Seasonal and Annual Precipitation Efficiency in the Eastern United States*

Jeffrey T. Lutz, Ph.D.

ABSTRACT

Precipitation efficiency (Pe) is the percentage of the average atmospheric water vapor above a station that is released and falls to earth as measurable precipitation in a given time period. Pe is a single parameter describing the efficiency of atmospheric mechanisms in releasing moisture. Temporal and spatial variations in Pe are controlled primarily by synoptic atmospheric systems. The relationship between atmospheric systems and seasonal/annual variations in Pe is investigated for the United States east of the Rocky Mountains.

Regional variations in seasonal and annual averages of Pe suggest the relative effectiveness of dynamic and thermodynamic precipitation mechanisms. Basically, the pattern of Pe reveals the importance of the greater range of cyclonic activity and frontal zones. The presence of dynamic mechanisms is a prerequisite for the release of precipitation, but topographic enhancement of precipitation and readily available moisture (enhanced PWV supplemented via advection) can also intensify the Pe value.

Precipitation efficiency is heightened by cyclonic and frontal activity over the Great Lakes and along the Atlantic coast as storms generate over the Gulf of Mexico and south Atlantic, migrating northward toward the New England coast. In season, hurricanes are important mechanisms for precipitation production in the eastern United States. During the warmer months convective mechanisms may account for most of the precipitation released, and for those stations located in southern Florida, convective mechanisms prove to be important year round.

Office of Advanced Technology
Bureau of Oceans and International Environmental and Scientific Affairs
U.S. Department of State
Washington, D.C. 20520

*The views expressed are those of the author and are not necessarily those of the United States Government.
Across the western half of the study area there is a pronounced trend toward decreasing values of \( Pe \) in a southwesterly direction, reaching the nadir over southwestern Texas. In general, precipitation activity over the Midwestern states is constrained by a low availability of moisture (distance from sources due to interior location) and prevailing stable atmospheric conditions associated with continental air masses.

Precipitation in various forms is a vital natural resource displaying spatial and temporal variations. Determination of the causes of variation in the amount of precipitation produced by particular atmospheric systems in specific locations is important in assessing water availability. A valuable approach to this problem is based upon investigation of precipitation efficiency (\( Pe \)). \( Pe \) is the ratio (%) of measurable precipitation (\( P \)) to the average precipitable water vapor (\( PWV \)) in a given time period:

\[
Pe = \left( \frac{P}{PWV} \right) \times 100
\]

\( Pe \) is thus a single, bulk parameter which is a means of estimating the efficiency of the atmospheric water vapor release mechanisms. \( Pe \) is known to vary spatially and temporally, and it can range from zero to values in excess of 100 percent depending upon the time period in question. Since temporal and spatial variations in precipitation efficiency are primarily controlled by synoptic-scale atmospheric systems (Lutz, 1976), analysis of the variation in \( Pe \) reveals the efficiency of various atmospheric systems in releasing moisture, and hence advances our knowledge of the causes of variability.

From considerations of the regional climatology of North America, which has been treated by numerous authors (e.g., Hare 1961, Trewartha 1968), one can suggest the causes of \( Pe \) variations. For example, the invasion of well-developed depressions into a region results in high efficiency and fluctuations in \( Pe \) associated with frontal passages. This assumes the presence of the necessary dynamic mechanisms for extracting moisture from unstable air masses which are forced to rise. In addition, supplemental inputs of moisture (advected from the Gulf of Mexico, Atlantic Ocean, etc.) and topographic influences can enhance \( Pe \).

There are many types of precipitation producing systems, but for mid-latitude stations in the eastern United States the primary contributors are cyclonic storms (including hurricanes) and convective storms. In the present study, cyclonic storms are defined as all cases where there is an organized atmospheric flow around a distinct low pressure center, including precipitation produced by general dynamic uplift and frontal mechanisms. In contrast, convective storms are more localized and essentially random in time of occurrence and location. For each type of storm, \( Pe \) is dependent upon both the intensity of the system and the location of the center relative to the station.

