PEER REVIEWED

Historical Patterns and Effects of Changes In Adirondack Climates Since the Early 20th Century

By J. CURT STAGER, STACY MCNULTY, COLIN BEIER, and JEFF CHIARENZELLI

Analysis of weather data from seven United States Historical Climatology Network stations in the Adirondack region reveals statistically significant warming over the last 30 years during June and September, but no significant trends in the other months. The warmest intervals of the 1926–2005 period were the early 1930s, 1949–1954, and 1997–2003. These findings are consistent with similar analyses of northern New York weather data by Kathie Dello, but somewhat less so with earlier works by the first author and others. In this paper, we also discuss the effects of various interpretive methodologies on the study of regional climate and present new phenological data from the Adirondack region. We find little evidence of major biotic responses to weather trends in recent decades, perhaps because most such trends are still largely obscured by interannual variability, but a significant reduction in the duration of ice cover has occurred on local lakes. In addition, an increase of river discharge during the 20th century probably reflects a long-term increase in precipitation, particularly during fall.

Introduction

As increasingly broad-based attention focuses on global climate change, interest has also intensified regarding changes at the local scale. But if we are to plan effective responses to coming climate shifts in the Adirondack Park, and to evaluate the validity of predictive scenarios and computer models that still operate mainly on global to regional scales, it is necessary to understand the nature and trajectories of local climatic changes in the recent past.

One of the first rigorous attempts to describe and predict climatic changes in the northeastern United States was the New England Regional Assessment (NERA, 2001), one of a nationwide series of similar studies. Using weather station data from the National Climate Data Center (NCDC), NERA's authors mapped patterns of change throughout New England and New York and found a great deal of regional variability, including long-term cooling in much of Maine and dramatic warming in much of New York State. The results of the NERA study were disseminated widely through an online report and traveling presentations, and they were made accessible to lay audiences by journalists and environmental writers (e.g., McKibben, 2002), bringing early attention to climate change on the home front.

Shortly after publication of the NERA report, Stager and Martin (2002) presented a follow-up analysis of daily temperature and precipitation data from eight weather stations within the Adirondack Park covering most of the 20th century. They found evidence of local climate trends and patterns that differed from those reported for New York State by NERA; for example, the Wanakena record registered an overall cooling trend since 1950, while much of the rest of New York and New England warmed. These discrepancies were attributed to NERA's reliance upon relatively large-scale coverage rather than local weather records from the Adirondacks, and to the choice of temporal scale for identifying trends in weather data with high natural variability, or "noise."

Subsequent research further challenged the NERA report findings by demonstrating that the NCDC weather records were flawed and unsuitable for the trend analyses conducted by NERA (Keim et al., 2003; Trombulak and Wolfson, 2004). Using more thoroughly vetted and standardized datasets, which are now published online by the United States Historical Climatology Network (USHCN), those studies found that several of the trends and patterns reported by NERA were incorrect because of gaps and errors in the raw instrumental records. When the Northeastern climate

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became the object of regional study for a second time, through the Northeastern Climate Impact Assessment (NECIA; Frumhoff et al., 2007) funded by the Union of Concerned Scientists, the work was based upon USHCN data and showed a more coherent array of warming trends that no longer included cooling in Maine.

In this paper, we revisit and improve upon previous analyses of climate change in the Adirondacks (e.g., Stager and Martin, 2002) through analysis of the latest USHCN instrumental records of temperature and precipitation from seven weather stations in the Adirondack region. Using these more reliable data, we summarize climate trends during the 20th century with particular emphasis on the last 30 years of primarily human-driven change. Our findings differ slightly from those of the former study which, like NERA, used uncorrected instrumental records from the NCDC archive. In light of these differences, we discuss the importance of using properly corrected data for evaluating patterns of change in complex and highly variable climatic environments. Lastly, we examine responses of selected Adirondack species and ecosystems to observed climatic changes in recent decades and invite further analyses.

Comparison between Different Methodologies and Datasets

When Stager and Martin (2002) used raw weather station data for their analysis of Adirondack climate trends, they assumed that this approach would yield results free from possible suspicions of statistical "massaging" that might favor a particular outcome. In fact, this approach virtually guarantees inaccuracy, as other investigators have also learned to their chagrin.

The reason for this discrepancy stems from the very nature of weather data collection and may best be described anecdotally here. Volunteers run most stations, often with limited economic, technical, and personnel resources. When volunteers fall ill or take a vacation or experience a family emergency, there may be no one to take over their duties and gaps in the sequence of daily weather measurements may therefore appear in the record. Such gaps shorten datasets and change the monthly and seasonal averages calculated from them. Later, a different volunteer takes over the station duties but has a different lifestyle that requires collecting weather data earlier in the morning. Because temperatures tend to be cooler at dawn than at noon, such a change immediately "cools" the average temperatures at that station.

Similar inaccuracies are introduced if a volunteer changes the frequency of daily measurements, skips more or fewer days, uses a new piece of equipment, or moves the station to another site where elevation, shading, lake effects, heat island effects, or wind exposure may be quite different.

The USHCN carefully examines the quality and completeness of data from every station in its national network, and stations that are unable to provide a full history of methodologies are excluded. Perhaps for this reason, the USHCN website does not list data from the Boonville, NY, station that appeared in the Stager and Martin (2002) study, leaving only six approved stations within the Blue Line (Figure 1). Gaps in the records are identified and filled by standardized methods of interpolation from neighboring stations. Optional adjustment factors that take into account the urban heat island effect and other biases can be applied to records or left out according to one's research needs, and all of these adjustment techniques are fully described on the website.

Using corrected USHCN data, for example, the Wanakena temperature record no longer displays the post-1950 cooling trend evidenced by the uncorrected NCDC version of the record (Stager and Martin, 2002). Several other USHCN-approved instrumental records from northern New York, however, do exhibit weak cooling since 1950, supporting the earlier finding that local-scale variability in the Adirondacks can be quite significant (Stager and Martin, 2002). Rather than refuting a global warming trend, this pattern reflects high temperatures in the Adirondacks during the 1950s, which were followed by a cooler period before temperatures began to rise more consistently again during the last 30 years (Figure 2).

For this paper, the records of all six USHCN stations in the Adirondack Park were combined to illustrate historical composite patterns of temperature and precipitation variability. By choosing this approach, we passed up the finer-scale resolution of climate trends on the level of individual weather stations in order to provide insights into changes that have affected the Park as a whole. We encourage further investigations into the histories of individual weather stations to supplement the composite records discussed here, particularly in relation to phenological observations made in the vicinity of one or more such stations.

The Adirondack sites used in this study were Dannemora, Indian Lake, Lake Placid, Stillwater, Tupper Lake, and Wanakena (Figure 1). We also included the Lowville, NY, station in our composite analysis because it lies in the narrow, low-lying corridor between the main body of the Park and the Tug Hill Plateau and represents conditions similar to those within much of the Park. Mean temperatures at Lowville were about 2°F warmer than those at other stations at higher elevations, but their patterns of interannual variability were similar (for example, correlations with Dannemora and Stillwater temperatures were 0.81 and 0.83, respectively). The National Weather Service includes all but one of these stations in the New York State Climate Division known as the Northern Plateau; despite its relatively high elevation (408 m), Dannemora belongs to the Champlain Valley Division.

