Highlights of This Issue

Geophysical Research Letters, July 1, 1998

Diurnal variation in near-surface moisture

Detection of an anthropogenic signal in climate has focused on the temperature record. Only a few studies examined changes in atmospheric moisture driven by human activities even though atmospheric water vapor plays an important role in a changing climate. **Schwartzman et al.** consider approximately 45 years of hourly data from 92 climatological stations in North America and find few statistically significant regional trends in mean dewpoint temperatures. Increases in daytime dewpoints relative to nighttime ones are seen during the warmer seasons, due more to a general trend in atmospheric moisture (and temperature) than to urbanization effects.

1997 El Niño prediction

In a series of hindcast experiments on a coupled model forced with observed SST anomalies, **Oberhuber et al.** predict the 1997 El Niño and the 1998 La Niña. They find that for eight experiments, initialized between January 1996 and October 1997, the 1997 El Niño event is predicted with reasonable skill, the only error being a systematic underestimation in the amplitude of the signal. The key to such prediction lies in the accurate initialization with assimilated data. A simple data assimilation scheme that generates a realistic subsurface thermal structure for oceans in the lower latitudes, and which has previously been applied for model validation and intercomparison, was used in the analysis.

Origin of nitrogen in subduction zones

Geochemical tracers can provide important constraints on the nature of the mantle recycling system. Based on a recently developed mass spectrometry method, **Sano et al.** measured nitrogen isotope and nitrogen/argon ratios in samples of island arc volcanic rocks (ARC) and back-arc basin basalts (BABB) and midocean ridge basalts (MORB) glasses. They infer that nitrogen from subducted marine sediments is the major source for ARC and is still significant for BABB relative to atmospheric and upper mantle sources.

The Arenal Volcano

The ~3000 years old Arenal Volcano in Costa Rica has shown Strombolian activity since 1984. The volcano degasses between explosions. **Garces et al.** have conducted simultaneous measurements of acoustic and seismic waves accompanying the explosions and find that the acoustic and seismic spectra are similar. They postulate that the explosions are triggered in the shallow parts of the magma conduit. During degassing, pressure waves are generated that propagate in the magma-gas mixture inside the conduit. These sensitive waves have the potential to serve as indicators of the chemical composition of the melt.

North-south asymmetry of AKR

A sudden increase in auroral kilometric radiation (AKR) can be a good precursor of substorm activity. **Kumamoto and Oya** analyze plasma wave data for March 1989 to February 1996 from the Akebono satellite, and report that the distribution of the average AKR intensity is stronger in the winter hemisphere than in the summer one. The authors find, too, that the asymmetry of AKR emissions may be associated with the seasonal dependence of the acceleration processes of auroral electrons.

Characteristics of VLF events

Subionospheric very low frequency (VLF) waves generated by lightning are associated with lightning-induced electron precipitation (LEP). The electrodynamics of the system can be inferred from the relative time properties of the VLF waves and LEP. Results of an analysis of a sequence of VLF events, which were associated with a summer storm system in France, are presented by **Corcuff**. Characteristics of LEP events, short duration events, and early/fast events indicate that the LEP events occurred when the storm migrated southeastward, that short-duration events reflected short-duration change in the electrical conductivity of the lower ionosphere, and that some early/fast events occurred in association with pairs of positive discharges.

Presunrise mesospheric echoes

Enhanced radar echoes from the mesosphere are often observed in the daylight summer hemisphere. New results from **Muraoka et al.** show that such events can even occur in presunrise conditions. They use data from the radar at Shigaraki, Japan, to show that their detection is possible even when electron concentration is low as long as the atmospheric turbulence is strong. The authors find, too, that presunrise echoes likely have no connection with field-aligned irregularities associated with sporadic *E* layers.

