Theor. Appl. Climatol. 38, 57–68 (1987)

Theoretical and Applied Climatology

551.589

[1] Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, U.S.A.
[2] Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, U.S.A.
[3] Battelle Pacific Northwest Laboratories, Richland, Washington, U.S.A.
[4] Oboe Engineering Limited, Ottawa, Ontario, Canada

Use of a Synoptic Classification Scheme to Define Seasons

R. A. Pielke[1], M. Garstang[2], C. Lindsey[3], and J. Gusdorf[4]

With 21 Figures

Received August 13, 1986
Revised December 30, 1986

Summary

This paper presents a synoptic surface weather map classification scheme, and uses the categorization technique to meteorologically define seasons. Winter is defined as that period of the year in which a location is most frequently poleward of the polar front, while summer occurs when the site is most commonly equatoward. Fall and Spring are the transition periods when, respectively, increasingly more frequent and less frequent periods of time poleward of the polar front occur.

Using 10 years of data, the application of this definition of seasons to the Gulf and Atlantic coasts of the United States is presented. While the frequency of the specific types of major synoptic weather features varied with latitude, the meteorological definitions of season are comparatively invariant with latitude (differing by no more than a month) for this geographic area. Using the meteorological definitions of season, the average winter for this region occurs from late October or early November to late March or early April. Summer is from late May to early June until late August or late September.

Zusammenfassung

Die Verwendung einer synoptischen Klassifikation zur Jahreszeitenbestimmung

Diese Arbeit stellt ein synoptisches Klassifikationsschema nach Bodenwetterkarten vor, das eine Kategorisierungstechnik verwendet, um die Jahreszeiten meteorologisch zu definieren. Der Winter ist als die Periode des Jahres festgelegt, in der ein Ort meist polwärts der Polarfront, während der Sommer jene Periode ist, in der er äquatorwärts der Polarfront liegt. Herbst und Frühjahr sind die Übergangsperioden, in denen zunehmend häufigere bzw. weniger häufige Abschnitte polwärts der Polarfront vorkommen.

Die Anwendung dieser Jahreszeitendefinition wird mit Hilfe der Daten aus 10 Jahren für die Atlantik- und Golfküste der Vereinigten Staaten vorgestellt. Während die Häufigkeiten bestimmter Wetterlagen mit der geographischen Breite schwanken, erwies sich diese meteorologische Jahreszeitendefinition demgegenüber als vergleichbar invariant (mit einem maximalen Unterschied von einem Monat) innerhalb des ausgewählten Gebiets. Der so definierte Winter dieser Region beginnt zwischen Ende Oktober und Anfang November und dauert bis Ende März bzw. Anfang April. Sommer ist zwischen Ende Mai/Anfang Juni und Ende August/Ende September.

1. Introduction

The definition of seasons for meteorological applications, in midlatitudes particularly, is usually made with respect to either the astronomical calendar or a division of the calendar into four three-month periods. Using this approach, seasons are conventionally defined as shown in Table 1.

Table 1. *Conventional Definitions of Seasons*

	Winter	Spring	Summer	Fall
Astronomical definition	autumnal equinox to winter solstice (on or about September 22 to on or about December 22)	winter solstice to spring equinox (on or about December 22 to on or about March 21)	spring equinox to summer solstice (on or about March 21 to on or about June 21)	summer solstice to autumnal equinox (on or about June 21 to on or about September 22)
Calendar definition	December January February	March April May	June July August	September October November

Unfortunately, these definitions are arbitrary and independent of geographic latitude, and thus are not very informative concerning actual meteorological seasons. An early, cold frontal passage in New England in early September, for example, is obviously indicative of colder season weather, yet using the astronomical definition of season in Table 1, one would presume it is still summer.

In this paper we hypothesize that meteorological seasons at a site could be defined with respect to geographic location relative to the polar front. A synoptic classification scheme was used to specify broad meteorological features. Conditions poleward of the front are assumed to be characteristic of the winter season, and, contrarily, locations equatorward of the front are experiencing the summer season-type characteristics. Section 2 of this paper presents the synoptic classification model used in this study, while its application to define seasons is presented in Section 3. Conclusions are discussed in Section 4.

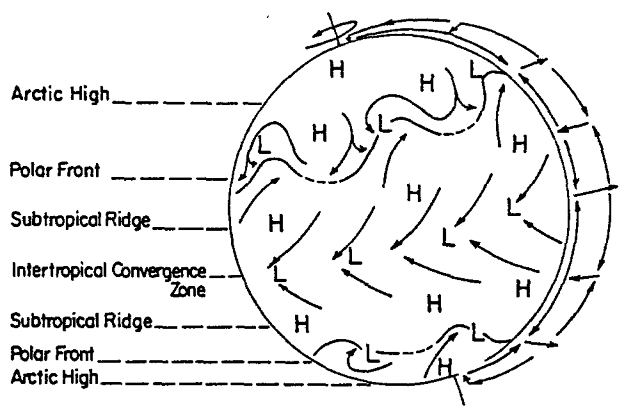

Fig. 1. Schematic of the general circulation of the earth in the northern hemisphere winter. There is average subsidence in the subtropical ridge and arctic high, and average ascent in the intertropical convergence zone and polar front region. The polar front separates air from upper latitude origin from lower latitude origination

2. Synoptic Classification Scheme

The general circulation of the global atmosphere can be schematically conceptualized into major regions, as illustrated in Fig. 1. This circulation is the mechanism by which heat, moisture and momentum are redistributed over the planet. In terms of heat and moisture, the polar front delineates the boundary between air masses originating in upper latitudes (i.e., colder, generally drier in the absolute sense) from air masses of lower latitude origination (i.e., warmer, generally moister in the absolute sense).