Because the records of some stations were longer than others, we limited our analyses to time periods that were covered by all stations. In the case of mean temperature, our composite records began in 1927, and for precipitation

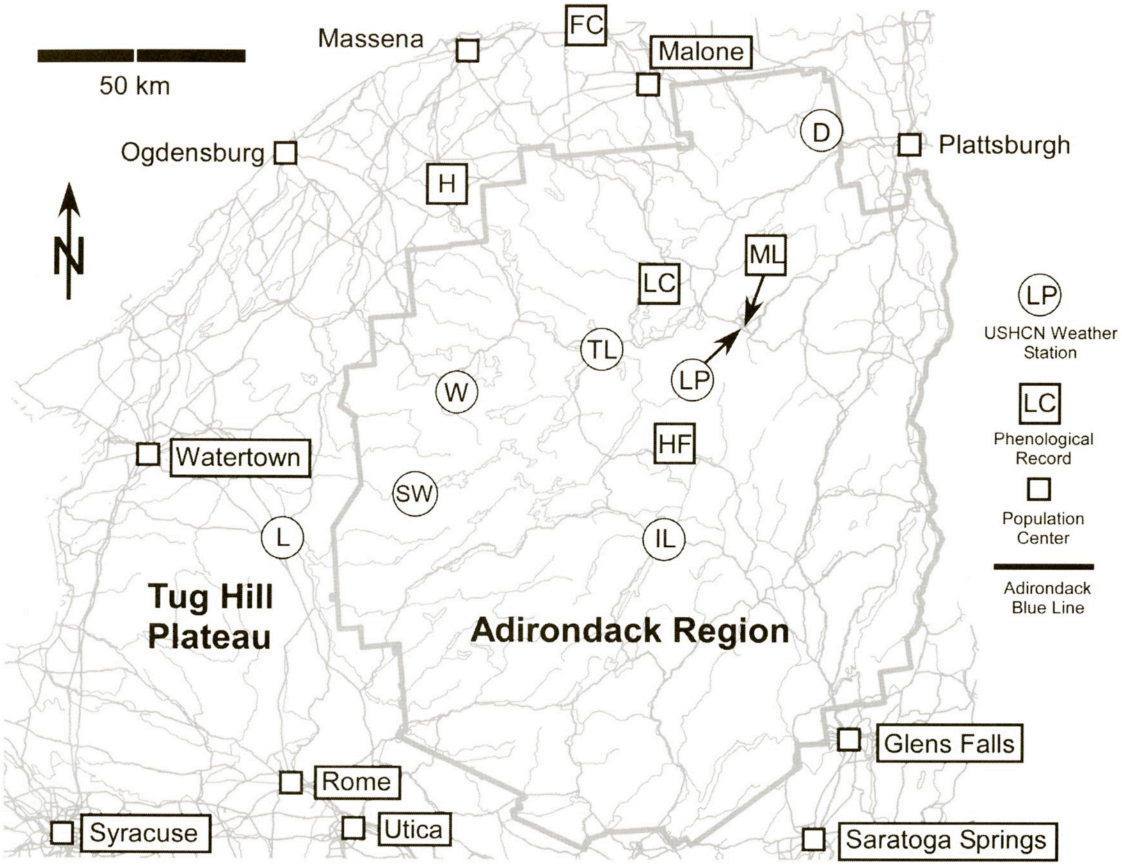

Figure 1. *Location map. USHCN-approved weather station sites (circles): D = Dannemora, IL = Indian Lake, LP = Lake Placid, L = Lowville, SW = Stillwater Reservoir, TL = Tupper Lake, W = Wanakena. Phenological data sites (squares): FC = Fort Covington, H = Hannawa Falls, HF = Huntington Wildlife Forest, LC = Lake Clear, ML = Mirror Lake. Major waterways and roads shown in background.*

they began in 1926. Both sets of records end in 2005, the year of the latest USHCN update. Our primary focus in this study was on monthly patterns, but seasons were also defined as follows: winter (December–February), spring (March–May), summer (June–August), and fall (September–November).

Interpreting Trends

Because climate records are widely available for use by nonspecialists, it is worth offering some basic advice regarding the interpretation of trends in such data. The high degree of variability in Adirondack weather patterns that is so obvious in the records presented here invites the drawing of simple trend lines through the confusing jumble of ups and downs in order to help make sense of overall patterns. This approach, however, comes with interpretive pitfalls, too. We caution against some of them below.

Although trends are presented with most of the records here, we caution the reader that drawing a smooth trend line can create an illusion of continuous change when the actual dynamics may be abrupt and/or erratic. For example, mean annual temperature in the Adirondacks fluctuated a great deal during the first half of the 20th century, then began a notable but erratic upward drift during the 1970s. A linear trend connecting these endpoints would incorrectly suggest gradual changes throughout the entire period.

A trend line also encourages extrapolation into the future, implies that past observations provide a sufficient basis for understanding future outcomes, and can create false confidence in simplistic climatic predictions. Climate scientists broadly agree that climate change is a complex and nonstationary process and that we cannot necessarily use measures of historical climatic variability alone to predict future climatic variability. Unless knowledge of underlying mechanisms can justify claims for why an observed trend should continue in its current form, projecting short-term trends forward using long-term units such as "degrees per century" is potentially misleading. Such oversimplification during a brief cool phase that developed shortly after a mid-20th century warm period led some incautious scientists to warn of an imminent ice age. Likewise, one could choose any number of warming or cooling trend lines in the Adirondack dataset as the basis for unrealistic projections. For these reasons, models that are used to predict global climatic changes are based upon the meteorological and physical mechanisms by which climate systems function rather than on simple linear trends projected forward into the future.

