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ART. XXXV.—*Daily March of the Wind Velocities in the United States*; by FRANK WALDO, Princeton, New Jersey.

[The following matter is extracted from a paper prepared by the writer for the Weather Bureau of the Agricultural Department, and is published with the kind permission of the proper authorities.]

IN the Appendix No. 14 to the Chief Signal Officer's Annual Report for 1890, the average wind movement is given, for a large number of stations, in miles per hour for each hour of the day (1 to 24), for each month of the year, and also the averages for all of the months of the seven years 1883–89.

This presents most valuable data and is certainly the most unique of the tabular compilations published by the Weather Bureau. Hitherto we have relied mainly on the papers published by Hann and Köppen for collected data concerning the daily period of wind velocities, and even in these there are comparatively few places of observation taken into account. The publication of such data as those which we are considering, from a large number of stations having a variety of immediate exposures, and distributed over so large a portion of an entire continent, furnishes material for a very complete treatment of the subject of hourly winds. The present paper is mainly devoted to a view of the conditions of the geographical distribution of some important phases of the daily march of the wind velocities. The material is sufficiently rich to serve as a basis for a number of similar and more complete investigations.

The hourly wind velocities as originally published are arranged according to synchronous hours of the 75th meridian time. It is inconvenient in that form for many kinds of inves-

tigation and so I have arranged the data for the four mid-seasonal months and for the year, according to the local times; and, moreover, have converted the published anemometer miles (with constant 3.00) into true miles by means of Marvin's Table published by the Signal Service. I have also grouped the stations geographically and not alphabetically as given in the original table of hourly winds. This table cannot be reproduced here on account of its length, but I may remark that the relations of the maxima and minima have been investigated; and in the unpublished table are given the amplitudes or ranges in miles per hour, the excesses and deficiencies in terms of the average, and the amplitudes in terms of percentage of the averages. An account of this will shortly appear in the *American Meteorological Journal*.

The curves showing the daily march of the hourly wind velocities for *January*, *July* and the *Year*, I have also drawn for individual stations, but these cannot be reproduced here on account of the expense of drawings. The characteristics of these curves show marked variations with changes of geographical position, as we should expect: and while the number of years of observations which have been employed, which for the most cases is 7, is not sufficient to remove all irregularities from some of the curves, yet in most cases a sufficiently good idea of the daily march is given. I have however given the curves for January and July for 20 stations more or less representative of the various sections of the U. S. See the curves and explanation of the diagram at the end of this paper. This material is of such importance that the curves deserve to be taken up for discussion for individual stations, but it is only possible, in the present instance, to treat them in groups. Without further preliminary remarks I will give the main characteristics of these curves in what seems to me to be a proper order. In counting the hours, midnight is given as 0^h. The wind velocities are given in miles per hour: written m. p. h. In mentioning the characteristics of these curves, it will be remembered that a sharp ascent or descent indicates a rapid change in the wind velocity from hour to hour; a flat curve indicates no change; a sharp crest or trough shows an extreme maximum or minimum of short duration, while when well rounded they indicate a period of several hours during which the conditions at these phases continue to prevail before the swing to the opposite phase sets in.

Atlantic Coast.—On the *exposed* Atlantic Coast (Curve 1) there is in *January* but a slight variation in the wind velocity from hour to hour during the whole day, the average wind being 15 or 16 m. p. h.; but for *July* there is a strongly defined maximum (12 or 13 m. p. h.) at about 16^h, and a mini-

mum (9.5 m. p. h.) at 4^h on the northern and 6^h on the Central Coast (7.5) and preceded in this last case by a slight secondary maximum at 3^h; while for the *Year* the maximum is well defined at 16^h on the northern (14.5 m. p. h.) and at 15^h on the southern (12.5 m. p. h.) coasts, and the minima occur at 0^h and 5^h for the former (nearly 13 m. p. h.) and about 22^h and 4^h for the latter (10.5 m. p. h.), and in both cases there is a slight secondary maximum at 3^h.

For the ordinary or partially sheltered Atlantic Coast stations (Curve 2) at which the land influence is strongly felt, there are in *January* well defined primary phases of max. (about 12 m. p. h.) and min. (about 9 or 10 m. p. h.), but the secondary phases are very weak and the curves become quite flat at these times. The max. phase becomes more marked with the southward progress from the north, not only on account of actual increase in the absolute height of the curves (which increase perhaps does not extend to places south of the Carolina Coast) but also on account of the fact that the crest of the curve becomes sharper and the rise and fall more abrupt. The daily curve during the hours of deficiency of wind (below the average) becomes more flattened out and of greater extent in the south. For *July* the upward swell of the curve is very much broader than for *January*, throughout the whole coast, but it is especially so at the south. The extreme maximum is more pronounced in all cases, but is most so at the north. At this season there is a remarkable similarity in the length of the swell of the curves (about 16 hours duration) throughout the whole coast.

For the *depressions* of the curves (i. e. periods of least wind) a greater irregularity is noticeable at the north, where slight secondary phases are visible.

For the *Year*, as might be expected, the curves possess characteristics between those for *January* and *July*; but they resemble the latter very much more closely than they do the former. The crest of the curve is, however, more rounded for the *Year* than for *July*; but the amplitude is not quite so great, nor the period of excess above the nearly level portion of the curve at the minimum quite so long, the latter for the *Year* being about half of the twenty-four hours.

