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CLIMATE VARIABILITY AND ECOSYSTEM RESPONSE: OPPORTUNITIES FOR THE LTER NETWORK

Abstract. Unusual ecosystem responses are frequently driven by meteorological events. The frequency and magnitude of these events and responses can be characterized through Long-Term Ecological Research (LTER). The LTER Climate Committee identifies four issues to be considered in future investigations: (1) the need to clarify terms and definitions used in discussing climate variability, (2) the importance of recognizing the various time and space scales of climate variability and ecosystem response, (3) the need to expand data beyond dependence on traditional summaries of temperature and precipitation, and (4) the value of insights gained from examining similarities and dissimilarities among climate episodes and ecosystem responses across LTER sites.

Key words: air mass; climate change; LTER; scale.

Introduction

The Long-Term Ecological Research (LTER) program (Franklin et al. 1990), sponsored by the National Science Foundation, is designed to facilitate investigation into those issues in ecology that are intractable using a short-term perspective. An obvious issue of this kind is the variation of climate over time. In the summer of 1988, one which was to become noteworthy for severe drought in many parts of the United States, the Climate Committee of the LTER program held a Workshop on "Climate Variability and Ecosystem Response." Eleven of the then 15 Network sites participated. Each site was asked to examine the longest time series of data for their site for temporal variability and to comment on the relation of that variability to ecosystem responses. Some sites could not respond directly in this framework because of the newness of their site to the LTER Network. Others believed atmospheric variability, other than temporal, might be important at their site. Clearly, the question of climate variability was easier to address than that of ecosystem response. Ten sites presented papers at the Workshop and a plenary session was held to consider issues emerging from intersite comparison. The individual papers are published elsewhere (Greenland and Swift 1990). The purpose of this report is to bring to a wider audience of the ecological community some of the points emerging from general discussion at the Workshop.

An important contribution of long-term ecological research is the ability to place unusual ecological events in perspective. In a study of 380 ecology papers, Weatherhead (1986) concludes that "the danger of short-term studies may be that they experience too many unusual events. The reason for this unexpected conclusion may be that we tend to overestimate the importance of some unusual events when we lack the perspective provided by a longer study." He also notes that abiotic atmospheric factors, particularly precipitation and/or temperature, cause the great majority of unusual ecosystem events. In their report on long-term research, Strayer et al. (1986) find that long-term studies are necessary to explore four major classes of ecological phenomena. They identify these phenomena as: (1) slow processes, (2) rare events, (3) subtle changes in systems, and (4) complex processes requiring long-term multivariate studies to detect change. We note that the static or no-change situation was not listed as an ecological phenomenon. The first three of these classes of change may be closely correlated with climate data, while climate data may be a significant variant in the fourth. Furthermore, according to Strayer and others, the measurement variables eventually selected in long-term research could be classified either as structural variables, such as species composition, or as functional variables such as primary productivity. Climate might be classified best as a set of functional variables, even though some of the functional relationships are not yet known.

The LTER Climate Committee discussed the application of long-term studies to research on climate variability and ecosystem response. The Committee focused on four main areas: (1) clarifying our terminology, (2) recognizing the importance of time and space scales in all aspects of such work, (3) developing and promoting climatic indices, other than standard expressions of temperature and precipitation, that may be useful in ecosystem studies, and (4) utilizing the similarities and dissimilarities between existing LTER sites.

Terminology

Even before the Workshop began, Committee members were debating the meaning of the term "climatic variability." The view was that the term, as used in the Workshop title, implies abnormality, whereas climate variability (or any other kind of ecosystem variability) is the normal condition. Climate variability was described as consisting of a pattern of "episodes" and "events." The time scale of the episode or event is significant. The following points led the group into the concept of episodes vs. events as it applies to Long-Term Ecological Research.

We defined weather as a real-time event, whereas climate is a synthesis or time integration of weather element values or weather systems. Climate has the component of expectation that a characteristic will occur (Hare 1985).