The regions dominated by persistent subsidence in Fig. 1 are associated with deserts, while regions with average ascending motion have significant precipitation. These regions of average upward and downward motion move poleward in the summer, equatorward in the winter in response to latitudinal changes in solar energy input during the year. While the influence of continents, mountains and other geographic features alter the specific pattern, the general circulation framework illustrated in Fig. 1 is a useful backdrop with which to discuss general global climatology. Of particular relevance to the study reported in this paper is the location of the polar front with respect to specific geographic areas.

In the United States, with the exception of Alaska, Hawaii and a number of territories, the country is generally influenced by the southern portion of the polar high, the polar front, and the northern side of the subtropical ridge. Along the polar front propagate extratropical cyclones which develop in response to the horizontal temperature gradient across the front. This temperature gradient typically extends from the surface to the upper troposphere, and is referred to as the thickness gradient.

Fig. 2a and b present examples of weather maps in July and December where cold and warm fronts on the polar front are indicated. Five major synoptic categories are defined using synoptic surface analyses that have the general characteristics summarized in Tables 2 and 3. Category 4, the region corresponding to an equatorward bulge in the polar high with sinking air through the lower and mid troposphere is a winter-characteristic air mass which is beginning the process of mixing with the warmer air at the lower latitudes. This, of course, is the mechanism by which the general circulation of the earth seeks (but does not reach) a thermal equilibrium. Category 5 is associated with the western periphery of a subtropical ridge. The subtropical ridge results from the descending portion of the Hadley Cell. Since, in general, over the United States high pressure regions (i.e., where the surface isobars are

Table 2. *Synoptic Classification Scheme (from Pielke, 1982; modified from Lindsey, 1980)*

Category	Air mass	Reason for categorization*
1	*mT*	*In the warm sector of an extratropical cyclone.* In this region the thickness and vorticity advection is weak with little curvature to the surface isobars. There is limited low level convergence with an upper level ridge tending to produce subsidence. Southerly low-level winds are typical
2	mT/cP, mT/cA, mP/cA	*Ahead of the warm front in the region of cyclonic curvature to the surface isobars.* Warm air advecting upslope over the cold air stabilizes the thermal stratification, while positive vorticity advection and low-level frictional convergence can add to the vertical lifting. Because of the warm advection, the geostrophic winds veer with height. Low-level winds are generally north-easterly through south-easterly
3	*cP; cA*	*Behind the cold front in the region of cyclonic curvature to the surface isobars.* Positive vorticity advection and negative thermal advection dominate, with the resultant cooling causing strong boundary layer mixing. The resulting thermal stratification in the lower troposphere is neutral, or even slightly, superadiabatic. Gusty winds are usually associated with this sector of an extratropical cyclone. Because of the cold advection, the geostrophic winds back with height. Low-level winds are generally from the north-east through south-west
4	*cP; cA*	*Under a polar high in a region of anticyclonic curvature to the surface isobars.* Negative vorticity advection, weak negative thermal advection and low-level frictional divergence usually occur, producing boundary layer subsidence. Because of relatively cool air aloft, the thermal stratification is only slightly stabilized during the day, despite the subsidence. At night, however, the relatively weak surface pressure gradient associated with this category causes very stable layers near the ground on clear nights due to long-wave radiational cooling. The low-level geostrophic winds are usually light to moderate varying slowly from north-westerly to south-easterly as the ridge progresses eastward past a fixed location
5	*mT*	*In the vicinity of a subtropical ridge* where the vorticity and thickness advection, and the horizontal pressure gradient at all levels are weak. The large upper-level ridge, along with the anticyclonically curved low level pressure field, produces weak but persistent subsidence. This sinking causes a stabilization of the atmosphere throughout the troposphere. Low-level winds over the eastern United States associated with these systems tend to blow from the south-east through south-west

* This discussion applies to northern hemisphere.

Table 3. *Overview of Meteorological Aspects of the 5 Synoptic Categories Illustrated in Fig. 1 which can be Directly Obtained from Synoptic Surface Analyses (Northern Hemisphere) (adapted from Forbes and Pielke 1985, and Pielke et al. 1986)*

Category Characteristics	Category 1	2	3	4	5
Category Class	mT: In the warm sector of an extratropical cyclone	mT/cP, mT/cA, mP/cA: Ahead of the warm front in the region of cyclonic curvature at the surface	cP, cA: Behind the cold front in the region of cyclonic curvature to the surface isobars	cP, cA: Under a polar high in a region of anticyclonic curvature at the surface	mT: In the vicinity and west of a subtropical ridge
Surface winds	Birsk SW surface winds	Light to moderate SE to ENE surface winds	Strong NE to SW surface winds	Light and variable winds	Light SE to SW winds
Vertical motions	Weakening synoptic descent as the cold front approaches	Synoptic ascent due to warm advection and negative vorticity advection aloft becomes positive vorticity advection aloft closer to low center, resulting in enhanced vertical motion	Synoptic ascent due to positive vorticity advection aloft (in this region this ascent more than compensates for the descent due to cold advection)	Synoptic descent (due to warm advection and/or negative vorticity advection aloft)	Synoptic subsidence (descending branch of the Hadley cell). Descent becomes stronger as you approach the ridge axis
Temperature advection	Little temperature advection at the surface	Warm advection above the frontal inversion	Cold advection at the surface	Weak temperature advection at the surface	Weak temperature advection at the surface
Inversion	Weak synoptic subsidence inversion caps planetary boundary layer	Boundary layer capped by frontal inversion	Deep planetary boundary layer	Synoptic subsidence inversion and/or warm advection aloft create an inversion which caps the planetary boundary layer	Synoptic subsidence inversion
Diurnal variation in boundary-layer stability	Moderate diurnal variability in the boundary-layer stability	Little diurnal variability in boundary-layer stability because of cloud cover	Little diurnal variability in the boundary-layer stability because of strong winds and destabilizing of boundary layer by cold advection	In the absence of snow cover, because of clear skies and light winds, there is large diurnal variability in boundary-layer stability	Moderate diurnal variability in boundary-layer stability
Diurnal variation in surface layer stability	Moderately unstable surface layer during the day	Stably stratified surface layer day and night	Near neutral surface layer day and night	Weakly to moderately unstable surface layer during the day unless	Moderately to strongly unstable surface layer during the day.