CF_4 and SF_6 in natural fluorites

CF_4 and SF_6 are long-lived (>10,000 years) greenhouse gases that have known industrial emissions and were assumed to be entirely anthropogenic. The two gases are included in the 1977 Kyoto protocol on climate protection. **Harnisch and Eisenhauer** report that the Earth's continental crust has reservoirs of CF_4 and SF_6. Their natural presence occurs in fluorite, a mineral

Cover: *The arrival of Labrador Sea Water approximately 10 years after formation along the western boundary of the Atlantic Ocean at 26.5°N is indicated, beginning in 1994, by a cooling (order 0.1 °C) and freshening (order 0.02) within the density range characteristic of this water mass. This 10-year advective time is considerably less than the 18-year time reported in earlier studies. (See the paper by Molinari et al. [this issue].)*

Observed changes in the diurnal dewpoint cycles across North America

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Abstract. We analyzed the record of hourly dewpoint data from 92 climatological stations in North America. The data were centered with respect to sunrise and sunset and divided into four geographic regions of approximately equal area in an attempt to uncover regional trends. Few statistically significant regional trends in mean dewpoint temperatures were found. However, the within-day variations were very well behaved and consistent across regions. They showed a relative decline in dewpoints in the late afternoon at most stations, and small declines just after sunrise. The results are consistent with urbanization signals described by *Oke* [1987]. An observed rise in midday dewpoint, followed by a fall in late afternoon, indicates some regional enhancement of convection, which may in part be from the urban effect, but other causes are possible. Our dewpoint changes are somewhat consistent with precipitation changes that have described by other researchers.

Introduction

Numerous studies have attempted to detect an anthropogenic signal in the surface climate on a regional or global scale. Most of these investigations have focused on the temperature record [e.g., *Jones,* 1994; *Karl et al.,* 1993]. However, fewer investigations have directly examined possible changes in atmospheric moisture as a result of human activities.

Atmospheric water vapor content plays a large role in the patterns of precipitation and cloud cover at all spatial scales, and in addition, is the greatest contributor to the earth's "greenhouse effect" [*Houghton et al.,* 1996]. Therefore, temporal and spatial variations in near surface moisture should be expected to have a noticeable impact on the climate.

Changes to near-surface water levels may arise due to a variety of influences including changes in regional atmospheric circulation patterns as well as changes in land usage both locally and regionally. Also, "significant" increases in tropospheric water vapor are expected to accompany increased levels of greenhouse gases [*Elliott et al.,* 1991].

There is some evidence that atmospheric moisture has been undergoing alterations in concentration and vertical distribution. *Henderson-Sellers* [1989] found a tendency for increases in cloudiness in the vast majority of North American stations analyzed for the period 1900-1980. *Angell* [1990] observed similar increases in cloudiness across the United States since 1950 with the greatest increase observed in autumn. There also appears to be increased amounts of precipitation in many parts of North America [*Karl et al.,* 1995]. Direct studies of tropospheric moisture levels over large areas using radiosonde observations have shown generally increasing trends over the past several decades [e.g. *Ross and Elliott,* 1996; *Elliott et al.,* 1991]. These studies, however, have generally assessed changes in moisture levels in the lower-to-mid-troposphere and have not focused on near surface moisture amounts. In addition, they have been limited to one or two observations per day. A direct determination of the *diurnal* variation in near-surface moisture characteristics will help the furthering understanding of these observed tendencies for change.

In an earlier work [*Knappenberger et al.,* 1996], we examined the temporal changes observed in the diurnal profile of temperature and dewpoint at 15 climatological stations within the contiguous United States. Here, we extend that analysis by expanding the number of stations to 92, expanding the region of study to include Canada and Alaska, and focusing primarily on the temporal changes in the diurnal moisture (*i.e.,* dewpoint) cycle. Changes in the diurnal temperature profile will be presented as well for the purpose of assisting in the understanding of the observed dewpoint changes.

Data and Analyses

Hourly surface climatological data were obtained from the National Climate Data Center (NCDC) and Environment Canada for over 200 stations across the United States and Canada. In all, 92 stations were selected from these data sets in an effort to provide the best combination of geographic coverage, availability of hourly data, and duration of available record. Hourly data in this data set generally began in 1948 (for the U.S. stations) or 1953 (for the Canadian stations) and ended in the early 1990s. Breaks in continuity of data for the U.S. stations (generally from the mid-1960s through the mid-1970s) represent years when many U.S. climatological stations changed observation frequency from hourly to three-hourly. Since we are primarily interested in the temporal trends of the data records, these "gaps" in the middle portions of the data sets do not greatly detract from our methodology. Selected stations contained at least 25 years of useable data.