Clear terminology is necessary because weather events and climatic episodes have political ramifications when reported to the public by popular media. Reports must clearly state whether a particular heat wave or drought is a significant event or part of the variability that is an integral component of routine weather. Unfortunately, terms such as "climatic normal" and "normal climate" detract from the reality that variability is the normal characteristic of a climate system. Federer has noted that we use the monthly interval in this paper. The month is an anthropocentric approximation of the lunar cycle and bears weak relation to many long-term physical or ecological phenomena. Federer believes strings of daily data would be more useful.

Because of their long-term emphasis and extensive spread over diverse ecosystems, LTER sites are key elements in the national effort to detect changes in the climate system. Without data, the detection of change is strongly molded by human bias toward a time scale that corresponds to the human life-span. Extreme weather events are ranked in severity against those events within the observer's memory. The "Great Southeastern Drought of 1986–88" is most significant to those who cannot recall the drought of the mid-1920s. A mature forest or natural grassland may be described as unchanging until someone obtains measurements of its characteristics over a period long enough to detect change. Botkin (1990) argues that the lack of perception of long-term dynamic change can impede efforts to preserve natural areas. Investigators must be able to evaluate the state variables of an ecosystem before they can begin to relate change to climate variation. Consistently collected, long-term climatic data are a most valuable and necessary tool to categorize weather events and climate episodes. The LTER Network provides opportunities to test for climate change and to relate it to ecosystem response without an anthropocentric time scale bias. This bias limits the ability to detect real changes between one episode and another. A corollary question might be, what other biases do we impose on the LTER ecosystems we study? For example, how do the sizes or sampling intensities of the LTER sites affect understanding of spatial scales?

Several cases of the cyclic nature of, and rapid changes in, climatic values were noted at the Workshop. Examples include data from Hubbard Brook (accumulated daily precipitation and temperature records), Northern Lakes (dates of lake freezing), and Niwot Ridge (recent annual temperature values). Step functions might be more common than smooth trends or cycles, even on an intra-annual scale and for all elements that were examined. On a seasonal scale, phenological changes may force step-function shifts in microclimate values. Albedo, light transmission, and litter temperature, for example, change rapidly with leaf development or leaf fall. Other discontinuities in the time series of climate variables are common at many LTER sites. These discontinuities may be more important than regular trends because they "reset" the ecosystem. For example, every storm establishes a new state for soils, vegetation, and associated hydrologic systems. Rapid change is a prime characteristic of the interval (event) between episodes.

For research on climatic cycles or step functions, members of the Committee cautioned against using methodology such as spectral analysis that looks for cyclic forms irrespective of the realities of the ecosystem. Regular cycles should not necessarily be expected. Such statistical techniques should simply be used to search for an explanation of variance. Spectral analysis was applied to the Niwot Ridge–Green Lakes system and limited power was found to explain actual ecosystem operation. Other, more appropriate, methodologies may be available for investigating value discontinuities in ecosystem and abiotic variables. An example is the work of Walsh and Richman (1981) on the rotation of orthogonal principal components. By examining the sizes of anomaly fields, they were able to identify sister stations in both time and space and define discontinuities in the records. This technique could be very useful for extrapolating out from LTER sites.

As a result of the above considerations, the Committee found that LTER scientists, and others working in the field of climatic variability, should be more specific than the term "climatic change" allows. For clarity, we should apply a distinction between "episodes" and "events." An "event" was defined as a single occurrence, such as a large rainstorm, often embedded in the functioning of the synoptic climatic scale. An "episode" was taken as a string of events, with its duration probably related to the time constant of the system. Some events and most episodes reset the time clock of the system. They result in a large change in the ecosystem at the time of occurrence followed by a long tail of less obvious adjustments.

The Committee recognized at least three commonly utilized perceptions of "climate episode." First, climate episodes are defined by the data of the climatic time series bounded by their indications of changes of state. Second, the perceived climatic episode is often described by means of climatic data, but is actually bounded by a time scale of human memory lasting between 40 and 80 years. Third, a climate episode may be best defined by responses of the components of the ecosystem. All are especially dependent on spatial scale, and the latter is specifically apropos for Long-Term *Ecological* Research.