Analysis of precipitation efficiency data on a seasonal or annual basis helps to focus attention on the efficiency of the primary dynamic precipitation mechanisms in an area. Generally, cyclonic storms prove to be the most important large-scale phenomena in explaining \( Pe \) patterns. Locally, thunderstorm activity is influential during the warmer months (and particularly over an area such as southern Florida year round).
RELATED RESEARCH

A very general basis for estimating a precipitation efficiency factor for the entire atmosphere exists. Sutcliffe (1956) mentions that if one notes that the mean global precipitable water vapor (daily average) is close to one inch (2.54 cm) and next notes that mean global precipitation is about 40 inches (101.6 cm) per year, he sees that an amount of precipitation just equal to the mean instantaneous stock of atmospheric vapor must fall every one-fortieth of a year, or about once in 9 or 10 days. Hence, on an average, for all climatic regions, about 10 percent of the water vapor overhead precipitates each 24 hours. Sellers (1965) reported the average value of annual precipitation efficiency (daily average on an annual basis) for the world to be 12 percent.

Few previous investigators have looked at the relationship between precipitation and PWV in detail, notable exceptions being the works of Huff and Stout (1951), Reitan (1957), and Tuller (1971, 1973). In a preliminary study of atmospheric moisture-precipitation relationships over Illinois during a three-year period, Huff and Stout calculated an average daily efficiency of 5 percent. In another study in Arizona, Reitan examined the statewide daily rainfall averages in relation to the amount of precipitable water vapor during the sharply defined summer rainy season (July–August). He found efficiency values of from 3 to 13 percent, with an average daily value of about 5 percent.

Tuller produced seasonal and annual maps of Pe for Canada, and less detailed ones for the whole world. However, this preliminary work did not consider atmospheric motions in detail, and hence did not explain Pe variations.

In the present study, Tuller’s approach will be refined. Variations in proximity to sources of moisture and the transport of moisture via winds will be investigated to determine their effects on atmospheric systems and hence, on precipitation efficiency. The concept of Pe will be used to focus attention on the dynamic mechanisms within atmospheric systems that produce different precipitation patterns in different areas.

Much has been written concerning synoptic aspects of cyclone development, cloud microphysics, precipitation mechanisms, and quantitative precipitation forecasting. A number of statistical synoptic climatological studies have been made in order to improve operational forecasting of heavy precipitation, and also to better understand the relationship between the production of heavy precipitation and low-level dynamic and thermodynamic parameters such as vorticity, moisture, and temperature advection patterns (for example, see Jorgensen, 1963 and Browne and Younkin, 1970).

Although computer models and sophisticated statistical techniques can be employed in the analysis of atmospheric phenomena, this is not the purpose of the present research. In the present study, a geographical approach is employed in evaluating the influence which atmospheric systems (in particular, migrating storm systems) exert on precipitation efficiency. The emphasis is upon a macro-scale analysis of spatial and temporal variations in Pe.

SIGNIFICANCE OF RESEARCH

Precipitation efficiency is a method of expressing the ratio of actual to potential atmospheric water sup-
ply at the earth's surface. Knowledge of its variations will be directly useful in assessing the water resources of an area. The index of Pe is a useful supplement to standard precipitation maps to help focus attention on the efficiency of dynamic precipitation mechanisms in an area, and to illustrate the relative importance of available moisture and these mechanisms in producing the observed precipitation patterns (Tuller, 1973).7

PROCEDURE

Precipitation efficiency calculations (based upon twice-daily radiosonde data) were performed for 40 upper air stations, representative of different climatic regions in the United States east of the Rocky Mountains. Station locations are shown in Figure 1. The study area comprises stations representative of contrasting topographic conditions and varying exposures to water vapor transport. Consequently, the influence of these factors (topography, moisture sources and transports) upon the dynamic precipitation mechanisms, can be considered in an analysis of variations in Pe.