	Moderately stable surface layer during the night			snow cover present or low Sun angle, in which case surface layer tends to be stably stratified. Very stable surface layer at night	Moderately-to-strongly stable surface layer during the night
Humidity near the surface	Often humid in relative and absolute sense	Often dry in absolute sense, but humid in relative sense	Dry in the absolute sense; usually dry in the relative sense	Dry in the absolute sense, humid in the relative sense at night/dry in relative sense during the day except when ground is snow-covered	Humid in relative and absolute sense
Cloud cover	Clear to partly cloudy skies except near squall lines	Mostly cloudy to cloudy	Clear to scattered or broken shallow to medium depth convective clouds	Clear except tendency for fog at night	Day: scattered fair weather cumulus Night: clear (except near the mesoscale systems listed below)
Dominant mesoscale systems	Squall lines	Embedded lines of convection	Forced airflow over rough terrain systems: lake effect storms	Mountain-valley flows, land-sea breezes, urban circulations (thermally-forced systems)	Mountain-valley flows, land-sea breezes, urban circulations (thermally-forced systems)
Precipitation types	Organized lines of convective precipitation	Often stable cloud types and precipitation. Overcast in general	Medium to shallow depth convective clouds, showery precipitation	No precipitation	Shallow low convective clouds with deeper convective clouds and precipitation organized by thermally forced mesoscale systems such as listed above
Ventilation	Moderate to good ventilation	Poor ventilation of low level (i.e. below frontal inversion) emissions	Excellent ventilation	Night or snow-covered ground: poor ventilation Day: poor to moderate ventilation	Day: moderate to good ventilation Night: moderate to poor ventilation
Deposition	Dry deposition except wet deposition in showers	Dominated by wet deposition	Dry deposition except in showers	Dry deposition	Dry deposition except wet deposition in showers and thunderstorms
Transport	Long range	Long range above inversion	Long range	More local as you approach the centre of the polar high	More local as you approach the centre of the subtropical high

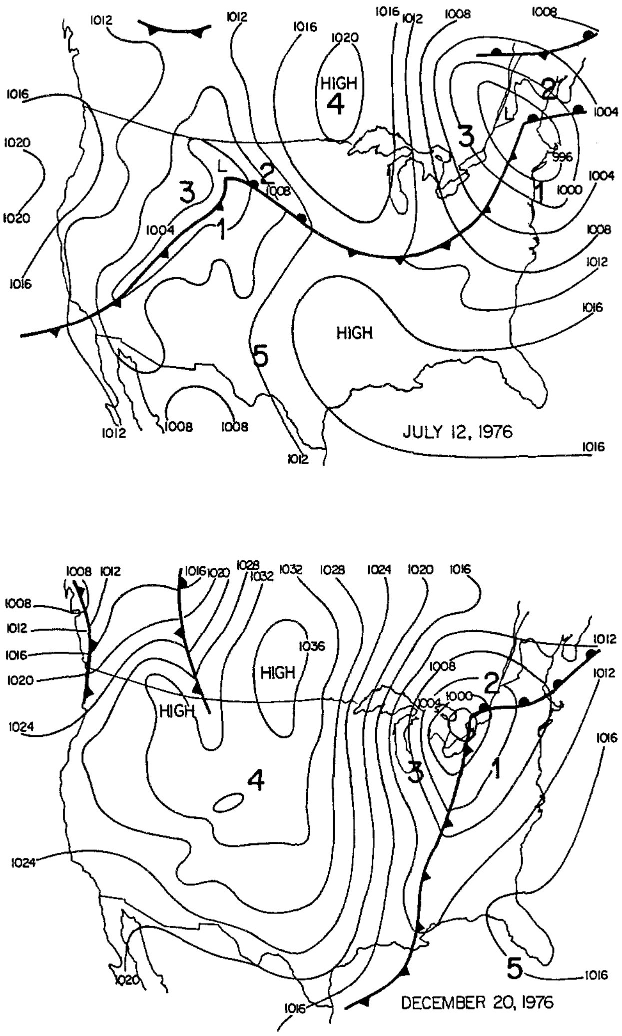

Fig. 2. Synoptic classification scheme illustrating typical (a) summer and (b) winter patterns

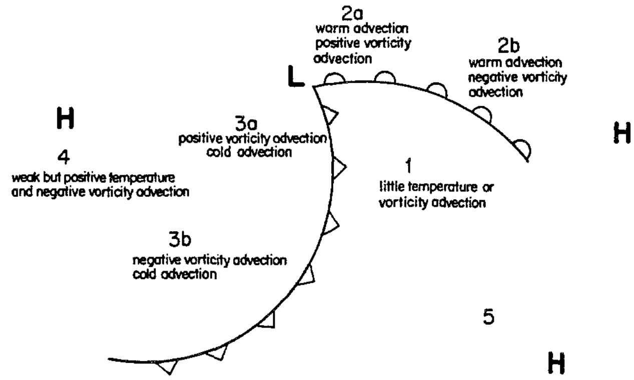

Fig. 3. Schematic as to how temperature and vorticity advection patterns could be used to refine synoptic classification scheme

anticyclonic) cover larger areas than low pressure circulations (i.e., where the surface isobars are cyclonic), it is expected that Categories 4 and 5 situations geographically should be more common than Categories 1, 2 and 3. Category 4 is most common poleward of the polar front; Category 5 is most common for tens of degrees of latitude equatorward of the front.

Using upper air synoptic analyses (e.g., 700 mb for temperature advection; 500 mb for vorticity advection), the synoptic classification could be refined further. Fig. 3 illustrates how the categories could be further classified using typical locations of cold and warm advection, and positive and negative vorticity advection. In the absence of conveniently available upper air data, however, the surface map alone can be used effectively in a synoptic climatological analysis.