Numerous diagnostic checks were performed on the data for each individual station in order to evaluate the quality of the data. Particular attention was given to extreme values, extreme changes (from hour to hour), and repeated values. Values deemed erroneous where changed to missing. Such alterations of the data sets, however, were minimal in number. Additionally, the method of measurement of dewpoint temperatures has undergone several changes during the time period of this study [*Elliott,* 1995]; however, scrutiny of the data for discontinuities in the time series showed them to be minimal and insignificant, a result similar to conclusions reached by other researchers [e.g., *Gaffen and Ross,* 1998].

The hourly data were initially converted from a clock-based time frame to a sun-based time frame. This was done first by calculating the time of local sunrise and sunset and then assigning to each hour of the day both a time-since-sunrise and a time-since-sunset value (in whole hours). This assignment introduced a maximum error of 30 minutes between the actual time of sunrise/sunset and the reported data. By using this floating reference frame, we were able to combine daily diurnal cycles to produce seasonal averages. Such a combina-

Paper number 98GL01843.
0094-8534/98/98GL-01843$05.00

tion is otherwise difficult since the length of days and nights varies by many hours over the course of the year.

A simple regression analysis was performed on the seasonally averaged (DJF, MAM, JJA, SON) dewpoint temperature (and dry-bulb temperature) for each of the 10 hours preceding and following both the time of sunset and sunrise as well as for the sunrise and sunset themselves. The slopes of the best fit least-squared lines through the seasonal time series for each hour in the sunrise-centered and the sunset-centered analyses were then used to produce a complete 24-hour diurnal cycle.

A plot of the hourly trends allows one to examine not only the trends in each successive hour of the day/night, but also the relationship of the hours to one another. The shapes of the hour-to-hour curves represent the changes in the diurnal profile of dewpoint (or temperature) and provide information regarding the wetting and drying rates (or warming and cooling rates) of the near-surface atmosphere.

Figure 1 shows the geographical distribution of the stations used. In order to summarize the results from the 92 individual station analyses, we aggregated the stations into four geographical regions of approximately equal area and averaged the hourly trends among the stations within each region (the number of stations in each region given in parentheses): the eastern U.S. (34), the western U.S. (33), the eastern high latitudes (10), and the western high latitudes (15). While standard significance tests could be performed on the hourly trends at the level of the individual stations, in aggregation, the significance could only be ascertained by way of t-tests, testing whether the combined average trend for each hour was different from zero (no trend). The combined trend was deemed significant if zero was outside of two standard deviations from the mean.

Results and Discussion

We present in Figures 2a-d the results from the four regions of North America. Points above zero indicate positive trends in dewpoint (or temperature) over the period of record and points below zero represent reductions. We have filled in those points which have a significant aggregate trend. The day/night lengths chosen represent the mean values across the region. Our discussion covers mean changes first, followed by the within-day (i.e., diurnal) variations. It is clear from Figures 2a-d that in aggregate, the trends in hourly dewpoint temperatures are not statistically significant over most of the study region. The only exception being the hours surrounding sunset during the fall season in the eastern high latitude region which show a decline in dewpoint temperature. The large downward dewpoint trends during the eastern high latitude winter are driven primarily by two stations in that region which exhibit marked declines, but the results are not statistically significant when taken in aggregate.

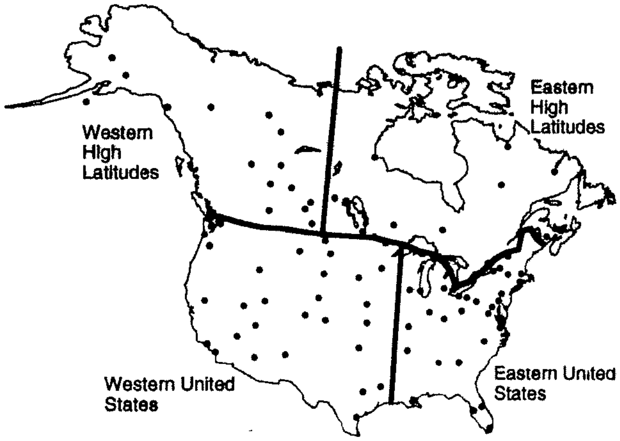


Figure 1. Location of stations and geographical regions.

