A SELECTED ASSEMBLAGE OF CLIMATE VISUALIZATION PRODUCTS FOR WASHINGTON DC AT VARYING SCALES: ANNUAL TIME-SERIES PLOTS TO “HOUR-BY-MONTH” CLIMOGRAMS

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1. INTRODUCTION

This presentation provides a medley of visualization products that depict selected climatological aspects of the Washington DC area for different time scales of interest - annually down to a combination of monthly/diurnally.

The observational periods of record for Washington DC area daily temperature and precipitation observations recently passed milestones of 150 years plus of uninterrupted recordings (complete year histories commencing with 1872 for the former and 1871 for the later), and thanks to the NOWDATA NWS online resource, the data are digitized in their entirety, and easily accessible (this also includes 1884-85 to present snowfall data). With such lengthy periods of record available, combined with the ongoing backdrop of Climate Change, it is of interest to describe the overall year-to-year pattern changes over the histories utilizing. year-to-year bar charts

Not nearly as lengthy in historical availability, but still appreciable in volume are individual hourly observations, which can be transformed into diurnal and seasonal graphs of means and extremes. In this case, thanks to the Iowa State METAR site, Washington D.C. National Airport hourly observations, in some cases available back to the late 1930's (but continuous from 1973), are readily accessible online as well. These include temperature, dewpoint, relative humidity, and wind direction/ speed. Thus the observations can be downloaded, reduced, and transformed into "Hour-by-Month" Climograms, a type of chart that depicts the diurnal vs. monthly variations of climatological parameters on single page layouts analogous to topographical maps. Some of the paired hourly observations such as temperature and winds or temperature and dewpoint can also be utilized to produce Wind Chill and Heat Index readings, respectively, which in turn can comprise annual year-to-year extremes charts.

The various graph types are gathered together into a single presentation, providing information on both the large-scale (long-term secular) and smaller-scale (diurnal/seasonal) features of Washington DC climate. The NOWDATA daily records dating back to probably at least the late 1940’s are from the National Airport, those for the older years, while not specifically identified as to location, were most likely within a mile of the National Airport and at nearly identical elevations (based on information from old Annual Summary publications of those eras).

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2. RESULTS

2.1 - Washington DC Time-Series Charts - Temperatures

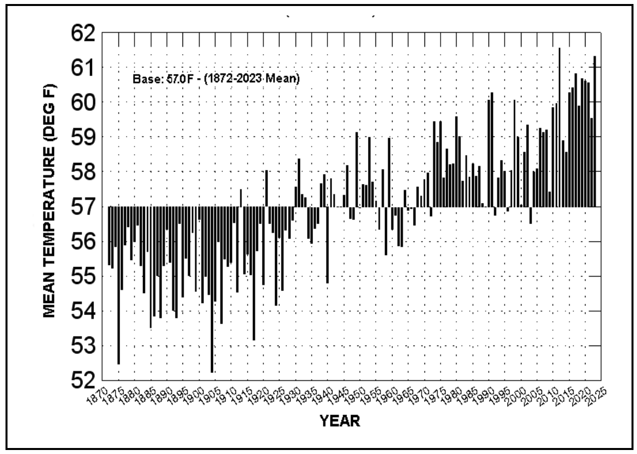

Figure 1: Annual Mean Temperature History for Washington DC – 1872-2023

Figure 1 depicts the Annual Mean Temperature history for Washington DC for 1872-2023. An unmistakable upward trend is evident, setting in from about 1973, with only three years since with averages below the baseline 57.0 F long-term mean. Presently, the warmest year since 1872 is 2012 (annual Mean: 61.6 F), the second warmest (61.3 F) for the year just passed (2023).

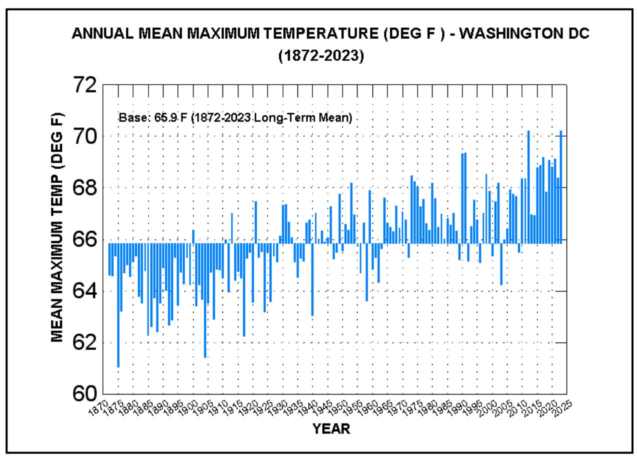

Figure 2: Annual Mean Daily Maximum Temperature History for Washington DC -1872-2023

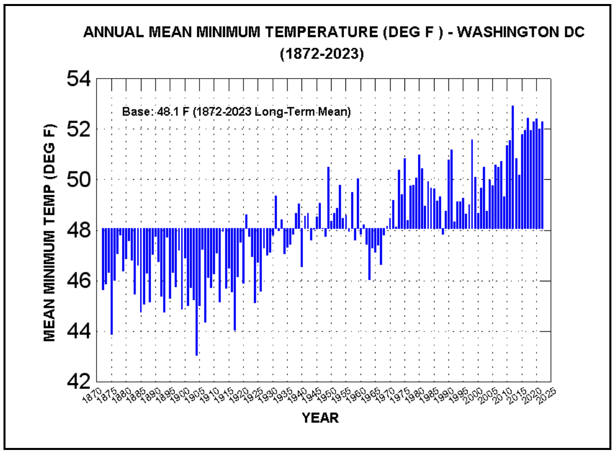

Figure 3: Annual Mean Daily Minimum Temperature History for Washington DC – 1872-2023

Figures 2 and 3 above, respectively, show the corresponding year-by-year figures for mean daily maxima and minima. The patterns resemble Figure 1 quite closely, and are highly correlated , the linear correlation coefficient between the two: r=+.903; 2012 and 2023 have highest means each for the daily maxima (70.2 F), 2012 with the highest for the daily minima (52.9 F).