The classification of surface weather maps can be performed subjectively. In the studies listed in the next two paragraphs, the maps were analyzed once a day, although more frequent evaluations are straightforward. In order to estimate the reproducibility of the categorization technique, at least two, and occasionally three individuals independently classify a sample set of weather maps for the area and time period of interest. In the eastern United States, there is agreement about 90 percent of the time. Disagreements occur either because the pattern is ill-defined, or a location is in transition between categories and there is ambiguity as to in which classification to place a location. In the mountainous western United States, because of the requirement to reduce pressure from terrain height to sea level using an arbitrary specification of temperature lapse rate, the degree of agreement between analysts reduces to about 80 percent. In several of the analyses (e.g., Yu and Pielke, 1986), an undefined category was identified for the situations in which it was not straightforward to identify a synoptic class.

As mentioned above, several investigations have used this synoptic categorization to analyze local climatology. In Yu and Pielke (1986), for example, the frequency and duration of these synoptic classes for a five-year period between October and May in southern Utah were determined as part of an air quality study. Pielke et al. (1986) have used these synoptic categories and subclasses related to surface synoptic geostrophic wind speed and direction within each category to estimate worst case air pollution dispersion situations over southern Florida. Garstang et al. (1980), and Lindsey (1980), where this synoptic classification procedure was first introduced, determined the daily frequency of the different synoptic categories for a 10-year period along the Atlantic and Gulf coasts of the United States. Lindsey and Glantz (1984, 1986) used this approach to characterize local meteorology at nuclear facilities.

Figs. 4 through 12 from Garstang et al. (1980) and Lindsey (1980) illustrate the 10-year average variation of the five synoptic categories during the year for several geographic locations. The data were produced for 52 stations from a 10-year record of twice daily observations with 9 representative sites presented in these figures. The data were smoothed using a 25-day running average.

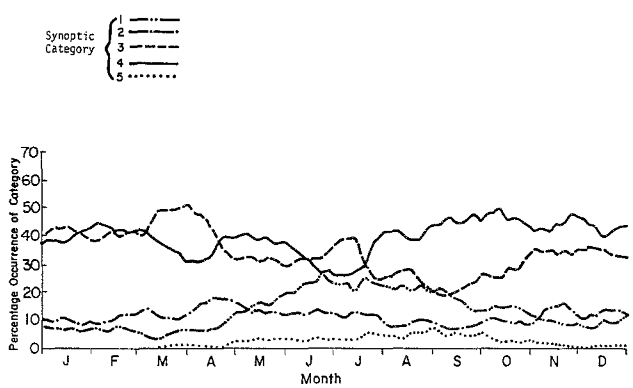

Fig. 4. 25-day weighted average frequency distributions of synoptic categories for Portland, ME stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

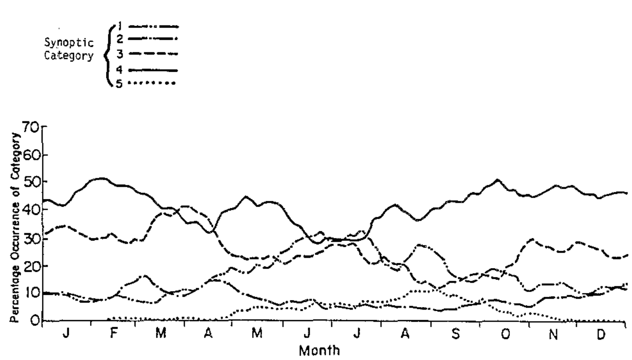

Fig. 5. 25-day weighted average frequency distributions of synoptic categories for New York City, NY stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

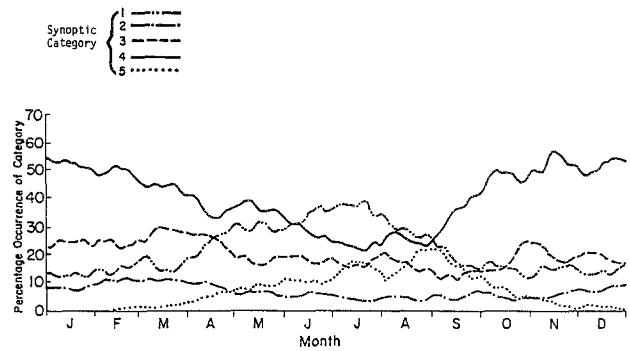

Fig. 6. 25-day weighted average frequency distributions of synoptic categories for Hampton, Virginia stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

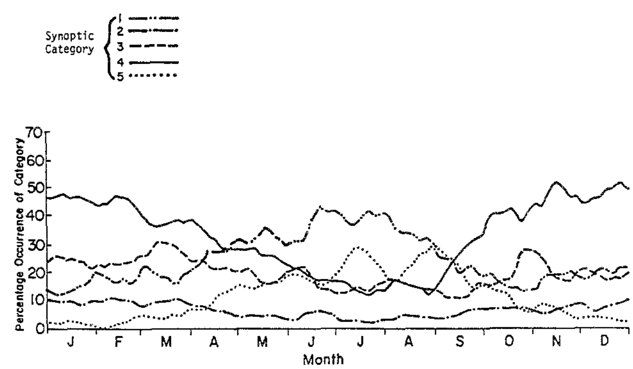

Fig. 7. 25-day weighted average frequency distributions of synoptic categories for Cape Hatteras, North Carolina stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