Pe was calculated by Eq (1) employing data for the years 1964 and 1968 (these years demonstrate the usual variable meteorological conditions, but no major climatic abnormalities). Precipitation data and upper air (radiosonde) data were purchased on magnetic tape from the National Climatic Center. PWV was determined from the data transmitted by the routine twice-daily radiosonde ascents which report upper air temperatures and relative humidities at standard pressure lev-

Figure 1. Station Locations
The relative humidity was converted to specific humidity by the Goff-Gratch formulation and then PWV was obtained by standard methods (List 1966,8 summing the contribution from all layers above the surface for which moisture data are available. Calculations were terminated at the 500 mb level since any changes in PWV are slight thereafter (Bannon and Steele 1966, and Titus 1967).9

The National Climatic Center monitors data quality to ensure adherence to the National Weather Service standards (Nordahl 1974, personal communication).10 Using these standards as a guide, individual PWV values are likely to be accurate to within ±5%. Precipitation corresponding to each ascent was obtained by summation of hourly precipitation totals for the 12 hours centered on the routine radiosonde ascent times of 00Z and 12Z. In spite of inherent problems in precipitation measurement, the precipitation data are considered sufficiently accurate (best data available) for this study. It is assumed that the precipitation guages for all stations are equally accurate, and therefore the major source of error in Pe calculations is derived from the relative humidity data.

Hence, if we assume an error of ±5% in the relative humidity data (Barry 1965, has estimated that the errors arising from the computation of PWV from upper air data yield a reliability of ±5% or ±0.08 cm at a representative value of 1.5 cm),11 this leads to a variation in Pe of approximately ±5%.

A problem was encountered in attempting to mesh the hourly precipitation and twice-daily radiosonde data. Since the radiosonde data are assumed to be instantaneous, whereas the precipitation data are based upon continuous hourly totals, the readings are not strictly compatible. However, considering the scope of the present study, these are the best data available. Any method of meshing these data depends upon the time period of interest.

The method used to calculate Pe essentially provides a 12-hour average value, and assumes that PWV is a temporally conservative parameter. However, realizing that the precipitable water vapor calculations are based on twice-daily “instantaneous” readings, and the precipitation data are comprised of continuous hourly totals, the actual amount of water vapor available at any given moment may differ considerably from the scheduled PWV reading. Also, for periods greater than a few hours the continual flow of moisture into an area can support rainfall totals exceeding the amount of moisture above the area at any given time. Accordingly, it is necessary to consider the transport of precipitable water vapor and therefore, moisture advection. In the present study, the potential for moisture advection was analyzed by using the radiosonde upper wind data.

Bannon, Mathewman and Murray (1961)12 found that the air flow at the 850 mb level gives a good approximation to the mean motion of water vapor throughout the whole column of the atmosphere, as most of the atmosphere’s water vapor occurs in the lower levels. Accordingly, geostrophic winds for the 850 mb level were used to provide order of magnitude approximations of water vapor transport. The wind data for the 850 mb level were divided into eight categories with a 45 degree range per wind direction category centered on the eight cardinal points (ordinates). Wind speed data (in meters per sec-
ond) were also recorded and considered in the analysis of moisture transport.

Due to the coarse station network, it was not possible to make precise measurements of moisture advection. Therefore, analysis was confined to determining the potential for moisture advection by making reference to precipitable water vapor levels and wind speed data for specific stations. Since the PWV data (in centimeters) and wind speed data (in meters per second) are measured in distinct units which do not mesh, an attempt at presenting a single measurement of moisture advection based upon these data would be meaningless.

Each occurrence of precipitation was assigned to a specific type of atmospheric system. The pertinent atmospheric systems were identified from microfilm copies of the National Weather Service publication “Daily Weather Maps”. In a previous study (Lutz 1976) it was determined that for specific stations in the eastern United States, the majority of convective storms are less efficient in releasing moisture at a particular point than are cyclonic systems.