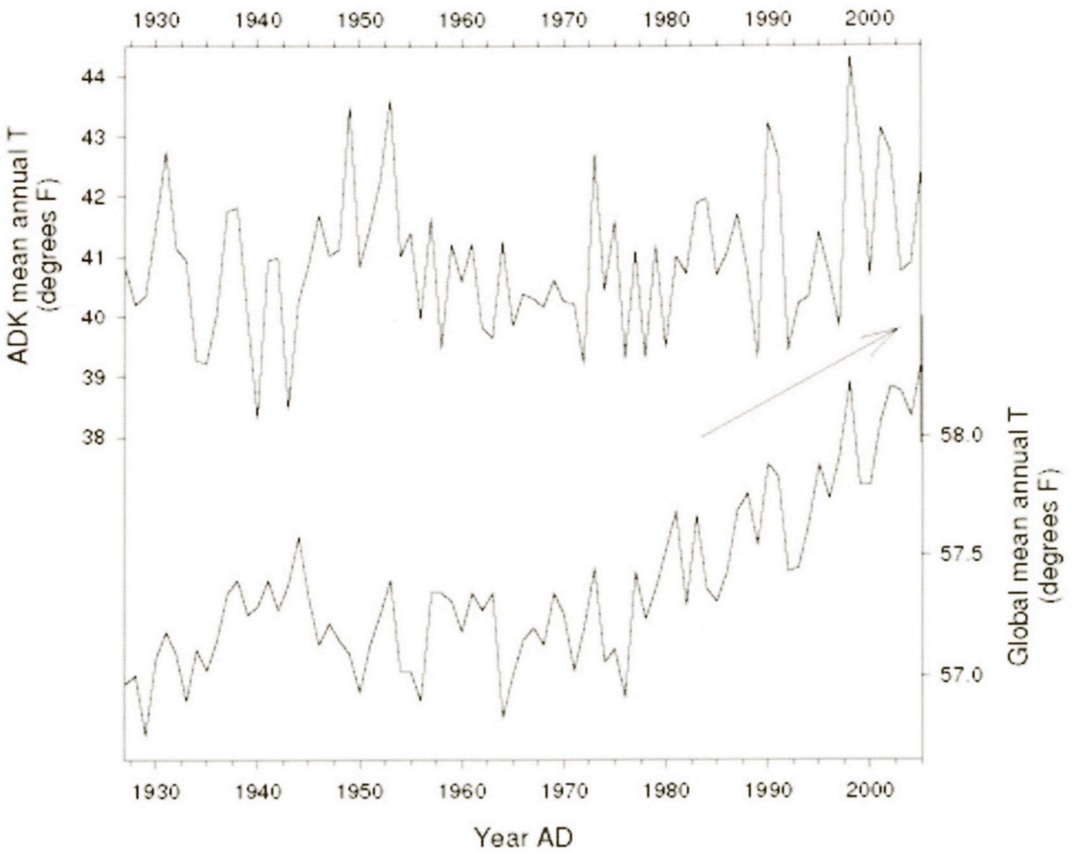

Figure 2. *Comparison of mean annual Adirondack and global temperature records, 1926–2005 (°F). Upper panel: Annual average of mean daily temperatures for seven North Country stations (this study). Lower panel: Global mean annual land–ocean temperature (NASA; http://data.giss.nasa.gov). Arrow indicates upward drift in both records. Note discrepancies between these records earlier in the 20th century.*

The choice of time intervals also strongly influences resultant trend lines in variable datasets. For example, starting one's analyses with an unusually warm episode can create a bias toward cooling trends. This was the case for NCDC datasets that registered overall cooling at several Adirondack stations since the warm 1950s (see Stager and Martin, 2002), and for two of the USCHN station datasets used in this study (Lowville and Dannemora) that also show weak cooling trends during the last five decades. Likewise, starting one's analyses in the relatively cool 1960s produces an opposite bias that favors warming trends. It is therefore important to provide clear justification for why one chooses to study a particular time interval rather than others.

Finally, it is necessary to consider whether a trend is statistically significant or not. If the statistics say "no" (i.e., not significant at the 95% confidence level or better), then great caution must be used in discussing the observed pattern of change no matter how nicely or poorly it fits expectations. This situation is particularly common when datasets are very noisy and/or too short in duration to reveal existing but relatively weak underlying patterns. To illustrate this point, records of Adirondack wildflower blooming dates investigated for this study indicated earlier flowering for several species. This might fit expectations in a context of global warming, but only one of those trends was statistically significant (see *Flowering Times*, below). Any inclination to use such findings to indicate biotic responses to local change should be tempered by the existence of opposite (although not significant) trends for some of the other datasets, such as that of the native lily, Yellow Clintonia (*Clintonia borealis*), at Lake Clear.

We now discuss composite Adirondack climate changes over two time periods—the full duration of instrumental record, covering the last eight decades, and the last 30 years, during which global climate has experienced the strongest directional changes.

Adirondack Climate 1926/1927–2005

Temperatures 1927–2005. Composite annual temperature records from 1927 to 2005 show that the warmest intervals were the early 1930s, 1949–1954, and 1997–2003 (Figure 2). Mean annual temperatures in the Adirondacks rose slightly since 1927, with warming greatest during spring and summer and only moderate during fall and winter. Year-to-year variability in the records is such, however, that none of the trends were significant at the 95% confidence level. Likewise, although we found apparent cooling during January and warming during December, both on the order of 2°F, none of the months of the year displayed statistically significant temperature trends during the last eight decades. This reflects the nature of Adirondack climates which, for a variety of reasons (e.g., topography, lake effects, jet stream dynamics), are among the most variable in the country (Thaler, 2006). That variability also makes it difficult to distinguish patterns driven by greenhouse warming from other changes produced by more localized factors such as the meandering and latitudinal shifting of westerly wind and storm tracks.

Precipitation 1926–2005. In contrast to regional air temperature, precipitation is more difficult to document and model accurately because individual rain and snowfall events can change dramatically over space and time, as in the case of the sudden whiteout of a Watertown lake effect squall or the passing summer downpour that leaves neighboring towns dry. The interannual temperature fluctuations in the seven weather station records described above were quite similar to one another (most correlation coefficients ranged from 0.8 to 0.9). On the other hand, the precipitation records from those stations differed much more from one another (typical correlation coefficients were 0.60–0.65). Therefore, although the composites presented here are meant to represent the region as a whole, they are not as representative of individual sites as the temperature patterns are.

Since 1926, the Adirondacks received more precipitation in spring, summer, and fall, but significantly so only during the fall, as September, October, and November totals gained 0.5–0.9 inches. Of the monthly records, however, only August precipitation displayed a statistically significant increase during the last eight decades, the monthly total rising by approximately 1.19 inches.

Adirondack Climate 1975–2005

There are at least two important reasons to focus on the last 30 years of weather in the Adirondacks in addition to considering longer time periods. First, a sliding 30-year scale is the standard temporal window used by climatologists to calculate average conditions for a given region. Second, the last three decades have seen a fundamental shift in the nature of global climate trends in which the upward track of global temperatures is mainly driven by anthropogenic greenhouse gas emissions rather than by solar variability or other complicating factors (IPCC, 2007). Of the entire record, the last three decades have seen Adirondack temperature trends move most closely into line with global trends (Figure 2). Because greenhouse gas concentrations are likely to continue to rise into the near future, it is reasonable to assume that this increasingly closer linkage between Adirondack and global climates could persist and may therefore have predictive value.

Temperatures 1975–2005. Limiting Adirondack weather records to the 1975–2005 interval changed the slopes of their embedded trend lines, although most of them were still not statistically significant at the 95% level (Figure 3). Noteworthy changes included strong warming in September (+4.7°F), December (+3.4°F), and June (+2.8°F) and an overall cooling in May (–1.7°F), but only the September and June trends were statistically significant. The overall winter warming trend in these records is weaker than that which Jenkins and Keal (2004) reported in *The Adirondack Atlas*, probably due to the use of different time intervals, weather stations, and datasets.