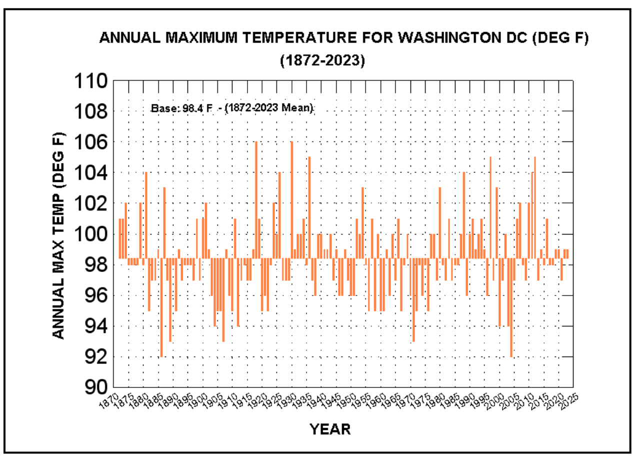

Figure 4: Annual Maximum Temperature History for Washington DC – 1872-2023 .

Moving into the annual temperature extremes' statistics, Figure 4 is a plot of the highest temperatures recorded in Washington DC, year-by-year, from 1872 to 2023. In contrast with Figure 2's mean daily maximum plot, there is no secular trend evident, relatively high and low figures spread throughout the time-series. The lowest annual maximum (92 F), originally recorded for 1886, was tied relatively recently, in 2004. Record warm

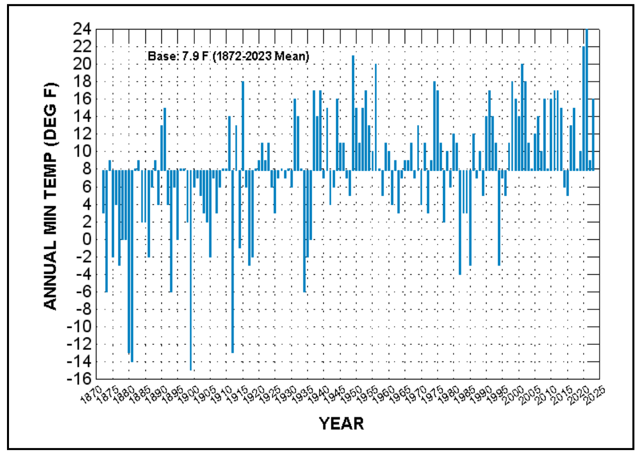

Figure 5: Annual Minimum Temperature History for Washington DC – 1872-2023

2012 had a 105 F on 7 July, but this was still short of the 106 F readings recorded during the 1930 and 1936 Dust Bowl years. The correlation coefficient between the annual mean maxima statistics in Figure 2 with that of the absolute maxima stats in Figure 4 is only r=+.292.

In contrast, the annual minimum chart in Figure 5 above shows a decided contrast between the figures of the early 20th century and those coming after. Annual minima colder than -10 F were a somewhat regular occurrence up through 1912, but the lowest minimum since that time has been -6 F in1934 and there have been only three subzero readings beyond that year, -4 F in 1982, and -3 F readings, each, in 1985 and 1994. Since 1997, some 26 years, there have been only two extreme yearly minima below the long-term mean (7.9 F), and these only slightly so (the 6 F for 2015 and the 5 F in 2016). In 2020, a new 22 F extreme "mildest" record was set, this surpassed the very next year in 2021 with 24 F. Correlation between the year-by-year annual mean daily minimum statistics in Figure 3 with those of the absolute minima in Figure 5 is r=+.559.

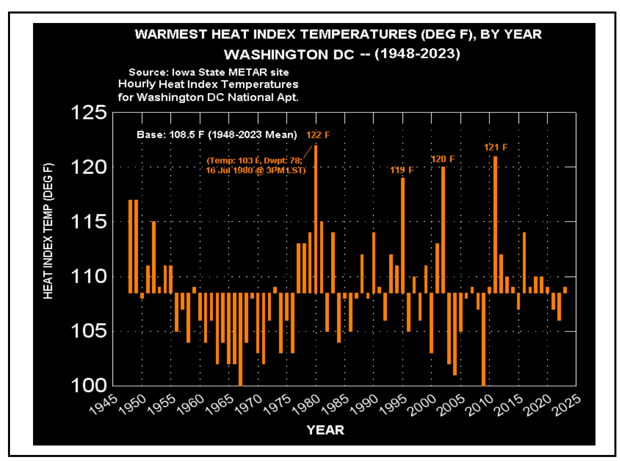

Figure 6: Warmest Heat Index Temperatures for Washington DC, by year, 1948-2023

Next, consideration turns to two other useful temperature variables, produced in combination, respectively, with dewpoints and wind speeds: heat indexes and wind chills. Figure 6, based on the 1948-2023 period of record, displays the long-term pattern of year-to-year maximum heat-Index temperatures, the NWS Rothfusz method utilized for the calculations. Common knowledge that it is, summer conditions can be quite sultry in Washington, the 46-year extreme value mean: 108.5 F, well past the 103 F "danger" level.

Inspecting the chart, for the lengthy 21 year-period 1956 to 1976, the annual warmest statistics were less than the 108.5 F mean for all but three, the lowest, a "coolish" 100 F in 1967. But for 1977-1981, the indices all surpassed the mean, and in 1980 the all-time record maximum 122 F was attained in July. Subsequent years have exhibited a more fluctuating pattern, 119 F noted for 1995, 120 F in 2002, and 121 F for 2011, but another "minimum", 100 F, for 2009. On an extreme average midnight-to-midnight hourly basis, three different years have almost identical record maxima statistics: 103.6 F means for 20 July 1980 and 15 July 1995 each, and 103.5 F for 22 July 2011.