Scale

In discussion, the Committee continually returned to questions about time and space scales in which episodes occur. Scale is an important consideration because it determines what kinds of questions can be asked about the operation of the ecosystem. Researchers must relate the scales on which climate systems operate to those scales on which the biotic parts of the ecosystems operate.

Actually, some of the difficulty in defining "climate" and "climatic variability" arose because of difficulty in defining the time scale of climate. The 30-year period over which "climatic normals" are calculated is an artificial human construct championed by the National Weather Service (NWS) of the United States and the World Meteorological Organization (WMO) and may have little relevance to ecosystem realities. Other averaging periods for climate data might be more meaningful (Kunkel and Court 1990). The averaging period will have a very large role in defining an '"episode" and its importance.

The definition of climate, as perceived by an individual component of the ecosystem, is directly related to scale. A soil microorganism might regard an individual rainstorm as a significant climatic event, whereas a tree at the Andrews site in Oregon would be acclimated to a climate range far exceeding that found in any 30-year climatic normal. Each ecosystem responder defines its own climate scale. Each organism has a condition where it is most successful and a band of tolerance within which it can exist. Species with narrow tolerances may become endangered by a new episode.

Partly because scale has been ignored, we do not have a good understanding of many ecosystems. Ecosystems are often described as complex, and may appear unnecessarily so because we have not considered the various time scales relating the functioning of systems to their elements. Thus, complexity may be a function of the way we study the system and not necessarily a characteristic of the ecosystem itself.

Definition of appropriate time and space scales can be a major contribution of the LTER Network. LTER scientists, and especially the climatologists, are well positioned to attack this problem. Sites should equip themselves with the tools to put events such as droughts and storms into perspective. An example of such tools is the Z–T methodology applied at the Coweeta site (Swift et al. 1990). The importance of developing such tools is demonstrated by the Midwest drought of 1988. Even in retrospect it is difficult to specify a tool to answer the question: When did the drought begin? Agroclimatic indices like the Palmer index suggested that this drought started in April. But the media only began asking questions about the drought in June, at least 2 months later. Part of the function of LTER is to answer questions from the public. Thus, we could adopt a goal of developing procedures that relate climate to the ecosystem and yet are understood by the public and the media. A major challenge would be to foster public understanding of research results at LTER sites where plant succession is a long time scale process, such as Cedar Creek, Minnesota and Bonanza Creek, Alaska. Another important LTER project might be to develop an index of drought (or any other abiotic variable) that would detect and define the short-term phenomenon that is superimposed and acting on a longer term process.

We may not have been characterizing the most relevant and comparable time and space scales between ecosystems and climatic events. Discussion suggested that hierarchy theory can be helpful, and that the functional factors of ecosystems would be used to select those climatic events that may be most important. The reverse process was also recognized. Ecologists are now asked to estimate ecosystem responses for the multitude of climate projections. In some cases, the rate of the projected climatic or environmental change exceeds the capacity of an ecosystem to respond gradually. What is that limit, and what alternate response can be predicted from research?

Various examples of environmental change exceeding the response capacity of the ecosystem are available in the LTER Network. A short time scale example is the inability of root growth in the Midwest to keep up with the lowering water table during the 1988 drought. On a long time scale, marsh growth on the Virginia Barrier Islands was unable to keep up with a relatively high rate of rise in sea level.

Our current climatic data impose several time and space scale limitations. The time limitation is that the length of the reliable observed climatic record in most parts of the U.S. is on the order of 100 years. This affected the results in several of the presentations at the Workshop. A scale limitation is that most modeling studies based on current General Circulation Models (GCMs) employed to investigate potential effects of increase in greenhouse gasses are on a scale so large that a state the size of Colorado might contain only one grid point.