Previous analysis of USHCN records from northern New York during the slightly longer 1970–2005 interval (Dello, 2007) produced similar results, though somewhat different methods were used. No significant changes in daily mean temperatures were found at individual Adirondack weather stations in January, March, October, November, or December. Only one of the Adirondack stations warmed significantly in April and July, and Lowville cooled significantly in May. Two stations warmed significantly in February, three did so in June and August, and four did so in September, the month that we also found to have warmed the most since 1975.

Precipitation 1975–2005. The 30-year precipitation records showed no significant wetting or drying trends despite an otherwise notable wetting trend in May of +1.3 inches (Figure 4). Dello (2007) also reported no significant change in mean annual precipitation from 1970 to 2005 at Adirondack stations except at Dannemora, which experienced an increase of approximately 8 inches. This is consistent with regional climate models that predict relatively flat precipitation trends in the northeastern United States until about 2050, when a long-term increase is expected to continue through 2100 (Frumhoff et al., 2007). Those models, however, failed to reproduce the severe aridity of the early 1960s, making their future projections less reliable for precipitation than for temperature.

Global climate models forecast more climatic instability during the 21st century, with extremes of temperature, flooding, and drought becoming more common in a warming world (IPCC, 2007). Because changing precipitation patterns could bring challenging stresses to Adirondack ecosystems and local communities, we examined summer drought patterns in daily records extending from 1911 to 2005 in order to seek evidence of changing intensity, frequency, or variability. We singled out one representative weather station for this analysis because, in this case, we wanted to avoid the loss of site-specific variability that results from averaging several records together. The Wanakena dataset was chosen because of its exceptional completeness, length, and the station's central location within the Park.

Drought frequencies and durations at Wanakena for every summer between 1911 and 2005 were tallied in units of days without rainfall, and the standard deviations of those data were used to represent drought variability. There were few notable changes in these drought patterns at Wanakena since the 1910s and 1920s, which saw the driest summers on record

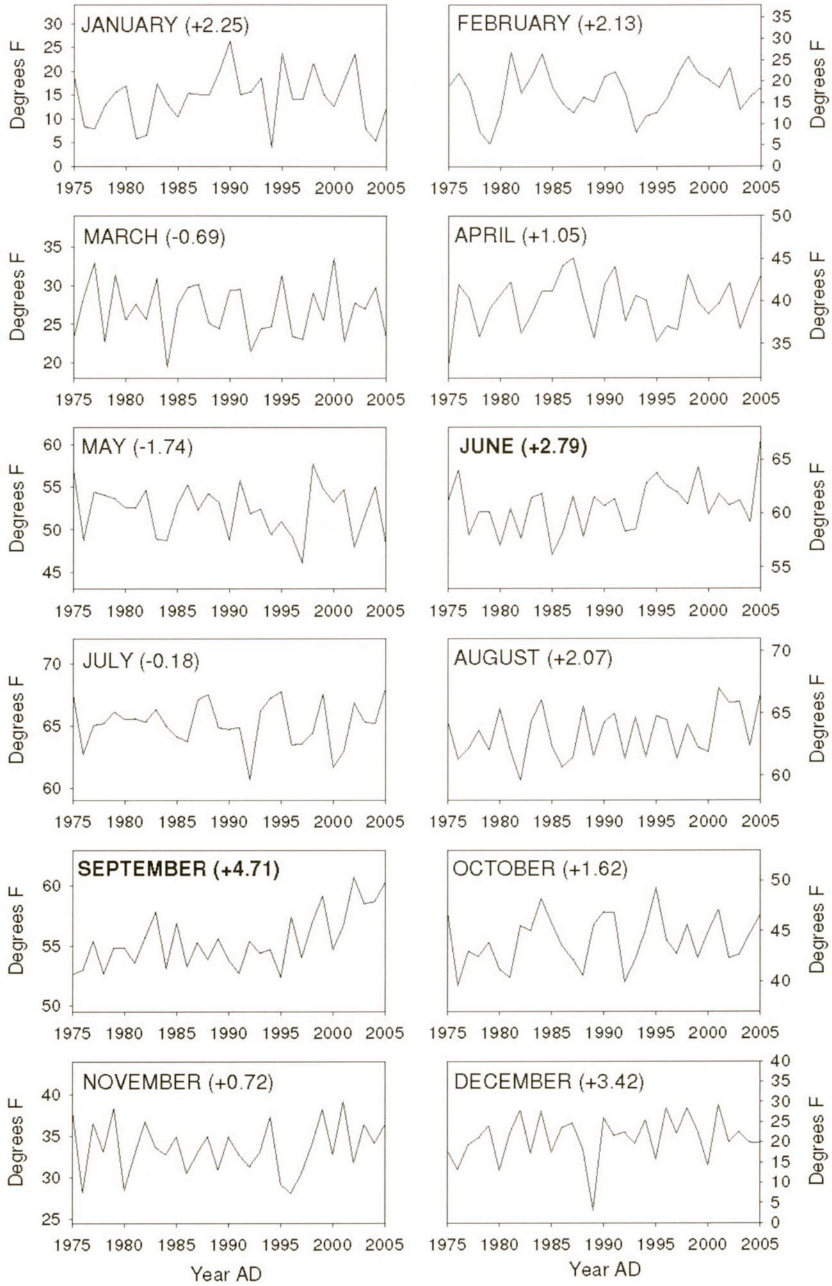

Figure 3. *Mean daily temperatures (°F) averaged by month for a composite of seven North Country weather stations for 1975–2005. Only September and June displayed statistically significant trends (bold font: +4.71°F and +2.79°F respectively).*

with droughts lasting much longer on average and occurring more sporadically than in subsequent decades.

In summary, the last three decades saw relatively consistent warming patterns throughout most of the year, but only two of nine monthly warming trends were significant at the 95% level (June and September). No monthly precipitation trends were statistically significant during this time period, and drought frequencies and durations at Wanakena changed little since the dry 1910s and 1920s. We now examine possible effects of recent climatic conditions on ecosystems and organisms in the Park.

Observed Responses to Local Climate Patterns

Considering the extreme variability displayed in Adirondack weather patterns of the 20th century, it is likely that many local species can tolerate fluctuating and often unpredictable climatic environments. Such adaptability can also make it difficult to identify biological responses to long-term global climate changes amid the background noise of large natural fluctuations, especially if observational records are relatively short. As a general rule of thumb, phenological records with fewer than 20–30 annual data points are unlikely to display significant trends unless the changes are truly dramatic (Hulme et al., 1999).

In 2007, North Country Public Radio (NCPR) invited listeners to contribute personal observations of changing signs of spring, which were compiled and presented online and in a live broadcast of the "Natural Selections" program. Contributions ranged from personal diary accounts of migratory bird arrivals to garden club records of flowering times and archives of ice-out contests. Most of those records displayed no statistically significant trends for a variety of reasons, including the brevity or incompleteness of most observational datasets and the aforementioned scarcity of significant climate trends. Some, however, did show noteworthy changes with potential biological and/or social significance, and we present several of them here.