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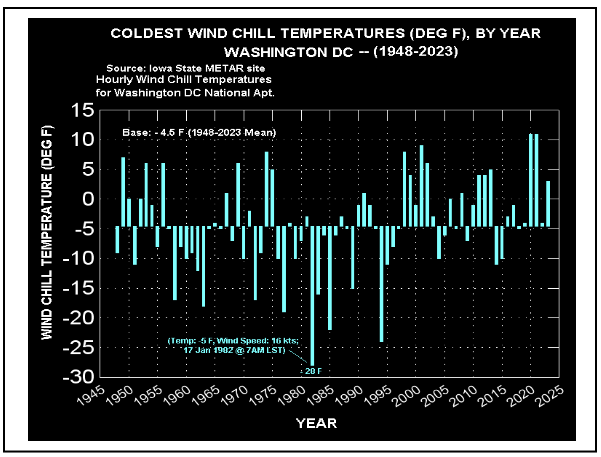

Figure 7: Coldest Wind Chill Temperatures, by Year, for Washington DC, by year, 1948-2023

Figure 7 shows the annual time-series of extreme wind chills, the long-term mean -4.5 F. Pattern-wise, a noticeable feature is that three of the coldest readings of the entire history are concentrated over just thirteen years, including -28 F in 1982 (the most severe), -22 F in 1985, and -24 F in 1994. Since 1995, though, no events of this character have been experienced, the majority of the of years with "balmy" extreme minimum wind chills above zero. The record "warm" readings (both +11 F) were calculated for the successive years 2020 and 2021. On a twenty-four hour basis, midnight to midnight, the coldest daily wind chill average of the 1948-2023 history is for 19 January 1994 (daily mean: -13.5 F), the second coldest for 10 January 1982 (daily mean: -8.5 F).

In summary for the temperatures, generation of the annual time-series charts seemed to pinpoint start of the common-knowledge secular warming trend at about 1973. The annual extreme minima from Figure 5 were positively correlated with the mean daily minima (Figure 2), but the former's ramp-up seemed to have been completed to a relatively stable level years earlier (in the late 1930's) compared to the latter's in the early 1970's, which continues to this day. The linear association between the annual extreme maxima (Figure 4), and the mean daily maxima (Figure 2) was only modestly positive. Annual extreme wind chill temperatures since 1998 have been predominately above the long-term mean, but there is no apparent secular trend for the heat index extremes.

Finally, Figure 8 below is a daily time-series of the high and low temperatures of 2012, the warmest year of record, presently, for Washington DC. The "Standardized Departure"' graph at the bottom is based on standardized anomalies of the daily means relative to those calculated for 1872 to 2023.

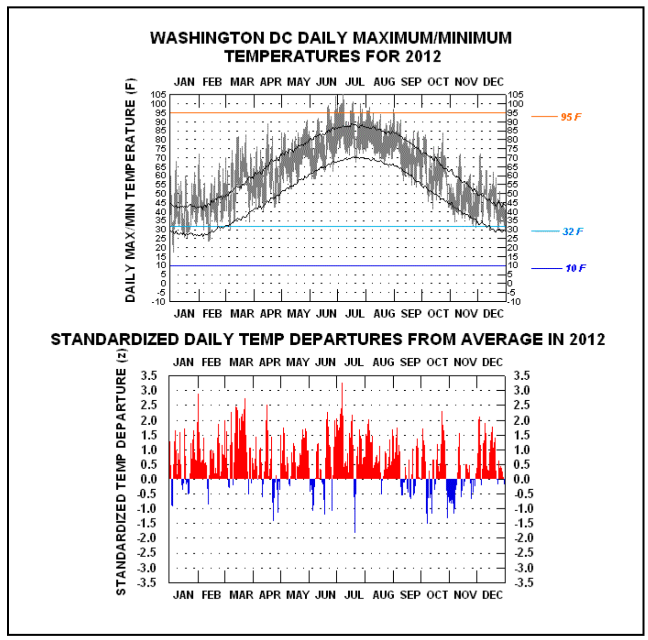

Figure 8 – Time-Series plot of 2012 Daily Maxima/Minima (top) and Standardized Anomalies of the Daily Means (bottom)

The 2012 year (mean temperature: 61.6 F) was 4.6 F warmer than the 1872-2023 long-term average, with 274 above average days (74 % frequency) and one daily departure in excess of three standard deviations above. March (56.8 F mean) was also the warmest in history, surpassing 1945's previous mark by 0.6 F.

2.2 - Washington DC Temperature Climograms

Reducing the scale to Seasonal/Diurnal, the following four temperature-related charts are "Hour-by-Month Climograms", depicting climatological variations on grids analogous to topographic maps (i.e., vertical axis representing the month, horizontal axis the hour of the day, and the parameter of interest's mean values by contours). Sunrise/sunset demarcations are also overlain to impart additional diurnal perspective. The Washington charts' period of record dates from 1973, the arbitrarily designated "start" of the secular warming trend.

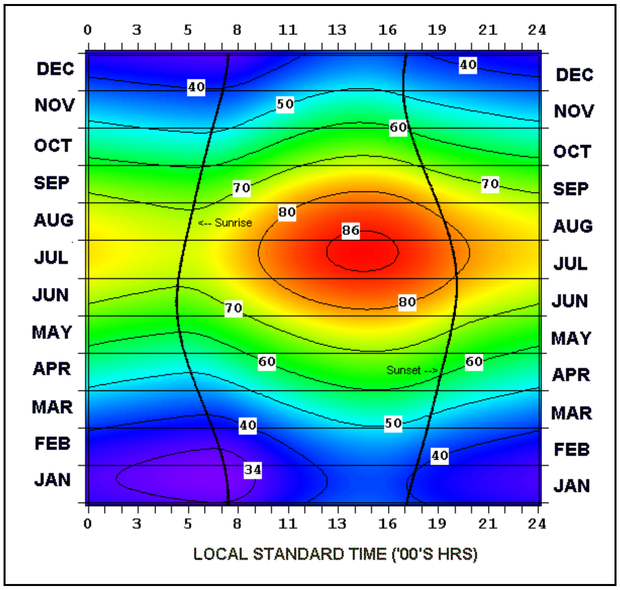

Figure 9 – Mean Hourly Temperatures (Deg F) for Washington DC – 1973-2023 Period of Record