Furthermore, each ecosystem has a significant spatial scale, yet each LTER site can study only a portion of its ecosystem. Tansley's (1935) original definition recognized scale as an element of the ecosystems. He said (p. 299), "These *ecosystems,* as we may call them, are of the most various kinds and sizes." Ecosystems are perceived and identified because they have a degree of resilience and resistance to episodic change and thus are able to transcend smaller time and space scale changes.

If we recognize that varying time and space scales are important in the structure of ecosystems, then how should this fact be included in research plans? One approach, based on hierarchy theory as noted above, can use elements of the ecosystem to identify important scales. A second method is to identify important scales in descriptive data.

Such an identification has been attempted elsewhere, and the Committee suggested that climatologists and ecologists refer to earlier attempts by Clark (1985), Delcourt et al. (1983), Di Castri (1988), and Mason (1970). For example, the Delcourt used log-log axes in diagrams that related ecosystem events to time scales and/or ecosystem events to space scales. Thus, we would display at one end of the scale the activities of soil microbes and, farther up the scale, plants and trees in a successional system. In making these time and space distinctions, we will be addressing the problems of complexity in the same sense as in the concepts of hierarchy theory. Those concepts were applied to ecology by such seminal works as Allen and Starr (1982) and O'Neill et al. (1986). In organizing our ideas around specific time and space scales we will be dealing with an organized complexity instead of disorganized complexity. All parts of the system do not interact at the same time because of the very existence of different time and space scales. For instance, microbial respiration rates are more related to individual rain events than to gap/phase succession events in forests that have been subject to long-lasting droughts. This approach for simplifying organized complexity will enable us to structure our view of systems, but ecologists and climatologists need to upgrade our key skills for sampling our systems. In all of these considerations, the functional ecosystem variables assume greater importance than the structural variables. Therefore, the climate variables that relate to ecosystem function rather than to structure should be emphasized.

Thus, we conclude that understanding climate variability and ecosystem response demands that we pay particular attention to space and time scales. We must beware of arbitrarily imposed, human-derived scales and concentrate on those scales that emerge from the functioning of the ecosystem and climate systems. Research should specifically identify those functions and processes of the ecosystem that cannot keep up with potential rates of abiotic change, such as postulated global warming rates.

Indices for Intersite Comparison

The LTER Climate Committee recognized a continuing need for consistency in obtaining

Table 1. Number of months of air mass domination at LTER sites 1948–1963.*

Site	North Pacific	North Atlantic	Ohio Valley	Arctic	Greenland	Klondike	High Plains
	Number of months of air mass domination						
Andrews, OR	12	0	0	0	0	0	0
Cedar Creek, MN	5	3	2	1	0	0	1
Central Plains, CO	8	1	2	0	0	0	1
Coweeta, NC	1	7	4	0	0	0	0
Illinois Rivers, IL	4	3	2	1	0	0	2
Jornada, NM	2	7	3	0	0	0	0
Konza Prairie, KS	5	5	2	0	0	0	0
Niwot Ridge, CO	8	1	2	0	0	0	1
North Inlet, SC	0	8	4	0	0	0	0
Northern Lakes, WI	3	2	3	3	0	0	1
Bonanza Creek, AK	6	0	0	5	0	1	0
Sevilleta, NM	7	3	2	0	0	0	0
Luquillo Forest, PR	0	12	0	0	0	0	0
Virginia Coastal Reserve, VA	1	7	4	0	0	0	0
Harvard Forest, MA	1	5	4	1	0	0	1
Arctic Tundra, AK	6	0	0	5	0	1	0
Kellogg Biological Station, MI	2	3	3	2	0	0	2
Hubbard Brook, NH	0	3	4	2	0	1	2

* The values quoted here have been revised and are considered to be more correct than those published in a similar table in Greenland and Swift (1990).

and handling data across the Network. A set of time series analyses across all sites would be useful. Also useful would be new indices, not directly dependent on monthly and annual mean temperature and precipitation values, to extend the information base beyond our earlier work (Greenland 1987). Federer believes that a water stress variable would be important to develop in this context. Such a variable might be accumulated deviation of daily precipitation (or temperature), or more complicated ones involving soil water budget factors. The effectiveness of an indirect index, the date of lake freezing at the Northern Lakes LTER site, was demonstrated in the Workshop (Robertson 1990). However, this index and storm surge data, suggested by Hayden (1990), are specific for those LTER sites and ecosystems they represent and cannot apply to most other sites.