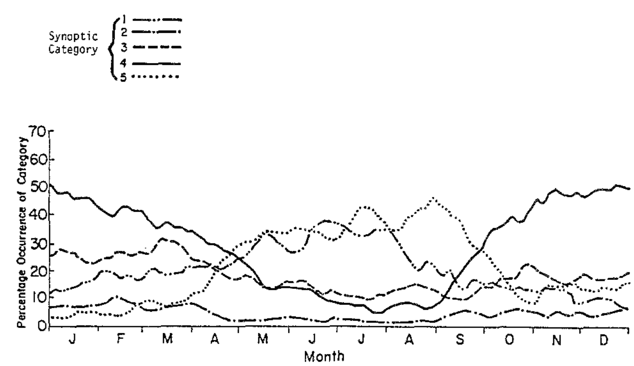

Fig. 8. 25-day weighted average frequency distributions of synoptic categories for Charleston, North Carolina stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

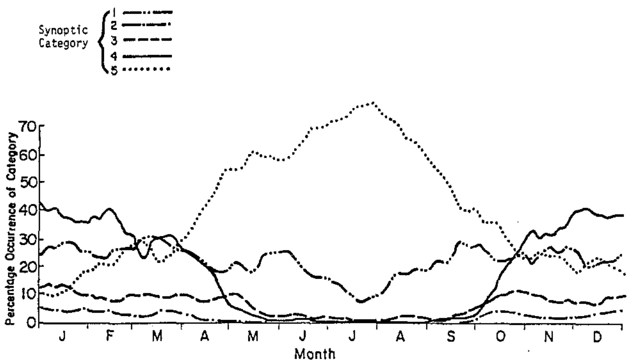

Fig. 9. 25-day weighted average frequency distributions of synoptic categories for Miami, Florida stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

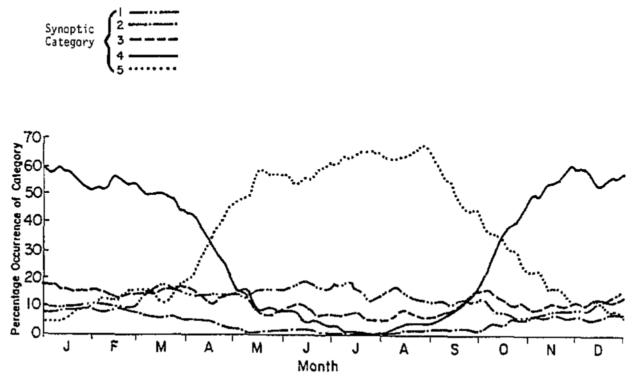

Fig. 10. 25-day weighted average frequency distributions of synoptic categories for Mobile, Alabama stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

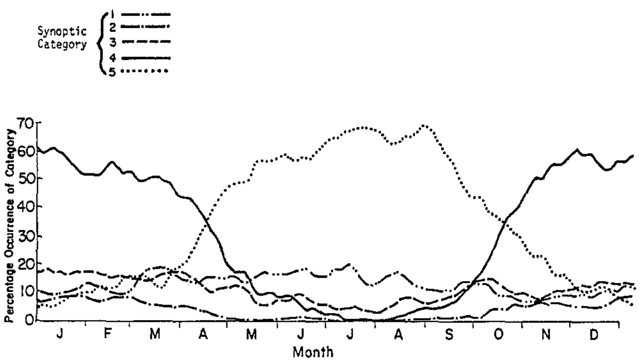

Fig. 11. 25-day weighted average frequency distributions of synoptic categories for New Orleans, Louisiana stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

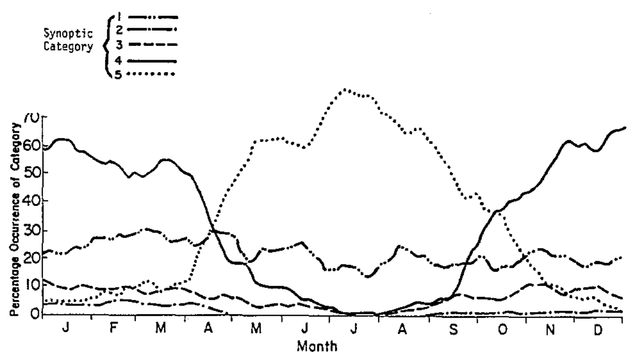

Fig. 12. 25-day weighted average frequency distributions of synoptic categories for Brownsville, Texas stations: January 1, 1955–December 31, 1964, from Garstang et al. (1980), and Lindsey (1980)

3. Definition of Meteorological Seasons

An obvious result of this type of analysis is that it is straightforward to interpret seasons in terms of frequency of time that a location is poleward and equatorward of the polar front. Categories 2, 3 and 4 occur poleward and categories 1 and 5 are situated on the warm side of the front. Therefore, meteorological seasons can be defined as

- winter: highest frequency of category 2, 3 and 4 occurrences,
- summer: highest frequency of category 1 and 5 occurrences,

with fall and spring being the transition to the more constant frequencies found during the winter (cold) and summer (warm) seasons.

To quantify this definition, the following procedure, originally reported in Lindsay (1980) and Garstang et al. (1980) was used. The cumulative changes in frequency of occurrence of categories 2, 3, and 4, defined as ΔS, were calculated and plotted, as shown in Fig. 13 through 21. ΔS for day n is defined as:

$$\Delta S_n = \Delta S_{n-1} + (C2_n - C2_{n-1}) + + (C3_n - C3_{n-1}) + (C4_n - C4_{n-1}) \quad (1)$$

where CN_n is the 25-day weighted average of the frequency of occurrence of category N on day n, and

$$\Delta S_0 = 0.$$

The slope of the ΔS plots, or $\Delta^2 S$, was used to provide a quantitative definition of seasons for any station as follows: $\Delta^2 S$ is measured across 91 days to eliminate short-term fluctuations. Thus, $\Delta^2 S$ for day n is

$$\Delta^2 S_n = \Delta S_{n-45} - \Delta S_{n+45}; \quad n = 1, \ldots, 365 \quad (2)$$