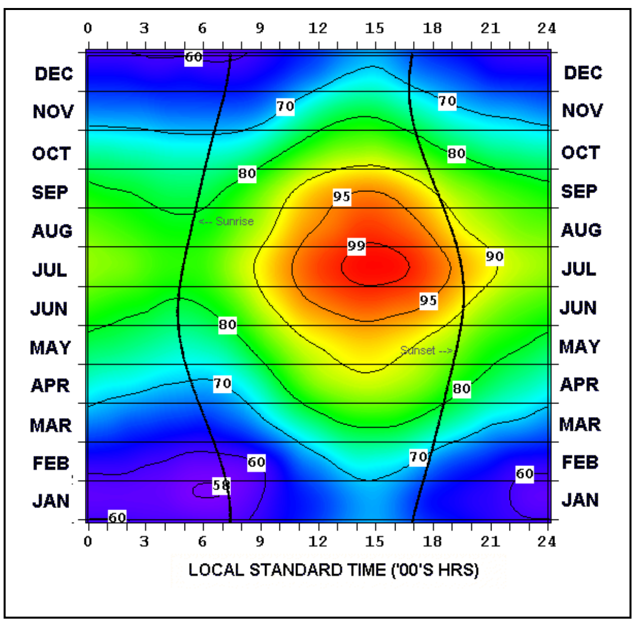

Figure 10 – Upper 99th Percentile (Warm) Temperature Thresholds (Deg F) for Washington DC – 1973-2023 Period of Record

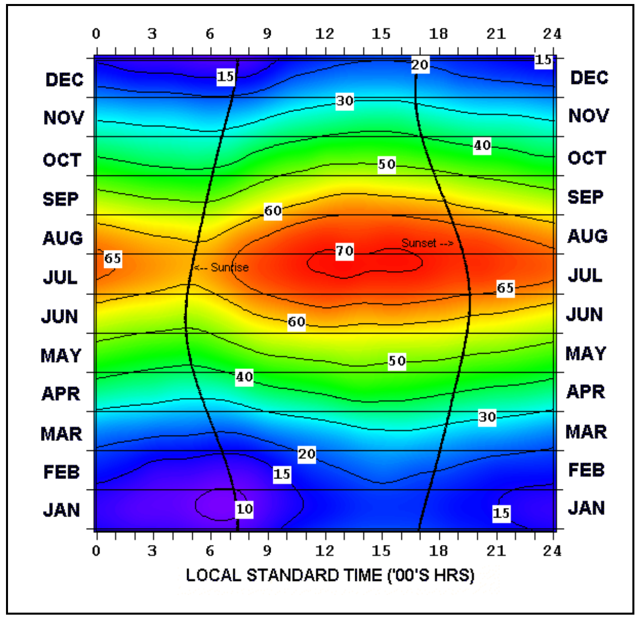

Figure 11 – Lower 1st Percentile Hourly Temperature Thresholds (Deg F) for Washington DC – 1973-2023 Period of Record

Figures 9 thru11, respectively, depict the seasonal and diurnal variations of Washington mean hourly temperature readings, plus calculations of the hourly upper 99th percentile levels, and those of the Lower 1st percentile ones. The contours represent slightly smoothed values of both the original mean hourlies and threshold statistics. The maximum mean and 99th percentile contours (86 F and 99 F, respectively) are each shifted seasonally (to July) and diurnally (to the mid and late afternoon), a typical feature of the mid-latitude stations across the U.S. The lower 1st percentile chart's 70 F contour, in contrast, centered in late July, stretches in elongated fashion from 11AM to 5PM, reflecting a lack of diurnal insolation, attributable, of course, to atypical cloudy periods, thunderstorm occurrences, or unusual cool snaps.

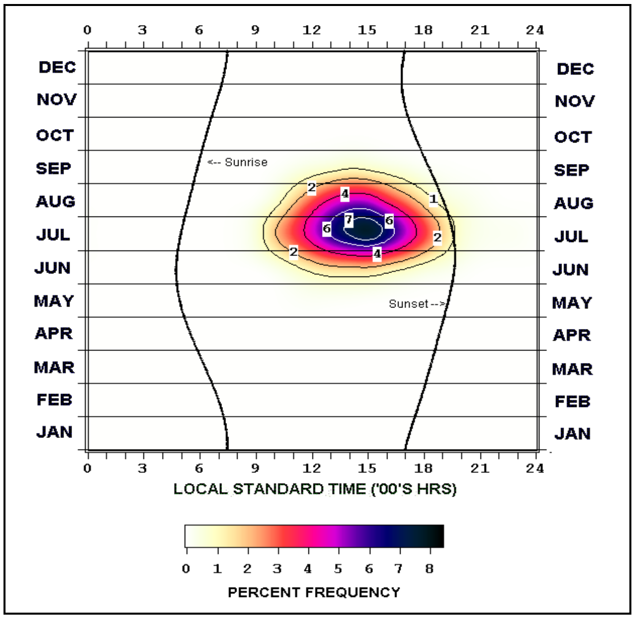

Figure 12 – Percent Frequencies with Heat Index Temperatures >= 103 F for Washington DC (1973-2023 Period of Record

Lastly, Figure 12 is a climogram with slightly smoothed contours of the percent frequencies of “Dangerous” (>= 103 F) Heat Index temperatures. The maximum zone (>7 percent incidence), not surprisingly, is centered over the mid-afternoon hours of mid-to-late July. On a detailed descriptive statistical basis, covering the 1973-2023 period of record, Washington experiences about 31 hours of “Dangerous” Heat Index temperatures per year, the highest yearly total, 121 hours for 1980, and the lowest, a single hour for 1996. For individual calendar months, August 1993 had the greatest count total (74 hours), and the dangerous levels have been experienced as early as 30 May 1991 and as late as 18 September, also in 1991.

2.3* - *Washington DC Time-Series Charts – Precipitation and Snowfall

Next, attention is turned to precipitation and snowfall, a number of time-series charts constructed. Figure 13 is a time-series plot of Washington annual precipitation from 1871 thru 2023.