However, the behavior of the regional plots does show remarkable within-day consistency, progressing smoothly from hour to hour. This feature captures the common behavior found in the individual station results and indicates that while the hourly mean trends vary considerably from station to station, the within station changes are very consistent across the population of individual stations. Therefore, examination of the behavior of the within-day aggregate trends provides information that is representative of the individual stations and is useful in studying within-day variations over time.

Most of the within-day changes are occurring between sunrise and sunset. The nighttime shows little hour-to-hour variation. This general behavior is found in all regions and during all seasons and holds for the dry-bulb temperatures as well.

The general dewpoint temperature trends show a gentle rise in successive hours starting from sunset and continuing into the early hours of the day after which begins a relative decline towards sunset. In the warmer seasons, this rise is interrupted briefly by a relative decrease in dewpoint temperatures immediately after sunrise.

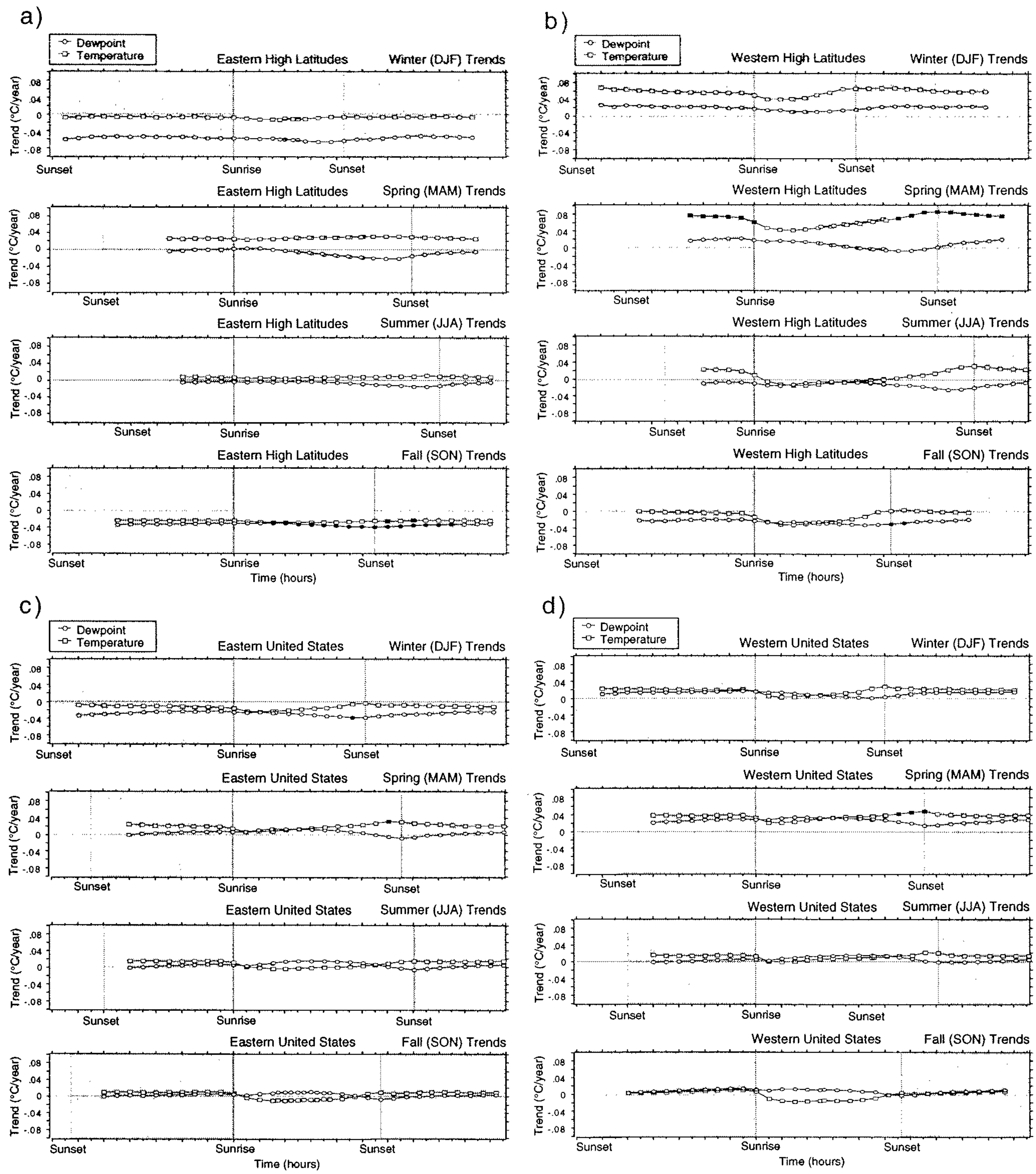
It is also interesting to note that changes in the daily temperature profile are generally opposite to those of the dewpoint cycle (i.e., hourly temperatures are declining relative to each other from sunset until shortly after sunrise and then rising until sunset).