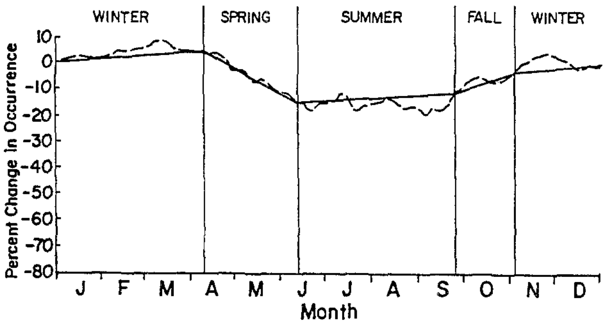

Fig. 13. Changes in frequency of synoptic categories 2, 3, and 4 for Portland, ME—1955–1964 using Fig. 4

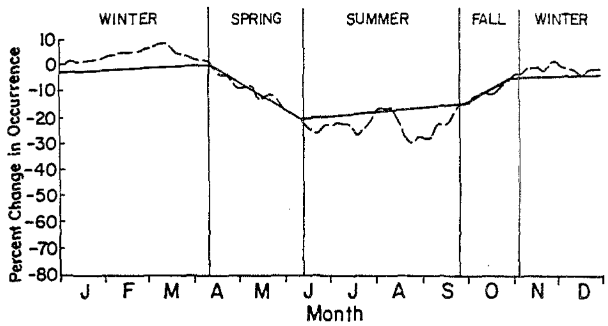

Fig. 14. Changes in frequency of synoptic categories 2, 3, and 4 for New York City, NY—1955–1964 using Fig. 5

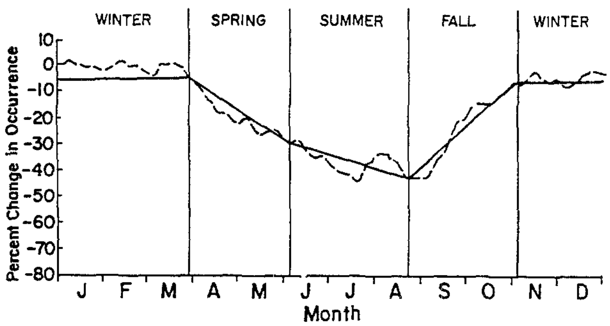

Fig. 15. Changes in frequency of synoptic categories 2, 3, and 4 for Hampton, VA—1955–1964 using Fig. 6

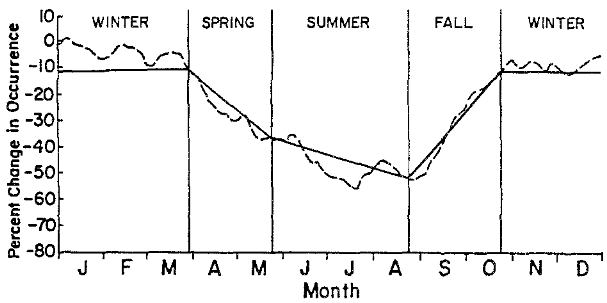

Fig. 16. Changes in frequency of synoptic categories 2, 3, and 4 for Cape Hatteras, NC—1955–1964 using Fig. 7

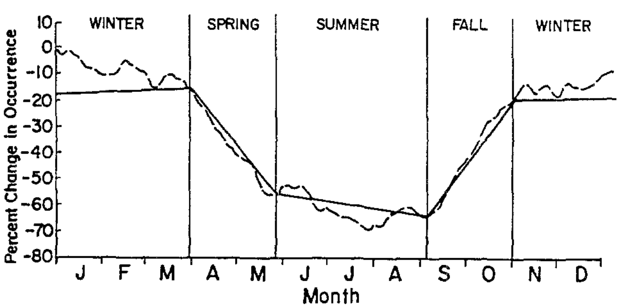

Fig. 17. Changes in frequency of synoptic categories 2, 3, and 4 for Charleston, SC—1955–1964 using Fig. 8

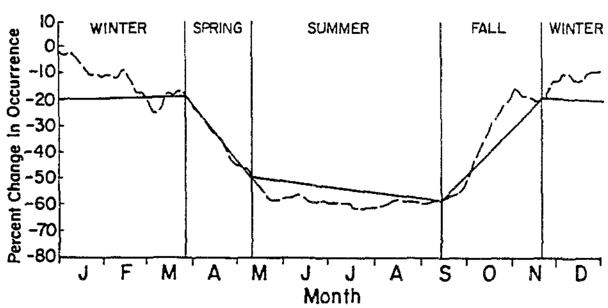

Fig. 18. Changes in frequency of synoptic categories 2, 3, and 4 for Miami, FL—1955–1964 using Fig. 9

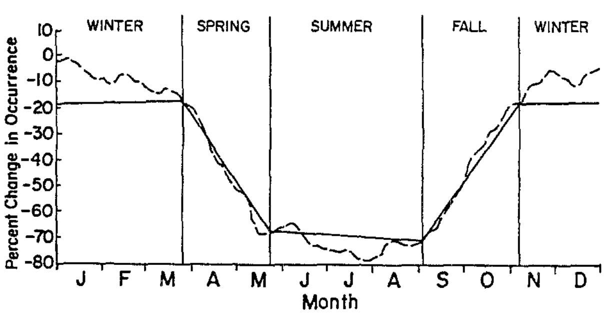

Fig. 19. Changes in frequency of synoptic categories 2, 3, and 4 for Mobile, AL—1955–1964 using Fig. 10

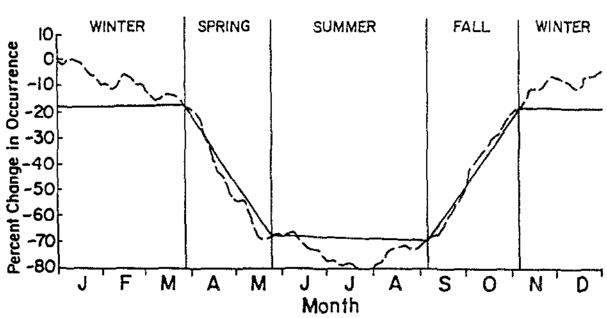

Fig. 20. Changes in frequency of synoptic categories 2, 3, and 4 for New Orleans, LA—1955–1964 using Fig. 11