At first glance, subjectively, there appears to be roughly three multi-year patterns of similar character: the generally wet years of 1876 to1891, a faint clustering of drier than average years from about 1960 to 2000, and the more recent conglomeration of mostly wet years covering about 2002 to 2021. Collectively, though, these only constitute about half of the history, and utilizing a Minitab Quality Control Test that considers a series in its entirety, results indicated no significant Trends, Clusters, Mixtures, or Oscillations beyond the .05 level. The wettest year yet recorded

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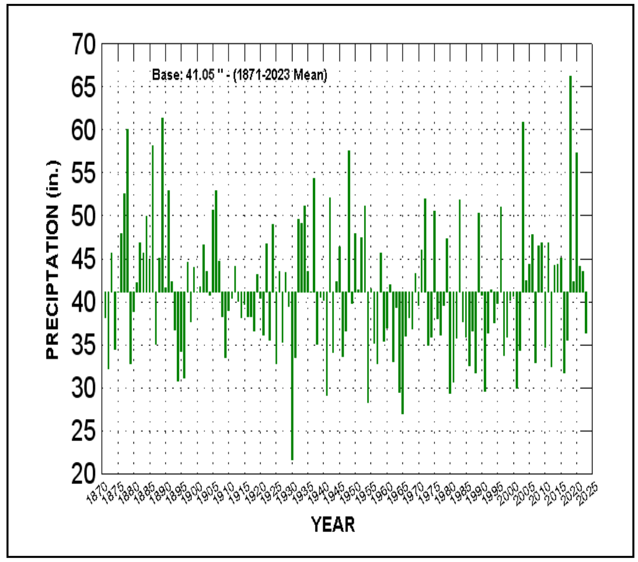

Figure 13. Annual Precipitation Totals (in,) for Washington DC, 1871-2023

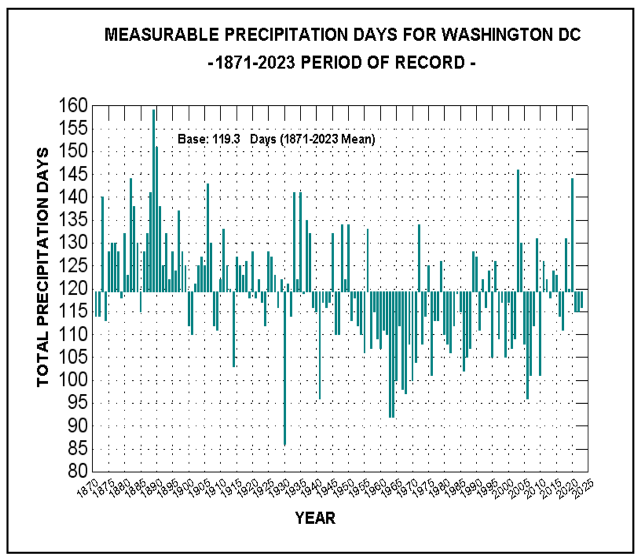

Figure 14 – Annual Measurable Precipitation-Days for Washington DC, 1871-2023

(66.28”) occurred just recently in 2018, the driest (21.66”) for the Dust-Bowl year 1930.

Viewed from another perspective, Figure 14 is a tally, by year, of measurable precipitation-days recorded over 1871 thru 2023,. A more visually striking pattern is shown with significant clustering, indicating a major contrast in precipitation count character between the late 1880’s thru 1890’s vs. the late 1950s thru early 1970’s. Measurable rain-day counts were above average for the fourteen consecutive years 1886 thru 1899, including the all-time maximum count (159) for 1889, but, conversely, below average counts were

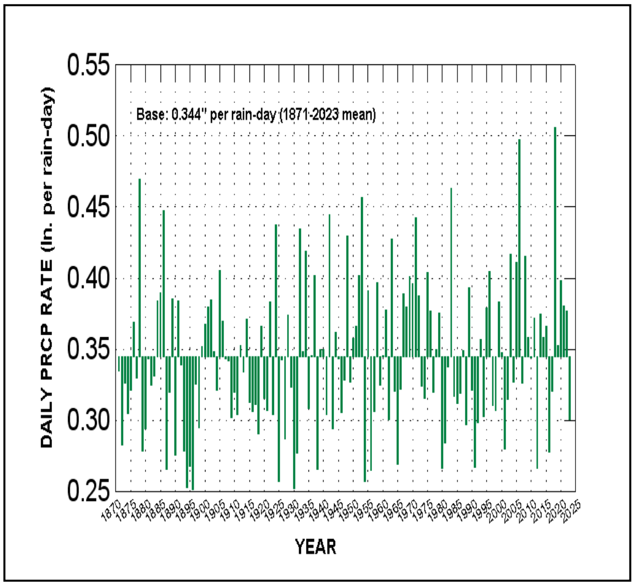

Figure 15- Daily Rainfall Rates per Measurable Rain-Day for Washington DC (1871-2023)

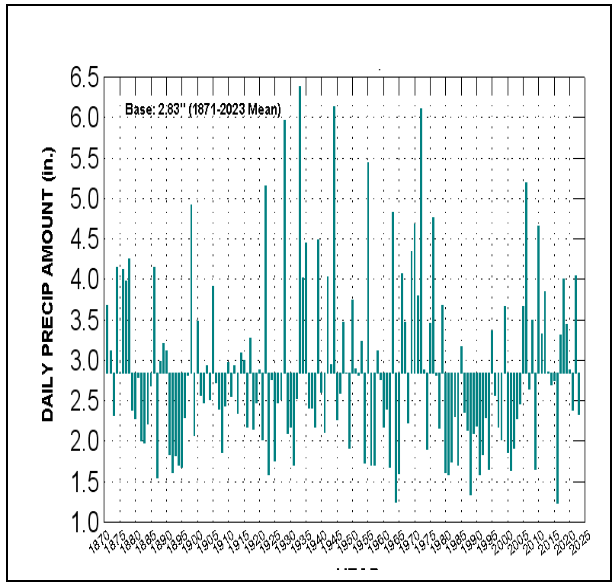

Figure 16 – Maximum Individual Day Rainfall Totals, Year by Year for Washington DC (1871-2023)

evident for the fifteen successive years 1957-1971. Comparing the fourteen and fifteen year precipitation means, respectively, 1886-1899's was 42.49", 1957-1971's 37.43". While the Minitab Quality Control routine produced a rejection of cluster count frequencies at the .001 level (too few individual ones), these being counts and not physical entities like rainfall amounts, a further analysis was in order, namely investigation of daily rainfall rates.