The frequency of occurrence of intense storm activity (high Pe values) directly affects the seasonal and/or annual averages of Pe data which consist of the daily average of cumulative twice-daily Pe values \([(00Z + 12Z)/2]\). The index of Pe also illustrates the relative importance of moisture availability in producing observed precipitation patterns. It is necessary to consider a station’s location in reference to available moisture sources and the frequency of storm passages (and/or convective activity) in proximity to the moisture sources in explaining Pe patterns. Terrain influences (orographic effects) can enhance the precipitation processes and therefore contribute to higher Pe values on the average.

Maps of average seasonal and annual Pe (Figures 2–4) illustrate the major distributional patterns. Although the station network in the current study is not dense enough to reveal fine details within a local area or even a particular state, the general patterns are sufficient to illustrate the broad regional variations and relative values of Pe.

RESULTS

Seasonal Patterns of Pe in 1964

Winter 1964. There is a pronounced east-west gradient in the pattern of Pe for the winter season in 1964 (Figure 2a). Northerly anticyclonic flow inhibited precipitation over the Central states and low efficiency was predominant in the west (particularly in Texas where all stations exhibit average daily Pe below 2.3). In contrast, precipitation mechanisms were active in association with a broad trough which extended from the southwestern Gulf of Mexico northeastward along the Atlantic coast to northern New England (where Portland, ME had an average daily Pe of 13.2). Winter storms were also active over the Great Lakes where, for example, Sault Ste. Marie, MI had an average daily efficiency in excess of 10%.

Spring 1964. A more complicated pattern appears for the spring season of 1964 (Figure 2b). High Pe dominates the southern Mississippi River Valley as part of a meridional belt of elevated Pe stretching northward from the Gulf of Mexico to the Great Lakes. A deep trough stretched from the upper Mississippi Valley into the Southwest, accompanied on the east by a prevailing southerly flow.
from the Gulf of Mexico. The trough was associated with considerable storminess and precipitation from the Mississippi Valley to the Appalachians.

Average $Pe$ values in excess of 7% also occurred in a zonal belt extending south of the Great Lakes from the South Dakota/Nebraska border eastward through Pennsylvania and over northern New England. In contrast, stable atmospheric conditions prevailed over western Texas and southern Florida where $Pe$ generally dropped below 3%.

Summer 1964. During the summer season of 1964 (Figure 2c) high $Pe$ values were concentrated over the southeastern and northwestern sectors of the study area as convective mechanisms were active along the south Atlantic coast (Florida and South Carolina, in particular), and the Northern Plains were affected principally by disturbances entering the continent in fast flow from the Pacific. On the other hand, precipitation activity was suppressed over
an area covering the state of Texas (Pe values below 2%) and extending northeastward to Ohio, and from eastern New York south to Virginia and north to Massachusetts.

In general, local thunderstorms played a dominant role during the summer months, whereas the influence of migrating cyclones was subdued. The uneven distribution of shower-type precipitation is reflected in the contrasting values of Pe.

**Fall 1964.** Extreme variability marked the monthly circulation and weather patterns for the fall season in 1964. Except for the persistence of dry conditions in the Northeast and portions of the Central states, precipitation and Pe patterns were also varied (Figure 2d).

In general, prevailing stable atmospheric conditions associated with well-developed anticyclones suppressed precipitation activity during the autumn season of 1964 (over thirty-six percent of the stations projected Pe values below 3%). Fortunately, pronounced drought conditions were averted since the hurricane season of 1964 in the Atlantic and Caribbean was more active than usual with six tropical storms attaining hurricane strength, four of which reached the coast of the United States. Most of this activity occurred in September and October when the mean circulation was generally favorable for the formation of such storms.

Interior stations did not benefit from the hurricane passages, however. Drought conditions (reflected in low Pe values) in the western High Plains were associated with anticyclonic northerly flow. Just east of the High Plains, however, a southerly flow transported moisture from the Gulf of Mexico, and well-spaced thunderstorms produced generous showers (with correspondingly higher Pe values) over portions of the central Great Plains and the Southeast.

