27</td>
<td>&lt;0.00005</td>
</tr>
<tr>
<td>Mean water vapor pressure (WV, hPa)</td>
<td>8.04</td>
<td>13.55</td>
<td>+</td>
<td>93.08</td>
<td>&lt;0.00005</td>
</tr>
</tbody>
</table>

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**Table 2.** Significant predictors of the diurnal range.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Partial correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ceiling (CIG, m)</td>
<td>+.59</td>
</tr>
<tr>
<td>Mean V-wind component (VWIN, kt.)</td>
<td>+.25</td>
</tr>
<tr>
<td>Mean day to day temperature differences ( (</td>
<td>\text{TMP}<em>0 - \text{TMP}</em>{-1}</td>
</tr>
<tr>
<td>(-56 \text{ to } -36 \text{ days after first leaf date})</td>
<td>+.15</td>
</tr>
<tr>
<td>(-35 \text{ to } -15 \text{ days after first leaf date})</td>
<td>+.12</td>
</tr>
<tr>
<td>Mean snow cover (binary, if snow depth ( \geq 2.54 \text{ cm} )) (SNOW)</td>
<td>-.08</td>
</tr>
<tr>
<td>(-14 \text{ to } -01 \text{ days after first leaf date})</td>
<td>+.06</td>
</tr>
<tr>
<td>Mean water vapor pressure (WV, hPa)</td>
<td>-.05</td>
</tr>
<tr>
<td>(+42 \text{ to } +55 \text{ days after first leaf date})</td>
<td>-.04</td>
</tr>
</tbody>
</table>
ten snow free before this last synoptic event. A graph of mean DTR changes relative to last frost date shows no connection to the timing of that event, except a sharp increase on the date itself (Fig. 5). This is not surprising given the singular nature of synoptic weather events typically responsible for late spring frosts (Schwartz 1990).

The last portions of the project tested the statistical significance of these observed DTR changes. Table 1 shows that mean DTR declines slightly over the period from just after first leaf (0–13 days) to several months later (42–55 days). Over this same period, 1) mean ceiling height, 2) mean day to day temperature differences, 3) mean relative humidity, 4) mean V-wind component, and 5) mean water vapor pressure increase, while 1) mean sky cover, 2) mean snow cover, and 3) mean U-wind component decline (Table 1). The phenological variables that enter into the multiple regression equation reveal the times and magnitudes of significant changes in the DTR trend relative to first leaf date (Table 2). The slope starts at +0.04°C/day (−56 to −36 days), increases to +0.05°C/day (−35 to −15 days), greatly increases to +0.08°C/day (−14 to −1 days), drops to +0.00°C/day (0 to +41 days), and finally becomes slightly negative −0.01°C/day (+42 to +55 days). These changes are consistent with variations in the daily maximum temperature reported by Schwartz and Karl (1990).

The multiple regression equation also reports which weather variables are significant predictors of the DTR and whether they exhibit a direct or inverse relationship. Of the predictors shown in Table 2, only mean snow cover and mean vapor pressure have an inverse relationship with DTR (neglecting the phenological variables). Therefore, it is apparent that an increase in mean ceiling height, mean V-wind component, and mean day to day temperature difference or a decrease in mean snow cover should result in an increase in DTR. At the same time, an increase in mean water vapor pressure should cause a decrease in DTR. Over the weeks before first leaf (−42 to −1 days), significant decreases in snow cover—combined with increases in ceiling height and V-wind component—appear to result in a much larger average DTR at the end of the period. However, after first leaf (0 to +55 days) snow cover is no longer a significant factor and further increases in ceiling height, V-wind component, and day to day temperature differences are apparently balanced by a rapid increase in water vapor pressure. The result is a leveling of the DTR trend, with even a slight decline near the end of the period (+42 to +55 days).

Therefore, the leveling off in the upward DTR trend near the time of first leaf is statistically related to changes in lower atmosphere moisture, which in turn appear connected to the onset of transpiration (as indirectly measured by first leaf phenology). Likewise, the initiation of the upward mean DTR trend prior to first leaf can be closely tied to the last snow date. These findings support the hypothesis proposed by this paper. Additional research will be necessary to establish a causal relationship between the increase in lower atmospheric moisture and the onset of plant transpiration.

5. Conclusions

The onset of spring in midlatitudes as a modally abrupt rather than gradual seasonal transition has been further defined by the results of this empirical study (Schwartz 1992; Schwartz and Marotz 1988). Contributing roles of land surface, atmospheric, and biospheric processes within this event have likewise been clarified. Climatologically, the spring DTR trend contains a period of rapid increase initiated by several factors (the loss of snow cover, more southerly winds, and higher cloud ceilings) and abruptly terminated by increased atmospheric moisture apparently associated with the onset of plant transpiration. Further study of the processes associated with these changes—ultimately developing physical links of satellite observations to surface vegetation events—may contribute to global change assessments and the improvement of atmosphere–biosphere simulation models.

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REFERENCES