Figure 15 is a time-series of rainfall rates per measurable rain day, year-by-year. Examination revealed, for the high count frequency period of 1886-1899, a conspicuous seven-year run covering 1892-98 with means well below the long-term average 0.346". In contrast, the low frequency period of 1957-71 had a five year run, covering 1967-71, with higher than normal rates.

Thus, while 1886-1899 was a bit wetter than 1957-71 in the mean, the contrast was made less so as seen in Figure 13 because of the lesser daily rain rates for roughly half of 1886-1899's years. In any case, for whatever physical reasons there might be, measurable rain-day counts for Washington DC have shown, over portions of the history, extended runs of relatively high or low counts year-to-year, these however not necessarily having the same degree of impact on actual total rainfall amounts.

Another feature worth mentioning from Figure 15 is that the 66.28" annual rainfall record for 2018 (see Figure 13) was associated with a new record measurable rain-day rate, .506. There were 131 rain-days, the 4th highest figure on record.

Correlation of 153 years of annual Washington DC precipitation totals with the number of Measurable Rain-days is +0.555, and +0.811 with the rain-day rates.

The last precipitation chart (Figure 16) is a time-series of maximum individual daily totals, year-by-year. Over the 153-year history, the extremes have ranged from 1.24" for 2016 to 6.39" for 1933, the mean 2.83". The higher "extrema" are scattered mostly over the relative middle years, from 1921 to about 1972. There are two noticeable clusters of relative minima, the first a six-year run from 1891 to 1896 and the second a nine-year run from 1986 to 1994. Another running of the Minitab Quality Control routine, however, produced no overall significant p-values for Clustering (lack of, or alternatively, excess) Mixtures, Trends, or Oscillations. Correlations of the individual daily extremes with the daily rates were +.479, and with the annual totals, +.378.

In summary, examination of long-term secular patterns of Washington DC precipitation from four different statistical perspectives seemed to reveal no conclusive recent trends suggestive of climate change influences. On a subscale basis, the sharp contrasts between the mid-1880's to late 1890's vis-à-vis the late 1950's to early 1970's in measurable precipitation-day counts, and to lesser extent, annual precipitation magnitudes, were interesting features to consider.

Finally, Figure 18 is the historical time-series plot of Washington DC seasonal snowfall. The period of record covers the June-July seasons from 1884-85 thru 2022-23, but excludes the 1886-87 and 1887-88 seasons, the tabulations of which were incomplete. While a new record total of 56.1" was set for the 2009-10 season, there is a visible clustering of lighter than average falls in general from the 1988-89 seasons onward. Also, with the exception of the 1957-58 thru 1967-68 seasons most of the heavier falls seemed to be confined to many

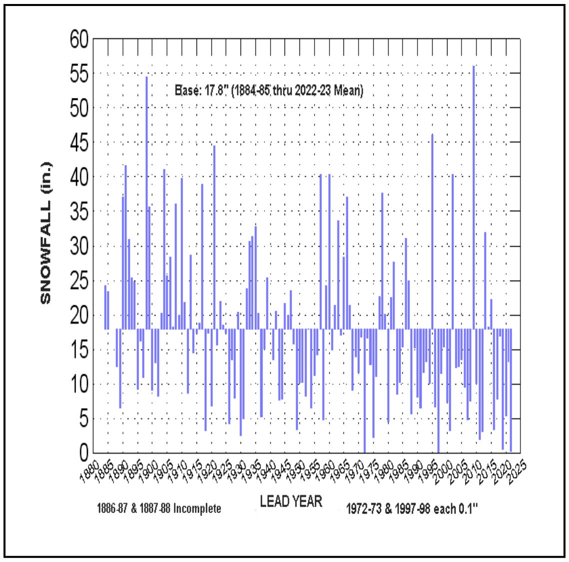

Figure 18 – Seasonal (July-June) Snowfall Totals (in.) for Washington DC (1884-85 thru 2022-23 seasons – sans 1886-87 and 1887-88)

years ago, over the 1898-99 to 1921-22 era, approximately.

The Minitab Quality Control test produced a rejection at the .001 level for number of individual cluster frequencies, and a non-parametric runs test rejected at the .002 level (too few individual runs). A third analysis (linear trend) computed a downward trend of about .08" per season from 1888-89.

2.3.1 – Precipitation Character of 1930 – A True Outlier

In the course of constructing, inspecting, and analyzing three of the four precipitation charts (Figures 14 thru 16), a striking feature of the bars in all three was the anomalously dry character of the year 1930. Total precipitation (21.66") was only 53% of the present long-term average (41.05"), more than 5 inches drier than second driest 1965 (26.94"), and total measurable precipitation days were also the least (86) of the record. In addition, the precipitation rate per wet-day (0.252") was second lowest, just a shade higher than 1896's 0.251" figure.

From this, it was of interest to evaluate 1930's annual precipitation total in an extreme-value analysis. Utilizing a software curve-fitting product that assesses the goodness-of-fits of a large collection of different continuous probability density distributions, the third best fitted model of more than forty was the Generalized Extreme Value (GEV), this chosen because it is frequently used in Extreme Value applications meteorologically. Calculation of a estimated return period for 1930's 21.66 figure produced an amazing 6700-year figure, which, of course, requires a major caveat, such that it's more than an order of magnitude larger than the actual period of record (153 years).

Suffice to say, for the current century and a half of Washington annual precipitation history, 1930 stands as an exceptional outlier. In contrast, the estimated return period for the 66.28" maximum for 2018 is a lesser but still prominent 320 years.

Figure 19 below is a histogram chart of the GEV fitting to the Washington 1871-2023 annual precipitation history (inset lists the GEV's three parameter values).