There are many potential factors that may be contributing to the these results, including large-scale circulation changes, microscale changes in evaporation or convection budgets, and atmospheric greenhouse gas concentration increases. Changes in these parameters are expected to contribute to alterations in the mean climate signal and/or the daily climate signal in predictable ways. Complicating attempts to fully understand these expectations is the fact that the contributors act concurrently. However, their expected impacts on the diurnal cycle of dewpoint may be sufficiently unique to allow for some discrimination among them.

Large scale (synoptic) circulation changes have occurred across the region during our period of record. For example, *Davis et al.* [1997] report a trend towards meridional flow with increased tendency for ridging in western North America and troughing in eastern North America during the winter. Such a change should have noticeable effects on the mean dewpoint and temperature values at the station level. However, even though our results do hint at such a regional signal (we find wintertime dewpoint (and temperature) increases in the western regions and decreases in the eastern ones) the results are not significant at the 95 percent level. It is possible that our regions do not precisely align geographically with the observed circulation changes which has the effect of weakening the strength of our aggregate signal. The within-day changes seem to be rather consistent across regions and seasons, indicating that circulation changes are not likely to be the primary cause.

Microscale changes driven by urbanization and other land use activities are expected to have a discernible impact on the dewpoint curves. Many of the stations used in this analysis undoubtedly have undergone a variety of land-use changes, including urbanization, deforestation, irrigation, and so on. Of these, the effects of urbanization is likely to be significant in our data since hourly recording stations are primarily first-order climatological stations that have evolved in an increasingly urban fashion.

The alterations of the surface composition and surface geometry associated with these changes greatly impact the radiation and water budgets in and around the expanding locality [*Geiger et al.*, 1995]. *Oke et al.* [1987] presents evidence that an urbanized location will have higher nighttime near-surface atmospheric moisture levels and two daytime moisture minimums relative to a nearby rural location. The nighttime moisture levels will be elevated because nighttime tem-



Figures 2a-d. Trends in hourly dewpoint (and temperature) for the station aggregates representing the following regions: (a) eastern high latitudes; (b) western high latitudes; (c) eastern United States; and (d) western United States. Significant trends are filled.

peratures in an urban setting are warmer than those of a rural locale, which lessens the atmospheric moisture depletion as a result of dew formation. This urban moisture excess rapidly turns into a relative moisture minimum when the sun rises and the morning dew is evaporated back into the rural atmosphere, raising dewpoints there. The relative late afternoon urban near-surface moisture decrease is caused by a difference in the nature of convectional processes once incoming shortwave radiation begins to decline in the late afternoon. Vertical mixing, which generally reduces near-surface moisture levels, attenuates more quickly in the rural areas [*Oke,* 1987], and thus dewpoints begin to rise there sooner. This produces a relative near-surface moisture minimum during this time in an urban (or urbanizing) setting, where elevated late afternoon and early evening temperatures prolong convective processes.