**Seasonal Patterns of Pe in 1968**

**Winter 1968.** During the winter season of 1968 there were marked contrasts in the pattern of Pe between the western and eastern sectors of the study area, as well as between north and south (Figure 3a). Disturbances were particularly active over the Great Lakes and northern New England, whereas precipitation mechanisms were suppressed over the western border states and Florida, where a continental circulation prevented the intrusion of southerly moisture-bearing streams.

The influence of moisture availability upon Pe was particularly evident during the month of February 1968 when northerly flow brought unusually dry conditions to much of the East. Precipitation was less than one-fourth normal in the Dakotas, upper Mississippi, Ohio, and Tennessee Valleys, and parts of the Northeast. Principal exception was the heavy precipitation falling to the lee of Lakes Superior and Michigan (for example, Sault Ste. Marie, MI had an average daily Pe exceeding 23%) as cold, dry air gained supplemental moisture in passing over the Lakes and deposited it, mostly as snow, on the leeward side.

**Spring 1968.** As was the case in 1964, precipitation mechanisms were most active during the spring season in 1968 as approximately 60 percent of the stations recorded Pe values in excess of 5%. As shown in Figure 3b, there was a zone of elevated Pe stretching from Little Rock, AR (11%) northeastward to Buffalo, NY (associated with a series of storm systems which developed in a South-
west trough and moved northeastward across the Middle Atlantic states, with average daily Pe values above 7% also encompassing the northeastern United States and an area extending from Omaha, NB to Green Bay, WI. Miami, FL (Pe of 7%) benefitted from convective storms whereas precipitation was limited across the rest of Florida and along the south Atlantic coast as anticyclonic conditions prevailed.

Summer 1968. Due to the showery nature of summer precipitation, the seasonal pattern of Pe was quite erratic in 1968 (Figure 3c). Precipitation mechanisms were relatively active (aided by a southerly anomalous component of flow in the Great Plains) over eastern Michigan, Minnesota, the Dakotas, and Kansas. In contrast, atmospheric conditions were particularly stable over Texas, resulting in low Pe values.

In general, cyclonic activity was suppressed during July as the Ber-
muda High increased in strength, with anticyclonic conditions dominating the Northeast (Albany, NY had its driest July in a 145-year record).

Further westward extension of the Bermuda High into the Southeast continued in August as a strong ridge developed northward to the Great Lakes region. Dry weather prevailed beneath the ridge in most states east of the Mississippi River (75 percent of all stations recorded Pe values below 5%). However, dry conditions were interrupted by occasional convective showers and, in particular, the Florida peninsula received abundant rainfall (enhancing the average daily Pe values) as a result of frequent thunderstorms.

Fall 1968. There was a definite southwest to northeast orientation to the pattern of precipitation efficiency for the fall season in 1968 (Figure 3d). Stable atmospheric conditions prevailed over the southwestern edge of the study area (with correspondingly low Pe over Texas). In contrast, most areas from the eastern Great Plains to the Atlantic coast were affected by consistent storminess associated with a deep mean trough and broad area of cyclonic flow.

The eastern United States benefitted from frequent frontal showers related to a series of storms that developed in the southwest and moved northeastward. Heavy thunderstorms contributed to high Pe values during the early part of October, and in mid-October Hurricane Gladys released widespread rainfall, affecting most of southern and eastern Florida, coastal Georgia and the Carolinas.

Annual Patterns of Pe in 1964 & 1968

1964. As displayed in Figure 4a, one can observe a general east-west gradient in the value of the average daily Pe for the year 1964. Precipitation mechanisms were more active east of the Mississippi River. Basically all stations with Pe in excess of 5% were primarily affected by cyclonic and frontal mechanisms as 1) storms generated over the Gulf of Mexico and south Atlantic, migrating (and transporting moisture) northward along the Atlantic coast, or 2) activity along the Canadian border and over the Great Lakes.