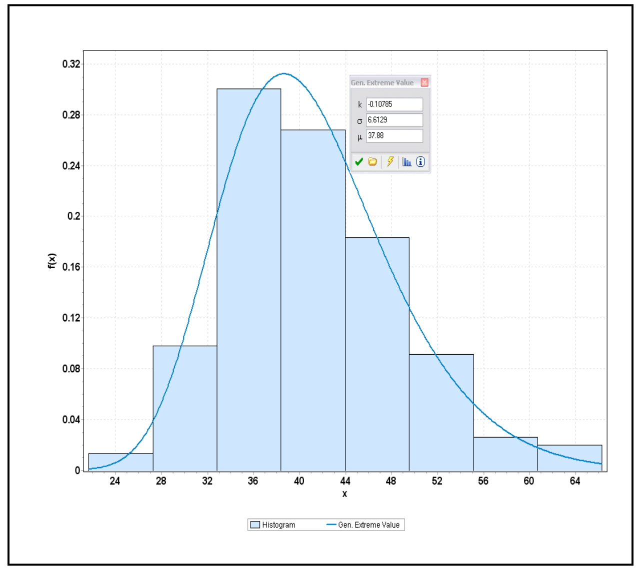

Figure 19 – Generalized Extreme Value Fitting (GEV) of Washington DC area Annual Precipitation Totals (1871-2023 Period of Record)

2.4. Climograms for Winds and Relative Humidity

Next, a sampling of climograms are presented that depict the mean seasonal/diurnal variabilities for Washington DC winds and relative humidities. These are based on hourly observations from the 1973-present period.

Figures 20-22 below present, respectively, Washington DC climograms for Mean Vector Wind Directions (otherwise known as resultant winds), Mean Vector Wind Directions combined with Mean Scalar Winds, and Upper 99th percentile extreme sustained wind speeds.

In the Figure 20 chart, Washington mean resultant wind directions, by month and hour, are plotted as arrow symbols, their corresponding "constancies" overlain in color . The constancies measure the degree of the mean vector wind direction's persistency from that direction on a scale of 0 to 100.

Calculation is performed by decomposing individual wind observations into their north/south and east/west components, adding the components, and then recombining their arithmetic averages into a single overall "mean vector wind" or "resultant wind". Since individual wind directions almost always show variability from observation to observation for a specified hour of interest, resultant wind speeds for that hour will be somewhat less that its' corresponding mean scalar wind speed (mean wind speed irrespective of direction). The ratio of the former to the latter multiplied by 100 measures vector wind “constancy”. Constancy values can range from 100 (individual wind observations unvarying in direction but not necessarily in speed) to 0 (individual wind observations canceling each other out exactly when added vectorially.

Interpreting some of the Figure 20 features, Washington DC south-southwesterlies show the maximum relative constancy, climatologically, for the June/July post-sunset hours, the red shading reflecting a ~40 magnitude. Another secondary feature is the afternoon mean north-westerlies in January and February, the orange shading portraying constancy values in the high 30’s. As these relative maxima, however, are somewhat modest magnitude-wise, they must be interpreted as reflecting general directional inclinations rather than preponderances. The same applies to a somewhat greater extent for all the hours in the climogram, mean constancy values only in the 20’s, Washington being in the heart of the mid-latitudes, where wind variability is a trademark feature.

In contrast, the blue low-constancy areas represent areas in which the directional character is transitional, climatologically, between contrasting wind regimes. For example, a blue colored area oriented predominantly vertically, would reflect a preferred diurnal changeover period, one horizontally oriented, a seasonal one. A case in point of the latter is the contrasting mean vector directions located above and below the horizontal blue (low) constancy area for September afternoons. The October mean vectors above are westerly, those for August are south-southwesterly.

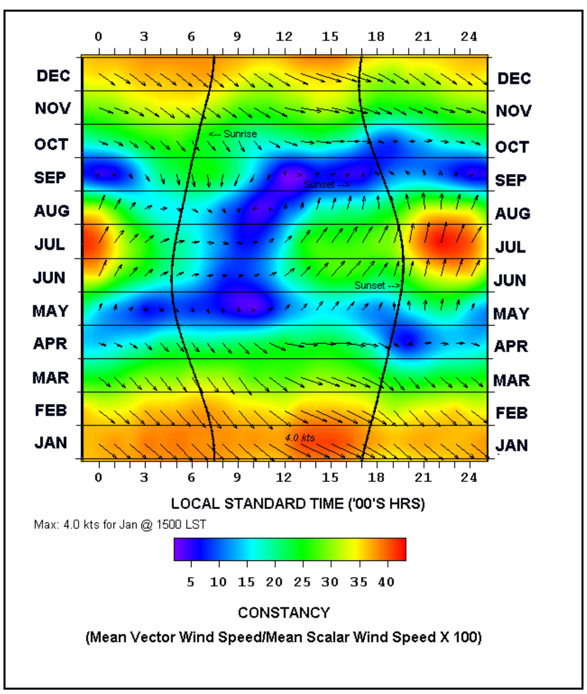

Figure 20 – Mean Vector Winds (Arrows) and Mean Vector Wind Constancies (Color) – Washington DC 1973-2023 Data

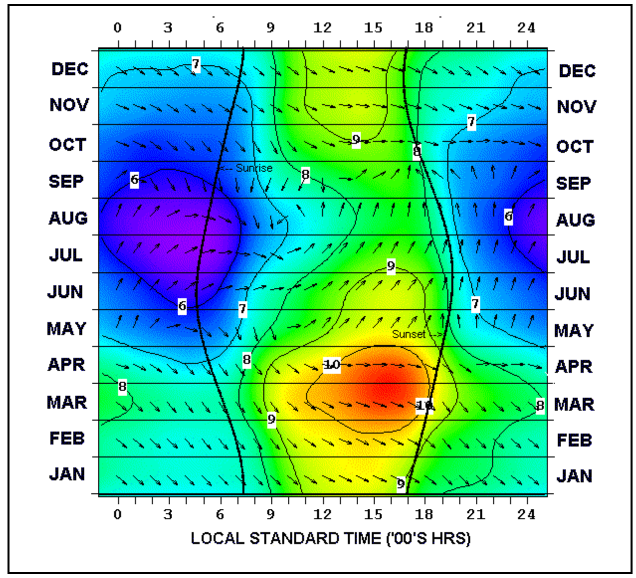

Figure 21 – Mean Wind Directions (Vectors) and Mean Overall Wind Speeds (Contours and Color) for Washington DC – Speeds in Knots – 1973-2023 Period of Record