Other data sets do exist that could provide general climatic indices. For example, the Department of Environmental Sciences at the University of Virginia has records of cyclone frequencies since 1885 and 500–1000 mb thickness levels for all LTER sites.

An index that seemed to have wide application for intersite comparisons emanated from air mass climatology. Climate at a place is dependent on exposure to a characteristic pattern of air mass types that integrate many climatic elements such as temperature, precipitation, and humidity. Wendland and Bryson (1981) refined the concept of frequency of air mass climatology by using streamline analysis to map airstream regions. The regions are defined by the boundaries between airstreams from different global source areas. Wendland and Bryson traced the source of these airstreams by mapping monthly surface level streamlines (i.e., lines of resultant winds along which air has flowed). Almost every LTER site1 experiences periods during the year when there is a shift between being in the region of one airstream and being under the influence of air from another. An index for comparing LTER sites might be the number of months duration in different airstream regions. The time pattern of airstream regions could also explain the seasonal distribution of precipitation and strong site contrasts such as the extreme between Jornada and Andrews. Variation might increase with distance of a site from the source of the airstream.

Wendland has since examined air mass frequency data for all LTER sites (Table 1). These frequencies can be refined to ensure that the boundaries for the air mass regions are based on data representative for each LTER site. For example, the elevated Niwot site is not expected to be in the same air mass as the Central Plains site, both based here on Denver data. Table 1 indicates the duration of each air mass from various source regions and is a representation of the climate or the 1948–1963 period. In another time period, the air mass frequencies might change, especially at sites near the confluences of airstreams. Thus, this data form may provide evidence of shifts from one climatic episode to another. There is a certain amount of subjectivity in some forms of air mass analysis and the subject is still being refined (Schwartz et al. 1985, Schwartz 1988, 1991). Nevertheless, we believe the approach has considerable potential for identifying climate variability for some biomes.

The Committee thus recommends that sites, singly and as a network, investigate new and nonstandard climatic indices to supplement the information obtained from standard climatic observations and summaries. Our goal is to define and refine relationships between climatic variation and ecosystem response.

Similarity and Dissimilarity

Outwardly, LTER sites appear so different that useful comparisons are either obvious or else impossible. A benefit of having LTER sites in very different biomes is that broad-scale comparisons, not often available to ecologists, can be made which should give valuable insights into ecosystem function and processes. This was demonstrated during the Workshop when similarities and dissimilarities between sites were examined.

Many sites have not yet identified clear or obvious ecosystem responses to slow climate trends or even to events of mid-scale severity. But most sites have experienced major responses to a severe weather event. The Hubbard Brook ecosystem, for example, was not markedly disturbed by the droughts of the 1960s but still shows the effect of a single hurricane in 1938. This may be yet another example of our inability to perceive long-term changes. Tree blowdown has been a repeated catastrophic wind event at several LTER sites and, since the Workshop, hurricane damage has significantly altered both the North Inlet and Liquillo sites. Many ecological responses are due to secondary effects of atmospheric events, such as flooding or landslides. For example, the redistribution of sediment by an intense rainstorm on the otherwise dry Jornada site has marked consequences on the biota either by burying them or by providing new microhabitats.