Ice cover duration. To our knowledge, the longest and most complete records of ice-on and ice-out dates from the Adirondack uplands are those from Mirror Lake. The primary dataset spanning 1903 to 2005 was obtained from Jerome Thaler's book *Adirondack Weather* (Thaler, 2006), and the 2006–2008 data were provided by Judith Shea of Lake Placid. As Figure 5 shows, ice now forms 14–15 days later and melts 3–4 days earlier on Mirror Lake than it did in the early 1900s, thereby reducing seasonal ice cover duration by slightly more than two weeks. The freeze-up trend is highly significant, but the ice-out trend is not.

Mirror Lake's ice-out date was strongly correlated with mean March and April temperatures in our regional composite records. March and April temperatures did not warm significantly

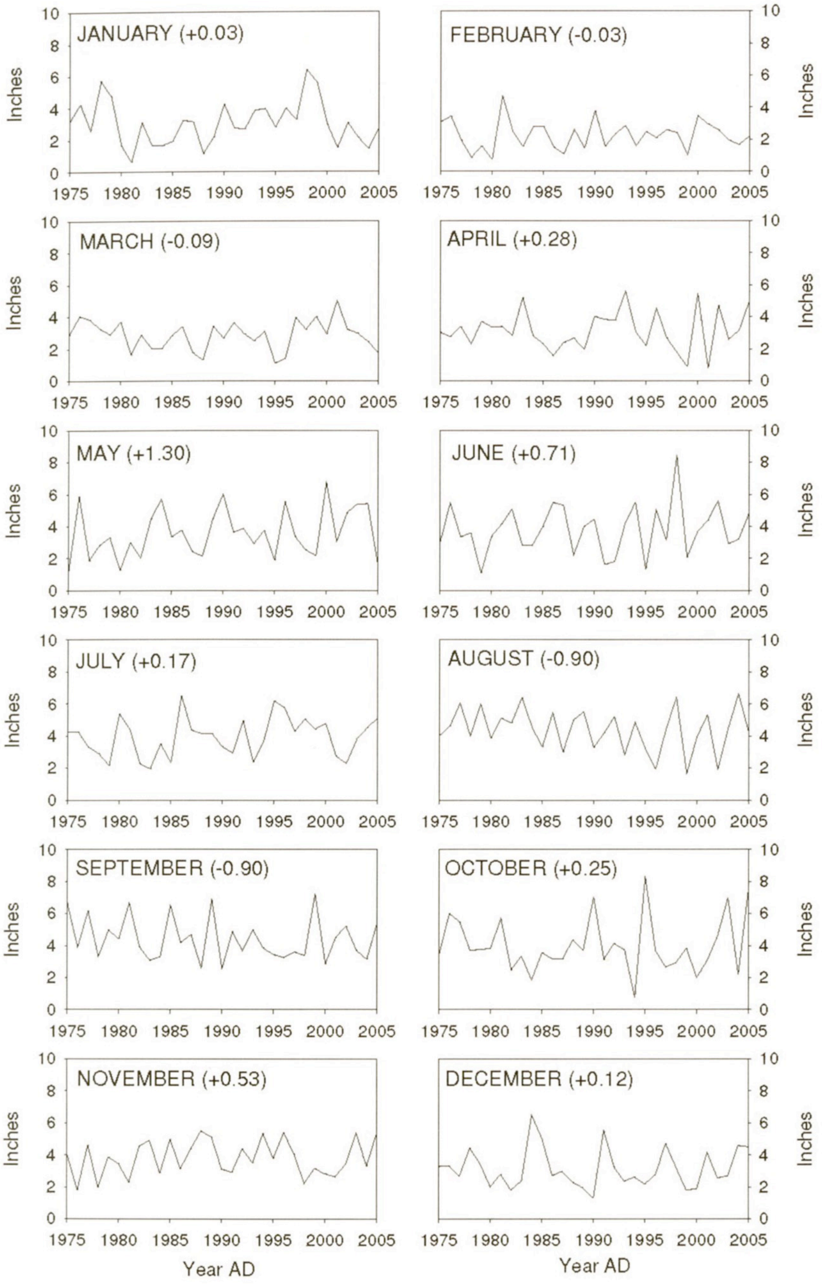

Figure 4. *Total monthly precipitation (inches) for a composite of seven North Country weather stations for 1975–2005. No statistically significant trends were found in these records.*

since 1927 in those composite records, but they did in the Lake Placid weather station dataset, which covered the 1910–2005 interval. We suspect that the lack of a significant trend in ice-out dates on this and several other Adirondack lakes reflects a combination of factors that includes a general lack of strong warming trends in spring, variability in the nature of insulating snow cover and mid-winter ice thickness, and the effects of erratic wind activity on the exact timing of ice break-up.

The date of fall freeze-up, however, is not complicated by snow cover and mid-winter ice growth, and in the case of Mirror Lake it was strongly correlated with regional mean November temperatures and somewhat less so with December temperatures ($p < 0.001$). The warming trends in those months were not statistically distinguishable from random variability in the regional composite, but they both were significant in the Lake Placid dataset over the 1910–2005 interval, particularly the November trend. This suggests that Mirror Lake has been warming enough in fall to affect freeze-up dates.

The roughly two-week shrinkage of Mirror Lake's annual ice cover duration is consistent with records from other Adirondack upland lakes as well. Shorter and/or less complete datasets from Cranberry Lake and Peck Lake (Thaler, 2007), Lake Colby, and Lower Saint Regis Lake, as well as Rich Lake and four others in the State University of New York College of Environmental Science and Forestry's Huntington Wildlife Forest show similar patterns of much later freeze-ups and/or slightly earlier ice-outs, though most lack statistical significance. Ice-out observations since 1962 of the main channel of the Raquette River at Hannawa Falls, provided by NCPR listener Donna Seymour, also fit the regional pattern.

Flowering times. Master gardener Dana Fast has kept meticulous records of flowering times of more than a dozen garden and woodland plants in Lake Clear since the early 1980s, none of which displayed significant trends except that of White Water Lilies (*Nymphaea odorata*), which now seem to bloom nearly two weeks earlier in June–July than they did in 1982. This may reflect heating of the lake due to summer warming, but there was only a weak negative relationship between blooming date and mean June temperature during the period of record and an even weaker relation to July temperatures, which showed no recent warming trend in our composite records. July warming trends since 1982 in Lake Placid and Tupper Lake, the two nearest sources of USHCN weather data, were also not significant. The steep slope of the lily trend line is largely due to two very late dates at the start of the record, and it might actually represent a shift in observational methodology rather than a response to temperature changes.