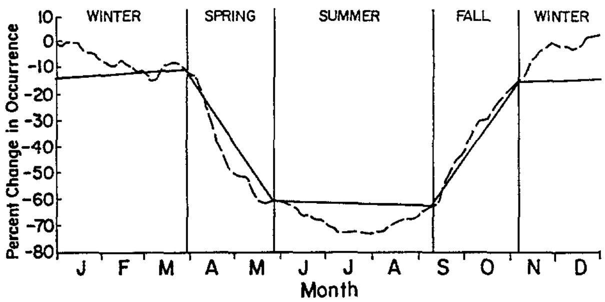

Fig. 21. Changes in frequency of synoptic categories 2, 3, and 4 for Brownsville, TX—1955–1964 using Fig. 12

(Since ΔS is based on 10 years of data, $\Delta^2 S$ can be taken across the end of the calendar year.) When $\Delta^2 S$ has been calculated for each day of the calendar year, a positive cut-off value β is selected, and the value of $\Delta^2 S$ for each day is compared with β. January 1 is defined as winter; as long as the value of $\Delta^2 S$ remains greater than or equal to $-\beta$, each succeeding day is classified as winter. When $\Delta^2 S < -\beta$, then the first day of spring is defined. As long as this condition is met, each succeeding day is classed as spring. Similarly, the condition for summer is $|\Delta^2 S| \leqslant \beta$, and for fall $\Delta^2 S > \beta$. Thus

$$\begin{array}{ll} \text{winter:} & \Delta^2 S \geqslant -\beta \\ \text{spring:} & \Delta^2 S < -\beta \\ \text{summer:} & |\Delta^2 S| \leqslant \beta \\ \text{fall:} & |\Delta^2 S > \beta. \end{array}$$

A problem arises in defining the last days of spring and fall because in many cases $\Delta^2 S$ changes from spring to summer and then back to spring conditions again, and similarly for fall-winter-fall. This problem is met by defining the first day of summer as the *last* time $\Delta^2 S$ changes from spring to summer conditions and the first day of winter as the last time $\Delta^2 S$ changes from fall to winter conditions.

Since the ΔS plots show a great variation in range (maximum ΔS—minimum ΔS), the cut-off value was made a function of the range of ΔS for each station. A Fortran program was used to calculate seasons for each representative station using seven cut-off values between $0.4\,x$ range and $0.7\,x$ range. Each of these seasons were drawn on the 25-day average synoptic frequency and ΔS plots, and the best one (shown on Figs. 13 through 21) was selected for each station. The criteria of selection were as follows.

On the ΔS plots lines were drawn connecting the intersections of the ΔS line with the seasonal demarcations. These connecting lines should be as flat as possible for winter and summer, and as steep as possible for spring and fall. On the 25-day average synoptic frequency plots, spring and fall should include most or all of the rapid changes in frequency of individual categories from their summer to winter levels.

When all of the best fitting seasonal plots were compared, we discovered that the coefficient by which the ranges were multiplied to get the best fits is itself an approximate inverse function of latitude φ. That is, if each range is multiplied by $(90° - \varphi) \times 0.0105$, the cut-off obtained is close to the selected best fit. All of the seasons displayed in Figs. 13 through 21 and in Table 4 are based on cut-offs determined by this formula. The ranges, latitudes, cut-offs and seasonal dates for each of the selected stations are shown in Table 4.

In going from the most northerly to the most southerly station, one might expect spring and summer to begin earlier, and fall and winter to begin later. Although there is a clear progression to earlier summers between Portland and Miami, the first days of summer for Mobile, New Orleans and Brownsville are not consistent with this trend. Furthermore, none of the other seasonal starts show consistent trends with latitude. For example, fall begins earlier at Hatteras than over New England. This is because the seasons are defined as periods of comparatively constant synoptic conditions (winter and summer) or of transition (spring and fall). They are not selected according to meteorological measurements such as temperature, or length of growing season (although there should be some correlation), so that, for example, winter in Brownsville does not indicate the same conditions as found for winter in Portland, but rather the period when the poleward front tends to move to its most equatorward position.

Thus, Brownsville winters are dominated by cold core highs that move southward in the wake of polar front lows that have moved eastward north of that site. Portland's winter weather is dominated by a progression of extratropical lows that generally move to its south and east, resulting in the frequent change from categories 2 to 3 to 4, and back to 2.

The analysis also suggests that the latitudinal movement of the front is not a steady, smooth

Table 4. *Determination of Seasons*

Station	Range	Latitude	Cut-off	First day of			
				Spring	Summer	Fall	Winter
Portland, Maine	27.67	43.65	13.56	4/11	6/14	9/26	11/5
New York City, New York	37.76	40.65	19.64	4/13	6/10	9/30	10/30
Hampton, Virginia	45.76	37.08	25.63	3/30	6/6	8/24	11/4
Hatteras, North Carolina	57.33	35.27	32.68	3/31	5/27	8/26	10/26
Charleston, South Carolina	68.34	32.78	41.00	3/29	5/23	8/31	10/26
Miami, Florida	61.22	25.80	41.02	3/30	5/13	9/16	11/23
Mobile, Alabama	78.77	30.68	48.84	3/28	5/25	9/5	11/8
New Orleans, Louisiana	80.91	29.95	50.97	3/29	5/26	9/7	11/7
Brownsville, Texas	75.03	25.92	50.27	3/31	5/27	9/11	11/7

progression but occurs as rapid and substantial changes in average position. This result should not be too surprising since after the spring equinox the northern latitudes of the United States can warm rapidly because of long daylight, thereby reducing or eliminating the horizontal temperature gradient which is required to support the polar front within the contiguous United States. The polar front thus reestablishes itself further north. In the fall the rapid cooling in northern latitudes of the United States permits a strong polar front to develop with vigorous extratropical storm development. These storms advect cold air (and therefore the polar front) southward over the country in their wake bringing a relatively rapid transition to fall even in the southern latitudes.