Several sites reported possible time coincidence for discontinuities in the values of climate variables. The years of climatic change suggested by shifts in freezing dates of Lake Mendota, Wisconsin, in 1880, 1940, and possibly 1980, were noted as times of change at some other sites and also in general climate data. LTER sites may benefit from examining their own records for common break points in data sets. Data at most sites, as well demonstrated by the Central Plains Experimental Range (Kittel 1990), follow hemispheric, or at least regional, trends in temperature and precipitation. This augurs well for the extrapolation of results from the LTER Network to larger areas. Yet unique or isolated sites such as Niwot Ridge will not display the same spatial and temporal trends as adjacent dissimilar lowland areas.

At first the Kellogg Biological site was believed to be functionally different from other sites because of its emphasis on monoculture of agricultural crops and the attention given to short time scale investigations emphasizing specific times of the year. These seasonal studies include winter impact on the life cycle of germination, and climatic influences on pollination and seed set. The lesson is that weather events are marked by phenological events, a phenomenon equally true at other LTER sites. The fact that the Kellogg ecosystem defines shorter time scales is another demonstration of the importance of recognizing all time scales, as was discussed earlier.

Discussion revealed that many LTER sites had considerably more data than simply monthly means and totals of temperature and precipitation values. In many cases, high-quality data for climate and ecosystem variables coexist. Opportunities were recognized for episodic studies on daily and other time scales in intersite LTER investigations.

In summary, several fertile areas for further research can capitalize on the similarities and dissimilarities of climate variability and ecosystem response across LTER sites. These include an investigation of (1) the importance of catastrophic events in relation to slower trends and cycles, (2) the time coincidence of certain major climatic discontinuities that appear to exist at several sites and the effects on ecosystems as they shift from one episode to another, and (3) the relationship of climate to phenological studies across the LTER Network.

Conclusion

Climatic variability and ecosystem response is clearly a topic having all the intricacies of a Gordian knot. Deliberations of the LTER Climate Committee have indicated some important starting points at which the knot may be unravelled. First, we must be very conscious of our terminology. Loose usage of terms may well hinder our conceptualization of reality. Second, we must put considerations of scale at the beginning of our investigations instead of making prior assumptions about them. There is a tendency, of which we must be cautious, to impose human-oriented concepts of scale on our real systems instead of letting the functions of the ecosystems themselves define our scale for us. Third, we have identified some exciting ways by which we can go beyond the use of simple temperature and precipitation values to relate to ecosystem functions or define discontinuities between climatic episodes. Finally, insights gained by comparing similarity and dissimilarity between the LTER sites will improve understanding of the on-site ecosystems as well as explain intersite variation.

None of these ideas is new, but within the context of climate variability and ecosystem response at LTER sites, they take on a new significance. The highly disparate nature of LTER sites allows the Committee to search for indices like air mass frequency that go beyond information restrained to local observations alone. This opportunity can lead to a broader search for new concepts and techniques in ecosystem science as a whole. The LTER Climate Committee Workshop generated ideas and concepts that should facilitate notable progress in understanding climate variability and ecosystem response in the future.

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Literature Cited

Allen, T. F. H., and T. B. Starr. 1982. Hierarchy: perspectives for ecological complexity. University of Chicago Press, Chicago, Illinois, USA.

Botkin, D. B. 1990. Discordant harmonies: a new ecology for the twenty first century. Oxford University Press, New York, New York, USA.

Clark, W. C. 1985. Scales of climate impacts. Climatic Change **7**:5–27.

Delcourt, H. R., P. A. Delcourt, and T. Webb. 1983. Dynamic plant ecology: the spectrum of vegetation change in space and time. Quaternary Science Reviews **1**: 153–175.

Di Castri, F. 1988. Enhancing the credibility of ecology: interacting along and across hierarchical scales. GeoJournal **17**(1):5–35.

Franklin, J. F., C. S. Bledsoe, and J. T. Callahan. 1990. Contributions of the Long-Term Ecological Research Program. BioScience **40**(7):509–524.

Greenland, D., editor. 1987. The climates of the Long-Term Ecological Research sites. Occasional Paper 44. Institute of Arctic and Alpine Research, Boulder, Colorado, USA.