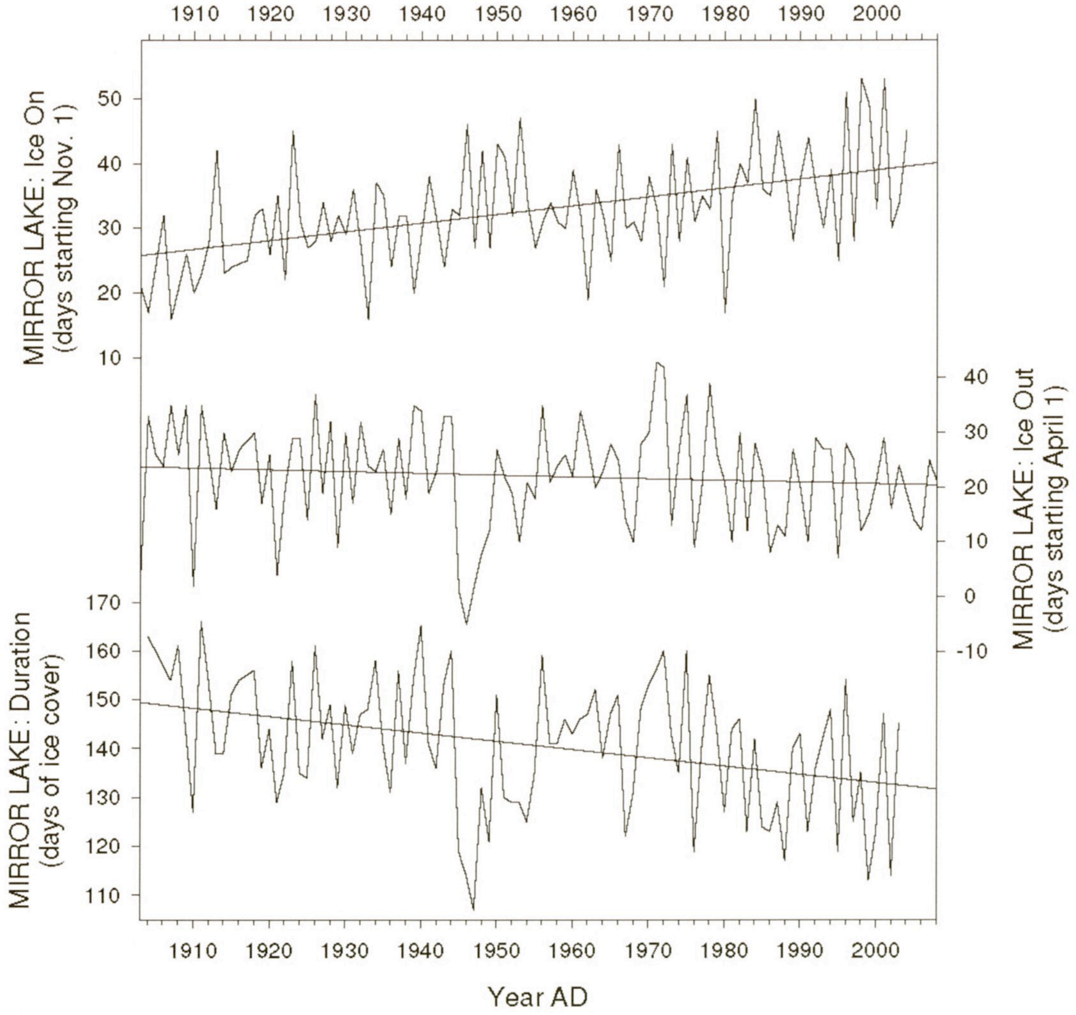

Figure 5. *Ice cover on Mirror Lake 1903–2008. Upper: Date of fall freeze-up, with significant trend. Middle: Date of spring ice-out, with insignificant trend. Lower: Duration of ice cover, in days, showing significant reduction of 2 weeks. (Jerome Thaler and Judith Shea)*

Observational records of flowering times from the Huntington Wildlife Forest (HWF) showed no significant trends in spring blossoming patterns among native woodland plants since the 1970s. Red trillium (*Trillium erectum*) blossoming times at HWF, however, closely resemble those recorded by Dana Fast at Lake Clear and they are strongly negatively correlated with April temperatures in our regional composite records, which likewise displayed no significant warming over the time period in question (Figure 6). Lake Placid and Tupper Lake experienced no significant April warming since 1975, either. In fact, the importance of taking measures of statistical significance seriously is well illustrated by the signs of the trend lines in the *Trillium* data; in both datasets, the trend lines show slightly later, rather than earlier blooming dates as global average temperature rose (Figure 6).

Migratory bird arrival. A record of male red-winged blackbird (*Agelaius phoeniceus*) arrivals in February–April was kept by NCPR listener Jerry Mueller at Fort Covington, NY, for 33 of the years between 1969 and 2007 (Figure 7). Mueller's observations indicated that the male blackbirds arrived about five days earlier in 2007 than in 1969, but the trend was not statistically significant. The arrival of male redwings can occur even when there is still snow on the ground in the North Country, and it is likely that conditions farther south along their migration routes also influence their arrival times. In addition, migrant arrival dates were significantly negatively correlated with mean March and April temperatures, which displayed insignificant trends during the years of observation in our composite records, although April did warm significantly at Lawrenceville, NY, a USHCN weather station located close to Fort Covington (March did not).

Stream discharge. Wetter climates should produce heavier stream discharge, and that is clearly the case in the Adirondacks. A composite record of yearly regional stream discharge (Chiarenzelli, 2008) corresponds closely to our composite precipitation records ($R^2 = 0.7$, $p < 0.0001$), providing a useful test of the validity of the two independent datasets (Figure 8). Both time series show an overall wetting trend through most of the 20th century, with a prominent depression during the 1960s and a leveling off since the 1970s. However, although the stream discharge trend is significant at the 95% level, the regional precipitation trend is not, perhaps because the complex responses of streams to precipitation may reduce much of the short-term variability that tends to obscure underlying trends embedded in "noisier" weather records.

Sugar maples. Several years ago, the United States Department of Agriculture Forest Service posted online maps of how potential temperature preference ranges of various tree species might change with warming during the 21st century (Prasad and Iverson, 1999).