This evaluation suggests that on the average winter occurs from late October or early November to late March or early April over the Atlantic and Gulf of Mexico coastal regions of the United States. Summer is from late May to early June until late August or late September.

Whether this type of analysis has utility elsewhere in the midlatitudes still needs to be examined, however the term "midlatitudes" itself is often used by meteorologists subjectively to describe regions which are equatorward on average with respect to the polar front in the summer, but frequently in its vicinity during the colder season. Over Europe, similar definitions should hold with northern Europe having less frequent incursions of polar air during the warmer season, and southern Europe being predominantly influenced by the subtropical ridge, well south of the polar front, during the summer.

4. Conclusions

This paper discusses the application of a synoptic classification scheme to define frequency of occurrence of major weather features as related to the polar front, and to use the frequency of times a location is poleward of the front to meteorologically define seasons. An example of the use of this technique is presented using 10 years of data from the Atlantic and Gulf coasts of the United States. While the frequency of the specific types of major synoptic weather features vary with latitude, the meteorological definitions of season are comparatively invariant with latitude (differing by no more than a month) for this geographic area. Using a meteorological definition, the average winter occurs from late October or early November to late March or early April. Summer is from late May to early June until late August or late September.

The application of synoptic climatological categories within geographic regions also permits more economical analyses of available climate data. In the original study (Garstang et al., 1980) from which this paper was derived, 52 stations along the Atlantic and Gulf Coasts were available for analysis. By using the climatological categorization, however, relatively homogeneous climate regions could be defined so that only one representative site within each region needed to be analyzed. Thus the 52 stations could be represented by the nine sites listed in Figs. 4 through 13.

The analysis presented in this paper suggests that public awareness on a day to day basis could be enhanced by knowledge of their relation to the polar front. In the astronomical summer, for example, the period a short time after the passage of a cold front is referred to as "fall" weather, as individuals perceive the transition to an air mass of polar origin. Similarly in the astronomical "winter", the period after a warm frontal passage is referred to as "spring" weather (particularly if the sun shines). Thus, in a meteorological sense, on a day by day basis, a region can transit from meteorological winter (interpreted as "fall" conditions) back to meteorological summer (interpreted as "spring" conditions). When the transitions between meteorological winter and summer become infrequent or occur with a more-or-less constant frequency, one of the two main meteorological seasons (i.e., winter or summer) has arrived. When the frequencies are changing substantially with time, the time of year corresponds to one of the transit seasons (i.e., fall or spring).

Changes in climatic conditions do not occur as just a gradual change in temperature or in the amount of precipitation but rather in the frequency with which a given region is subjected to the dominant synoptic systems, such as defined in this paper. The net result of the aggregation of synoptic systems yields climate. If the aggregation changes, climate changes.

Acknowledgements

This work was supported in part by the Pacific Northwest Laboratory under contract with the Wind Energy Technology Division of the Office of Solar Power Applications in the Department of Energy under contract DE-AS06-76ET20274, and by the Electric Power Research Institute under contract RP-1630-53. Doug Wesley is thanked for providing Fig. 2. The editing and typing of this manuscript was very capably handled by Mrs. S. Rumley, Susan Einarsen and Dallas McDonald.

References

Forbes, G. S., Pielke, R. A., 1985: Use of observational and model-derived fields and regime model output statistics in mesoscale forecasting. Presented at the Nowcasting Symposium at the IAMAP/IAPSO Joint Assembly, August 7, 1985, Honolulu, Hawaii. *ESA J.,* 207–225.

Garstang, M., Nnaji, S., Pielke, R. A., Gusdorf, J., Lindsey, C., Snow, J. W., 1980: Coastal zone wind energy, Part 1. Synoptic and mesoscale controls and distributions of coastal wind energy. DOE Contract DE-AS06-76ET20274, March 1980.

Lindsey, C. G., 1980: Analysis of coastal wind energy regimes. Dept. of Environmental Science, University of Virginia. M.S. thesis.

Lindsey, C. G., Glantz, C. S., 1984: A method to characterize local meteorology for air pollution studies and emergency response needs. Reprint, *AMS Fourth Joint Conference on Application of Air Pollution Meteorology,* 16–19 October 1984, Portland, Oregon, 260–263.

Lindsey, C. G., Glantz, C. S., 1986: A method to characterize local meteorology at nuclear facilities for application to emergency response needs. Report prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-3882 PNL-5155, 53 pp.

Pielke, R. A., 1982: The role of mesoscale numerical models in very-short-range forecasting. In *Nowcasting* (ed. K. Browning), New York: Academic Press, pp. 207–221.

Pielke, R. A., Segal, M., Arritt, R. W., Moran, M. D., Yu, C. H., 1986: Effect of local power plant emissions on air quality in Everglades National Park. Report for contract NA81RAH00001, Amendment 17, Item 15, U.S. National Park Service. June, 1986 (in press).

Yu, C.-H., Pielke, R. A., 1986: Mesoscale air quality under stagnant synoptic cold season conditions in the Lake Powell area. *Atmos. Environ.,* **20**, 1751–1762.

Authors' addresses: Prof. R. A. Pielke, Department of Atmosphere Science, Colorado State University, Fort Collins, CO 80523, U.S.A., Prof. M. Garstang, Department of Environment of Sciences, University of Virginia, Charlottesville, VI 22903, U.S.A., C. Lindsey, Battelle Pacific Northwest Laboratories, Richland, WA 99352, U.S.A., and J. Gusdorf, Oboe Engineering Limited, Ottawa, Ontario K1P6JG, Canada.