Considering those areas which exhibit the highest average Pe for 1964, cyclonic and frontal mechanisms were most active during the winter months over northern New England and the Great Lakes. Eastern Georgia and South Carolina (specifically Athens and Charleston) were affected by coastal depressions drawing upon readily available moisture from both the Gulf and Atlantic, supplemented by convective precipitation during the summer months. In particular, Charleston, SC experienced an extremely rainy month in July (60.3 cm of precipitation and an average daily Pe of 23.5) as a result of active thunderstorm mechanisms. Stations in the Southeast also received showers associated with hurricane activity in 1964.

Along the east coast, the Mid-Atlantic states did not receive the full force of Atlantic coastal depressions as these storms tended to veer out to sea over the North Carolina/Virginia border and then return toward land over the northern New England coast. Lower Pe values were also maintained over southern Florida, which was situated south of the main storm tracks. Convective precipitation mechanisms proved to be more prevalent there.

Pittsburgh, PA and Buffalo, NY
were affected by cyclonic and frontal activity over the Great Lakes, inland storms, and major coastal depressions. Also, topographic effects can enhance precipitation activity over both Pittsburgh and Buffalo. Efficiencies trailed off southwestward from the Great Lakes due to the interior location of stations (considerable distance from available moisture sources), lack of orographic enhancement and more stable atmospheric conditions.

The lowest $Pe$ values for 1964 were concentrated over the southwestern edge of the study area where a lack of dynamic mechanisms is corroborated by the low values of $Pe$ over Texas. Excluding Fort Worth ($Pe$ of 4.2), daily $Pe$ values averaged below 3% for the Texas stations in 1964.

1968. The map of average annual $Pe$ for 1968 (Figure 4b) presents a complicated distribution in contrast to the rather uniform patterns displayed in 1964 (Figure 4a). Once again however, the impact of frequent cyclonic and frontal activity is reflected in the higher $Pe$ values in proximity to the Great Lakes and along the Mid-Atlantic and New England coasts.

It is hypothesized that the high $Pe$ values (relative to the surrounding area) over northeastern Louisiana and western Arkansas result from the occasional invasion of intense storms which generated over the Gulf of Mexico and moved inland. For example, the impact of major storm activity (with high $Pe$ on successive days) as contributing to an enhanced average daily $Pe$, is elucidated by data for Little Rock, AR. A stationary front was situated over Little Rock on successive days during May 1968, and heavy showers associated with the front contributed to a high monthly $Pe$ value (16.7). This same storm affected Victoria, TX whose annual average ($Pe$ of 4.7) was greatly enhanced by the anomalously high monthly $Pe$ value of 17.3 for May.

Elsewhere, Athens, GA was exposed to vigorous cyclonic systems which generated over the Gulf and south Atlantic during the winter
months, supplemented by summer convective precipitation. Intense convective storms (particularly during the months of May, June, and October) also assisted in providing Miami, FL with a relatively high value of \( P_e \) (6.9).

Hurricane activity was suppressed in 1968 and annual averages of \( P_e \) were correspondingly low for many gulf coastal stations. For example, Montgomery, AL registered a pronounced dip in the average daily \( P_e \) between 1964 (6.2) and 1968 (4.0). Excluding the months of November and December, active precipitation mechanisms were much less prevalent in 1968 compared to 1964.

In general, an extensive zone encompassing the mid-section of the study area had an annual \( P_e \) ranging between 5 and 6 percent. This pattern is complicated by slightly lower values over the area southwest of Lake Michigan (for example, the average daily \( P_e \) of 4.7 over Peoria, IL was hampered by a marked reduction in precipitation during the spring season of 1968).

Mirroring the situation in 1964, prevailing stable atmospheric conditions dictated the distribution of low average daily \( P_e \) values over the western border of the study area in 1968, with the lowest values of \( P_e \) occurring in Texas.

**SUMMARY**

Clearly, analysis of precipitation efficiency data on a seasonal basis focuses on the efficiency of the primary dynamic precipitation mechanisms. Although individual convective and cyclonic storm systems can give high \( P_e \) values, they usually affect a station for only a short time. Hence, the seasonal and annual average \( P_e \) values are generally less than 7%.