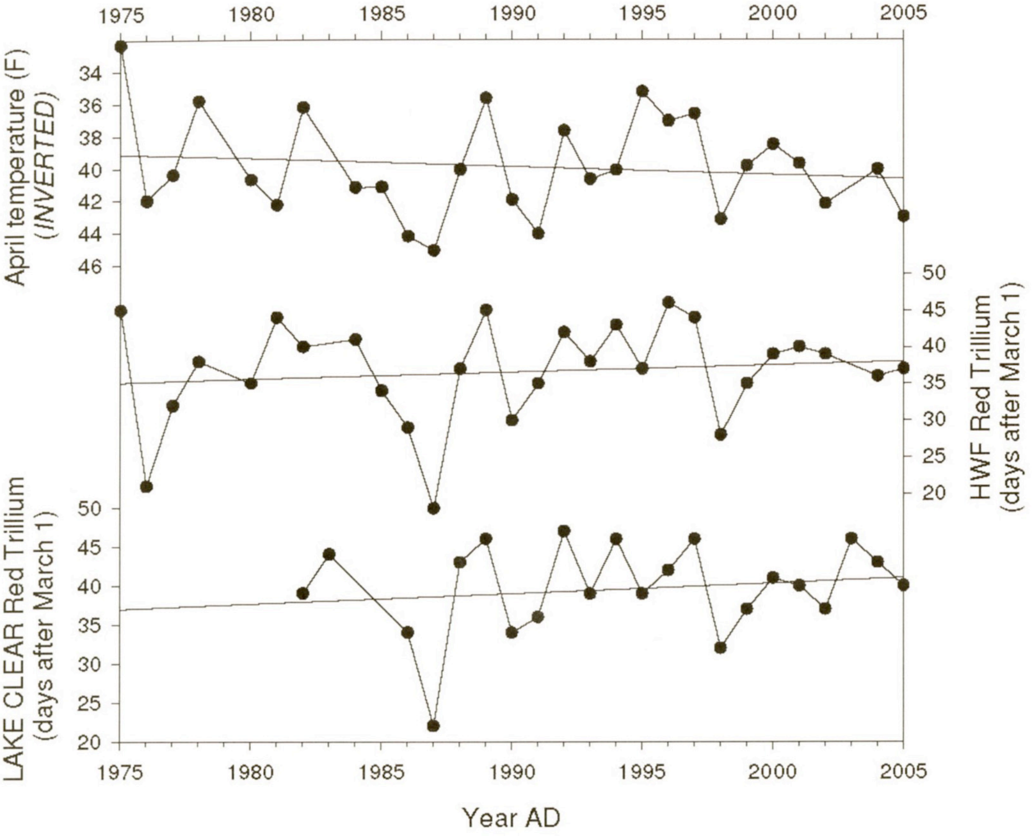

Figure 6. *Red trillium blooming dates vs. temperature, 1975–2005. Upper: April mean daily temperature, with inverted scale. Middle: Blooming date at Huntington Wildlife Forest, Newcomb. Lower: Blooming date at Lake Clear (Danna Fast). No trends were significant, but strong correlations among the records suggest regional coherence between flowering dates and temperatures.*

Most of the maps show dramatic northward shifts and they have been widely cited (e.g., NERA, 2001; McKibben, 2002), but they are also widely misunderstood. As the website now more clearly points out, the maps merely show presumed optimal temperature conditions, not actual tree migrations.

In the case of sugar maples (*Acer saccharum*), worries about a loss of bright fall colors and a decline of maple sugaring in coming decades are at odds with the opinions of several local maple experts such as Mike Farrell, director of Cornell University's Uihlein Field Station in Lake Placid. In a 2008 presentation to the Adirondack Research Consortium conference, Farrell reported that there are more maples in West Virginia than here in the northern part of their range, and that maple sugaring can be as successful in the Blue Ridge Mountains as in the North Country. Farrell also suggested that several degrees of additional warming are unlikely to harm maples or the sugaring industry in the Adirondacks and that, apart from acid rain, deer browsing, and insect pest threats, future increases in summer drought stress could be a more serious threat to maples than warming. We have found no evidence of increasing summer drought intensity or frequency in the Adirondacks, and climate models predict a regional wetting trend for much of this century (Frumhoff et al., 2007). Future warming, however, might nonetheless produce ecologically important drought stress by enhancing evaporation.

Updating Stager and Martin (2002). How do the addition of five more years of weather observations and the use of USHCN data affect the previous conclusions of Stager and Martin (2002)? Most of the findings reported in that paper remain unchanged. Extreme variability in Adirondack weather still obscures most regional-scale trends in our composite records, though the last three decades show clearer signs of greenhouse gas–driven warming. Most months and seasons of the year still show no statistically significant trends in mean temperature or precipitation and a few North Country sites still show slight overall cooling rather than warming since 1950, but Wanakena is no longer among them when raw NCDC data are replaced with USHCN data.

Perhaps the most important revision to be made can be found in the final paragraph of the earlier paper, which concluded that regional-scale climate projections for New England seem to be of little use here in the Adirondacks. Now that USHCN and NECIA have corrected many of the false irregularities in northeastern climate patterns, we find much greater coherence between what is happening in the Adirondacks and in the Northern Forest region of New England.

Looking Ahead

New generations of "down-scaled" climate models are being developed that can forecast long-term climate changes at high, subregional spatial resolution. Until these become widely available, we are still left with relatively coarse-scale models of future conditions in a warming world. However, the weather and phenological data presented here help to refine general ideas of how the Adirondacks might soon be affected by global and regional changes. Although it is impossible to know what exactly will happen here during the 21st century, the findings presented in this paper can provide glimpses of future events in terms of "what *probably* will happen here *if*. . . ."