Greenland, D., and L. W. Swift, Jr. 1990. Climate Variability and Ecosystem Response: Proceedings of a Long-Term Ecological Workshop, Boulder, Colorado, 21–23 August 1988. United States Forest Service Southeastern Forest Experiment Station General Technical Report **SE-65.**

Hare, F. K. 1985. Climate variability and change. Pages 37–68 *in* R. W. Kates, J. H. Ausubel, and M. Berberian, editors. Climate impact assessment. John Wiley, Chichester, England.

Hayden, B. P. 1990. Climate change and ecosystem dynamics at the Virginia Coast

Reserve 18,000 B.P. and during the last century. Pages 76–84 *in* D. Greenland and L. W. Swift, Jr., editors. Climate Variability and Ecosystem Response: Proceedings of a Long-Term Ecological Workshop, Boulder, Colorado, 21–23 August 1988. United States Forest Service Southeastern Forest Experiment Station General Technical Report **SE-65.**

Kittel, T. G. F. 1990. Climate variability in the short-grass steppe. Pages 67–75 *in* Climate Variability and Ecosystem Response: Proceedings of a Long-Term Ecological Workshop, Boulder, Colorado, 21–23 August 1988. United States Forest Service Southeastern Forest Experiment Station General Technical Report **SE-65**.

Kunkel, K. E., and A. Court. 1990. Climatic means and normals—a statement of the American Association of State Climatologists (AASC). Bulletin of the American Meteorological Society **71**(2):201–204.

Mason, B. J. 1970. Future developments in meteorology; an outlook to the year 2,000. Quarterly Journal of the Royal Meteorological Society **96**:349–368.

O'Neill, R. V., D. L. DeAngelis, J. B. Waide, and T. F. H. Allen. 1986. A hierarchical concept of the ecosystem. Princeton University Press, Princeton, New Jersey, USA.

Robertson, D. M. 1990. Lakes as indicators of and responders to climate change. Pages 38–46 *in* D. Greenland and L. W. Swift, Jr., editors. Climate Variability and Ecosystem Response: Proceedings of a Long-Term Ecological Workshop, Boulder, Colorado, 21–23 August 1988. United States Forest Service Southeastern Forest Experiment Station General Technical Report **SE-65.**

Schwartz, M. D. 1988. Integrating the objective and subjective approaches to air mass classification. Abstract. Page 169 *in* Program of the Association of American Geographers Annual Meeting, April 1988, Phoenix, Arizona, USA.

———. 1991. An integrated approach to airmass classification in the North Central United States. Professional Geographer **43**(1):77–91.

Schwartz, M. D., J. Harman, and G. Marotz. 1985. Air mass characteristics over the North Central United States. Geographical Perspectives **56**:13–26.

Strayer, D., J. S. Glitzenstein, C. G. Jones, J. Kolasa, G. E. Likens, M. J. McDonell, G. G. Parker, and S. T. A. Pickett. 1986. Long-term ecological studies: an illustrated account of their design, operation, and importance to ecology. Occasional Publication 2, Institute of Ecosystem Studies, Millbrook, New York, USA.

Swift, L. W., Jr., J. B. Waide, and D. L. White. 1990. Application of the Z-T extreme event analysis using Coweeta streamflow and precipitation data. Pages 13–18 *in* D. Greenland and L. W. Swift, Jr., editors. Climate Variability and Ecosystem Response: Proceedings of a Long-Term Ecological Workshop, Boulder, Colorado, 21–23 August 1988. United States Forest Service Southeastern Forest Experiment Station General Technical Report **SE-65**.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. Ecology **16**:284–307.

Walsh, J. E., and M. B. Richman. 1981. Seasonality in the associations between surface temperature over the United States and the North Pacific Ocean. Monthly Weather Review **109**:767–783.

Weatherhead, P. J. 1986. How unusual are unusual events? American Naturalist **128**: 150–154.

Wendland, W. M., and R. A. Bryson. 1981. Northern Hemisphere airstreams regions. Monthly Weather Review **109**:255–270.

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