Our dewpoint (and temperature) results contain signatures of urbanization. The hour-to-hour dewpoint changes exhibit relative reductions (or "dips" in Figure 2a-d) in the early morning and again in the late afternoon, and the diurnal temperature cycle is marked by nighttime temperature increases relative to the daytime and elevated temperatures in the late afternoon. However, the expected signal of moister nights relative to days is not uniformly observed. In fact, during the warm seasons in the United States, the daytime dewpoints, especially in the middle part of the day, have risen relative to the nighttime levels. The midday relative rise in dewpoint levels is not consistent with an urban signal.

An increase in "greenhouse" forcing, driven by increases in atmospheric greenhouse gas concentrations during the period of record, is expected to increase atmospheric moisture levels as part of a positive feedback with rising surface temperature [*Elliott et al.*, 1991]. However, the lack of consistent increases in dewpoints across regions and seasons indicates that these forcing considerations are, at this point, unremarkable or hidden by the compounding or interference of other factors. In fact, the shape of the dewpoint trend curves is remarkably consistent, regardless of whether temperatures trends are increasing or decreasing.

It is interesting to consider the possible effects of increasing midday dewpoints accompanied by relative declines later in the day. The relative dewpoint depression in the late afternoons is likely an indication of increased convection as it is tends to be much larger during the warmer seasons, while the relative rises during the midday hours would seem to indicate a general increase in daytime moisture levels. A higher water availability, accompanied by enhanced convection, likely would produce an increase in precipitation. As previously discussed, the observed pattern of dewpoint trends bears some resemblance to an urban effect and therefore could likely produce a similar precipitation effect. The effect of enhanced and prolonged convection in an urban environment is to increase precipitation there (or slightly downstream). *Landsberg* [1981] documents that cumulus clouds begin to form over cities well before they develop over nearby rural areas and *Changnon* [1981] found an increase in precipitation just downwind of the St. Louis urban center. The precipitation enhancement was found not to be an increase in the frequency of events, but instead in the amount of rainfall produced in high intensity events.

The observed dewpoint changes, however, are not entirely consistent with urbanization, and therefore, it is possible that they are an indication of an alteration of the water cycle on a broader scale. In fact, an increase in the precipitation delivered in more intense rainfall events has been reported by *Karl et al.* [1995] for the summer across the United States. Our results are not inconsistent with this finding. Nonetheless, this signal is small in our dataset as there are almost certainly significant urban influences.

Conclusions

In this paper we examined changes in the diurnal cycles of dewpoint throughout the United States and Canada for approximately the last 45 years with hourly data from 92 climatological stations. We found that within our geographical aggregates, the regional trends of dewpoint temperature (and dry-bulb) temperature did not exhibit changes that were statistically different from zero. However, the consistency of the within-day aggregate trends, and their similarity in pattern to those exhibited by the individual stations, indicated that the regional aggregates were capturing a true behavior within the system and thus were worthy of further scrutiny. Relative declines in dewpoints were observed in the late afternoons across all regions and seasons, although they are most pronounced and accompanied by a slight relative decline just after sunrise in the warmer seasons. In addition, daytime dewpoints during the warmer seasons are increasing relative to nighttime dewpoints. This seasonal and temporal pattern of change is a possible indication of an enhanced convective cycle.

Large-scale circulation changes over the past half-century likely have an impact on the mean dewpoint (and temperature) values, although it is possible that our geographical regions do not accurately capture this change. However, within-day changes in dewpoint suggest that additional factors are important. These changes appear to be at least somewhat attributable to land-use changes, particularly urbanization, at or near the climatological stations examined, in that they bear a pattern of change similar to that which would be expected from urbanization effects. However, increases in daytime dewpoints relative to nighttime ones are not sufficiently explained by urban effects and may, in fact, be an indication of a more general trend in moisture cycles.

Due to the confounding effects of urbanization in our long-term records of hourly data, care must be taken when trying to extrapolate a more general cause and effect, although the observed patterns of change are not inconsistent the those that would be necessary to produce an increase in precipitation from strong storms such as that reported by *Karl et al.* [1995].

Acknowledgements. Financial support for this research came from the U.S. National Oceanic and Atmospheric Administration and U.S. Department of Energy. We thank University of Virginia Environmental Scientist Robert E. Davis for his critical insight on this complicated problem.

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(Received December 15, 1997; revised May 19, 1998; accepted May 27, 1998.)