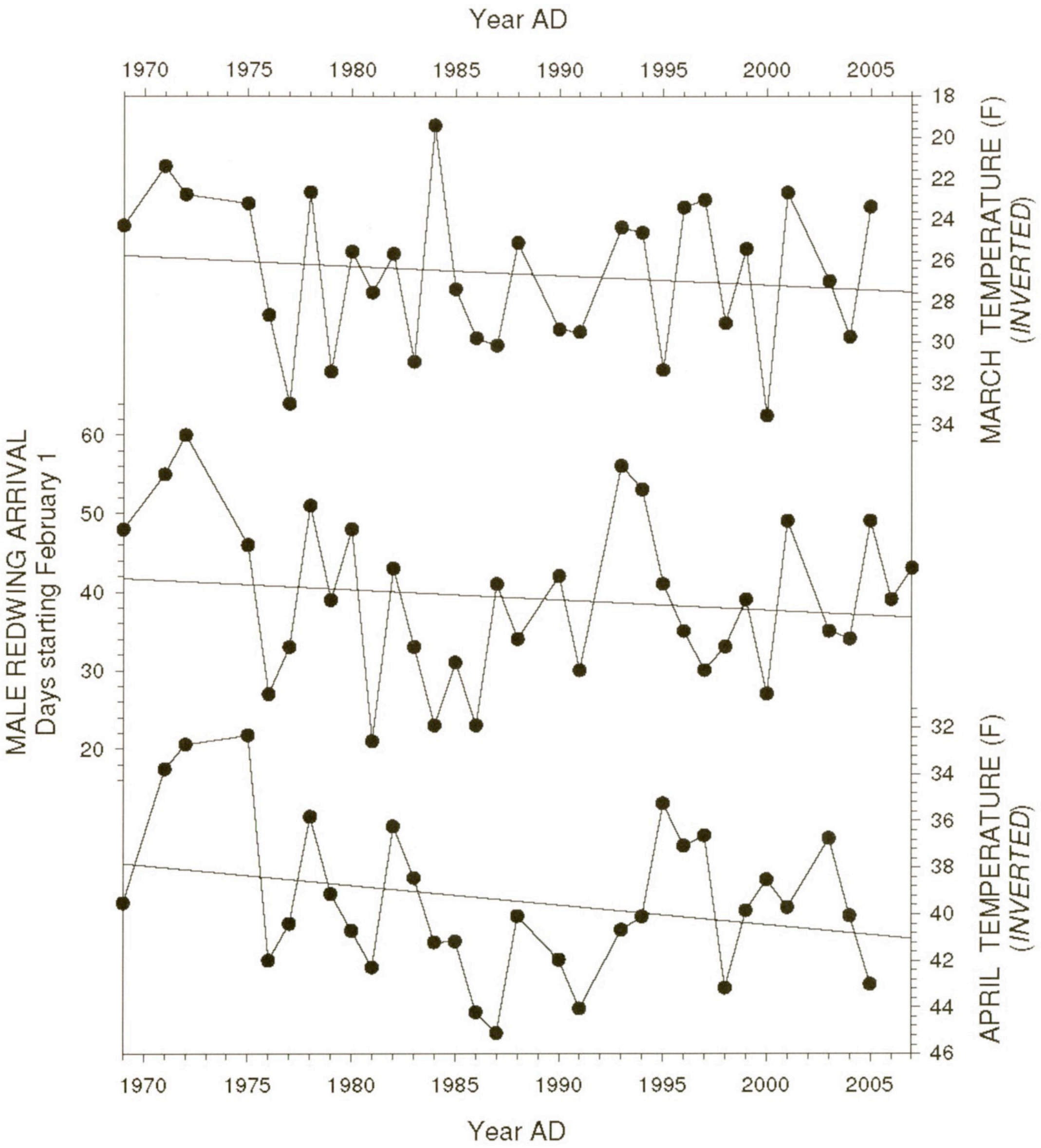

Figure 7. *Bird migration vs. spring temperatures, 1969–2007. Middle: Spring arrival date of red-winged blackbirds at Fort Covington (Jerry Mueller). Upper and lower: March and April temperatures, with inverted scale. No significant trends were found.*

If, as appears virtually certain, greenhouse gas concentrations continue to rise through the 21st century, then further global average warming is inevitable. And if the Adirondack region responds sensitively to such global changes, then the Park is likely to warm, too. If spring temperatures warm significantly, then the blooming dates of plants such as red trillium may drift earlier in the year, as may the seasonal arrival of migrants such as red-winged blackbirds. Not all species, however, will adjust to such changes with equal success. In Europe, higher spring temperatures over a 23-year period induced earlier vegetation growth, resulting in an earlier peak availability of food for great tit (*Parus major*) nestlings (Visser et al., 1998). Yet this climate shift has not led the birds to begin egg-laying earlier, suggesting a decoupling of behavior from the environment that might also occur among some Adirondack species.

If fall temperatures warm, then ice may continue to form later on Adirondack lakes, probably shifting more dramatically on the calendar than ice-out dates will. But if ice-cover trends continue steadily along the same negative trajectory that they have followed for the last 30 years (~3 days shorter per decade), then it may still take three or four centuries for Mirror Lake to become ice-free in winter. Lakes at low elevations would, of course, become ice-free before that; the main body of Lake Champlain is at or near that point already.

If precipitation trends continue as they have during the last three decades, then the Adirondacks will likely remain about as variably wet/dry as they are today, at least until the middle of this century, when regional models predict the onset of a long-term wetting trend. River discharge will also probably continue to increase as it has in the recent past.

The much-heralded dulling of fall colors and the demise of maple sugaring seem, for a variety of reasons, to be unlikely to occur during this century. They might occur later on, however, if, as a growing consensus of climate researchers expect (e.g., Archer, 2005), global temperatures climb much farther and remain higher than those of today for thousands of years beyond 2100.

The long-term impacts of climate change on Adirondack ecosystems will be complex and interrelated. Decades of research have resulted in a solid understanding of acidic deposition here, but the story of Adirondack climate change is only just beginning to unfold. We anticipate and encourage further investigations into the history, nature, and biotic effects of past and future climate changes in the Adirondacks. Closer study of individual station records would help to clarify patterns and causes of long-term variability and local phenological responses to climatic changes. Careful comparison of Adirondack weather records to those of external forcing factors such as the Arctic Oscillation and the North Atlantic Oscillation would help to identify the sources and possible future of local climate variability in a warming world. But to fully understand the impacts of this global issue on the Adirondacks will require sustained, cooperative, interdisciplinary study, and we encourage such broad-based endeavors in the future.

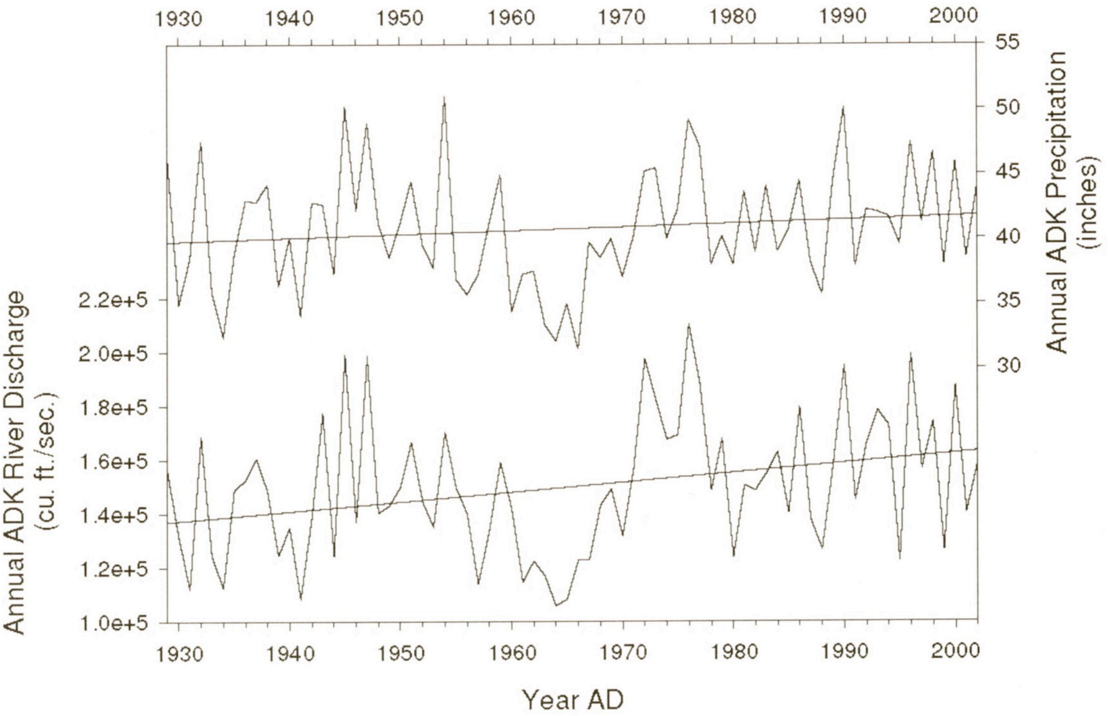

Figure 8. *Stream discharge vs. precipitation, 1929–2002. Upper: Total annual Adirondack precipitation. Lower: Total annual Adirondack stream discharge (Chiarenzelli, 2008). Only the increase in discharge was significant.*

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