Figure 21 overlays the Mean Vector Wind orientation icons of Figure 20 onto a color contour chart of Mean Scalar wind speeds, creating a more comprehensive but still compact presentation. The vectors are set to unit length, and are considered a sort of weighted average direction. For example, the vector shown for 1500 hours in March represents a northwesterly “average” direction at a speed somewhat higher than 10 knots, the red shading denoting the higher mean scalar speeds situated within the 10 knot contour.

Lastly for the winds, Figure 22 depicts the diurnal/seasonal patterns of upper 99th percentile wind speeds. The contours range from 13 knots, situated for those times an hour or so either side of sunrise in late July/early August, to 24 knots for the mid-afternoons in late March to early April, the familiar relatively blustery times of early Spring. The sunrise demarcation line frames the relative minima contours effectively.

Next, hour-by-month climograms were constructed for mean humidities (Figure 23), followed by one for extreme low humidities at the lower 1st percentile level (Figure 24). In Figure 23, the contour magnitudes range from 47 percent (mid-afternoon hours from mid-March to mid-April) to 82 percent for the near sunrise hours of August and September. In those for Figure 24, the relative configurations are situated similarly, the range being 55 percent (August) down to 17 percent for March to early April.

The parameters displayed above, of course, are just a few of the possibilities, others related to ceilings, visibilities, combinations of these, probabilities of extreme wind chill temperatures, and others lend themselves to this treatment.

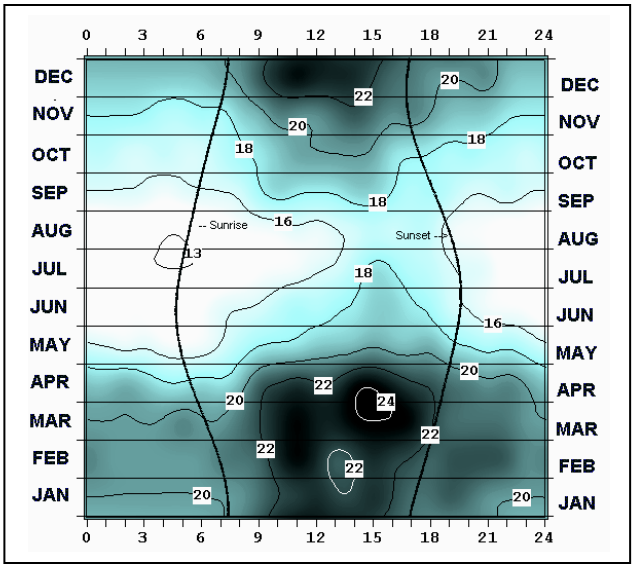

Figure 22 – Upper 99th Percentile Wind Speeds (kts) for Washington DC (1973-2023 Period of Record

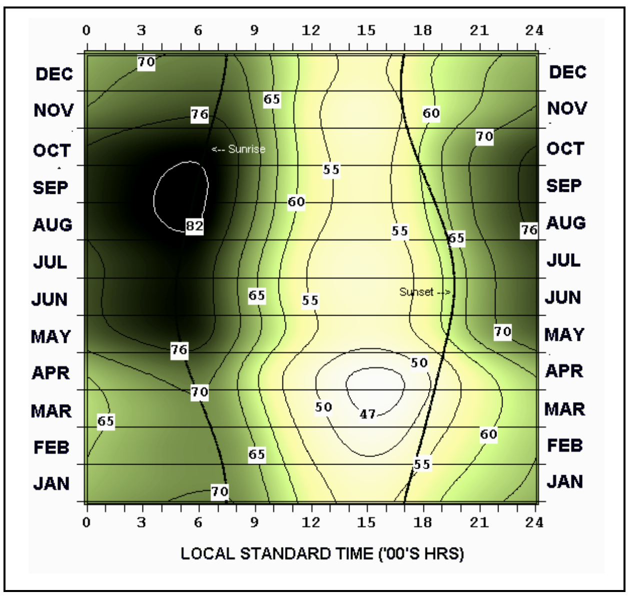

Figure 23- Mean Hourly Relative Humidities for Washington DC (1973-2023 Period of Record)

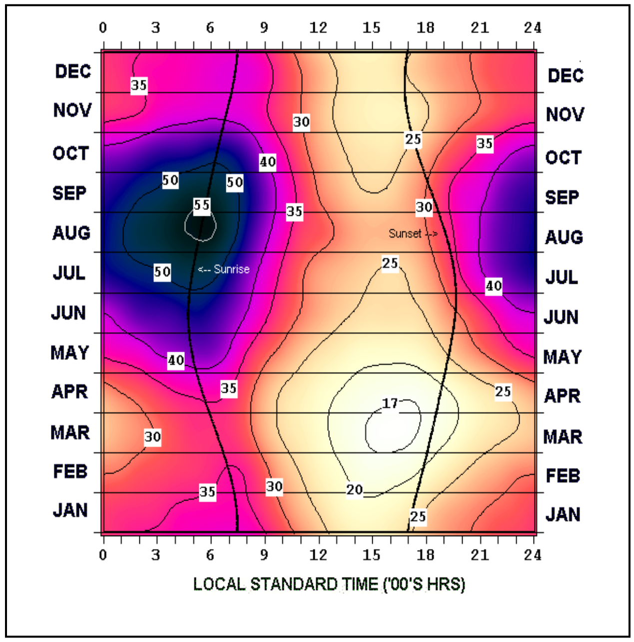

Figure 24. Lower 1st Percentile (Unseasonably Low) Relative Humidities for Washington DC (1973-2023 Period of Record)

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