However, there are distinct seasonal patterns (Figures 2 & 3) indicating a maximum efficiency in winter and spring when cyclonic storms are active and frequent, and a minimum in late summer and fall when there are few active systems (cyclonic or convective) and anticyclonic flow prevails. \( P_e \) is low in the summer months despite a high total number of storm systems. The smaller number of cyclonic storms which occur in summer are usually much weaker than in winter. Increased convective activity during summer is insufficient to compensate for the drop in \( P_e \) resulting from decreased cyclonic activity.

Table 1 indicates the average number of cyclonic storms (centers identified for 24 hours or more) per month which affected the eastern United States in 1964 and 1968. Clearly, cyclonic storm activity is dominant during the winter and spring seasons whereas convective mechanisms tend to become more important in the summer months when fewer cyclonic passages are experienced.

The maps of annual precipitation efficiency (Figure 4) essentially reflect the cumulative effect of the seasonal sequences. The difference between the patterns of \( P_e \) in 1964 and 1968 is evident. On a seasonal

### TABLE 1

<table>
<thead>
<tr>
<th>Season</th>
<th>Average Number of Storms Per Month</th>
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<tbody>
<tr>
<td>Winter</td>
<td>10</td>
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<tr>
<td>Spring</td>
<td>9</td>
</tr>
<tr>
<td>Summer</td>
<td>5</td>
</tr>
<tr>
<td>Fall</td>
<td>6</td>
</tr>
</tbody>
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basis, the most striking contrasts occurred between the respective winter and fall seasons in 1964 and 1968.

As shown in Table 2, storm mechanisms were generally less effective during the winter season of 1968, as compared with 1964. During the winter of 1964 the eastern United States came under the influence of a greater number of active coastal depressions (with 58 percent of the stations exhibiting \( Pe \) values in excess of 5%).

In general, precipitation mechanisms were considerably more active during the fall season of 1968 than in 1964. Several stations experienced frequent thunderstorm activity in the autumn months of 1968 whereas convective activity was suppressed in 1964.

The present data suggest that the major cause of high seasonal average \( Pe \) values is increased cyclonic activity. Since convective activity is seasonally variable, high average \( Pe \) values are generally associated with a greater frequency of, or more intense, cyclones. In contrast, the minimum average \( Pe \) values appear to be dependent upon the suppression of both cyclonic and convective activity, with anticyclonic flow dominating.

### TABLE 2

Percentage of Stations with Seasonal \( Pe \) Greater than 5% and Less than 3% in 1964 and 1968

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</thead>
<tbody>
<tr>
<td>( Pe &gt; 5 )</td>
<td>58%</td>
<td>42%</td>
<td>62%</td>
<td>59%</td>
<td>30%</td>
<td>26%</td>
<td>17%</td>
<td>41%</td>
</tr>
<tr>
<td>( Pe &lt; 3 )</td>
<td>33%</td>
<td>29%</td>
<td>19%</td>
<td>16%</td>
<td>32%</td>
<td>18%</td>
<td>36%</td>
<td>21%</td>
</tr>
</tbody>
</table>

be 12 percent.\(^{15}\) Tuller (1973) calculated average \( Pe \) values in excess of 12 percent for most of Canada.\(^{16}\) Therefore, he concluded that Canada is better endowed than many countries with an effective system of dynamic mechanisms that are efficient converters of available water vapor into measurable precipitation. From the preliminary observations included in the present study (limited to data for 1964 and 1968) it can be suggested that the United States (at least for selected upper air stations in the conterminous United States east of the Rocky Mountains) exhibits an average annual value of \( Pe \) below 12 percent.

### NOTES


7. S. E. Tuller, *op. cit.*


14. For purposes of the present study, the winter season comprises the months of December, January, and February of the same year.

15. W. D. Sellers, *op. cit.*

16. S. E. Tuller, *op. cit.*