Gulf of Mexico Coast.—The eastern, western, and north-western coasts are represented (Curves 3 and 4). For *January* there is but slight absolute change in the irregular curves for these three coast sections. The curves for the extreme eastern and western coasts are somewhat similar as to the times of the phases, but the early afternoon maximum (at about 15^h) is much more strongly marked in the west than in the east. In the northwestern part (Galveston, Texas) the amplitude is not

so great, and the ill defined crest is several hours earlier than in the other sections just mentioned.

For *July*, in the eastern part, a well defined and gradual but not excessive maximum rises above a fairly level period of deficiency, there being no strongly marked individual minimum; but in the northwestern part the maximum and minimum are very sharply marked, in each case the curve comes to a point, the amplitude is rather large for a coast exposure and the time of maximum (at 17^h) is considerably retarded as compared with that in the eastern part (at 12^h). In the extreme western part (at Corpus Christi) a curve of very marked peculiarities presents itself; it has a single rather sharply defined minimum of 5 m. p. h. at (5^h) about the same time as in the northwestern part, and a very high but round-crested maximum of nearly 15.5 m. p. h. (at 14^h to 18^h) with very steeply inclined sides which extend to the sharp angle of the minimum with as rapid a slope throughout the whole length as is ordinarily observed for inland stations at about (or a little after) the noon hour. It is seen that the whole amplitude of fluctuation thus becomes enormously great (over 10 m. p. h.).

For the *Year*, in the eastern and northwestern parts the maximum is well marked but the crest of the curve is very much flattened; and there is in both cases a nearly level minimum for about half of the twenty-four hours, with a rather steep but slight increase to a nearly level maximum which lasts for six hours. At the extreme west there is an open and very well rounded maximum and a well rounded minimum with a steep ascent, but with a more gradual descent connecting the two: the amplitude is about the same as that for an ordinary inland station.

The Great Lakes (Curve 5).—In *January* the curves are nearly all irregular, but the amplitudes of the irregularities are not great. The early afternoon maximum, although slight, is plainly marked in all cases: it is sometimes rounded and sometimes sharp-crested; that for the lesser absolute wind velocity being usually the more rounded, and that for the greater wind, which indicates a better water exposure, becoming sharper. The nearly flat minimum portion of the curve is usually somewhat lower for the hours succeeding midnight, than for the hours just preceding it. Secondary phases are quite plainly shown in some of the curves.

In *July* the max. is well rounded and strongly marked on all of the curves, and this period covers more than half of the twenty-four hours in most cases. When the minimum portion follows midnight it is in many cases a little higher than when preceding it, and is consequently somewhat of a reversal of the conditions for January. Secondary phases are not present.

For the *Year*, as is usually the case, the curves form a sort of mean between those for January and July. There is a nearly level min. period and a very well marked max.; this last with characteristics very similar to those for July. The period of the mid-day rise above the level minimum is about half of the twenty-four hours. Secondary phases are not noticeable.

Some peculiarities which distinguish the Upper from the Lower Lake Regions are mentioned farther along in their proper place among inland stations, and the above remarks are offered for comparison with those pertaining to the Gulf coast.

Pacific Coast (Curves 6, 7 and 8).—For *January*, at the *north* there is a nearly mid-day principal minimum, with a slight min. shortly after midnight, and with two nearly equal maxima from four to six hours before and after midnight; the changes are gradual and relatively small. On the *Central coast* the rise of the single max. above a somewhat level min. period is gradually accomplished in about twelve hours, the slope of the curve being gentle but the actual crest sharp. At the *south* a single early afternoon max. rises rapidly from a nearly level minimum; the slopes of the sides of the max. which separate to eight hours apart at the base are steep, and the actual crest slightly rounded. (On the high bluff at Cape Mendocino, near the center, the sharp crested max. occurs shortly after noon, and the sharp pointed trough of the min. at about midnight; and while the descent from the max. is steep and regular, the ascent is at first steep and then from 4^h to 11^h there is little change, then another steep ascent; the whole range being excessive and greater than that for mid-summer.)

For *July*, at the *north* there are both primary and secondary phases of max. and min.; but the secondary ones are slight, and the primary occur at nearly a reversal of the times for January, although the amplitude is slightly greater in July. On the *central coast* there is a single max. and min., but with an enormous amplitude. The crest is slightly rounded, but with a very steep slope, while the trough is more rounded, and the slope of descent becomes more gradual as the trough is approached. At the *south* there is a high max. with rather rounded crest, and steep sides, especially for the ascent; the curve for the period of minimum wind is quite flat during seven or eight hours, when the rise for the max. begins abruptly and finally ends nearly as abruptly. (The curve for the high bluff at Cape Mendocino, near the center of the coast, is quite similar in shape to that for the *south*, but the maximum is not quite so pronounced.)

For the *Year*, at the *north* the reversion of the phases noticed for January and July is such as to cause practically almost an erasure of the phases of max. and min., and the curve nearly becomes merely an irregular line with little variation of

level. For the *central coast* the curve is quite similar to that for July, but the phases are not so great in amplitude and the slopes of the max. are not so steep. At the *south* there is a well rounded max. which rises for half the day above a nearly level min. period; the whole curve exhibiting phases about half way between those for January and July.

At the high station of Cape Mendocino the curve for the first half of the day resembles that for July, while for the latter half of the day it is similar to that for January for the same hours; but the amplitudes are less than for those months.

Having mentioned the *Coast* regions, we now pass to the various *Inland* sections of the U. S.

Inland: Northeastern U. S. (Curve 9).—For *January* there is a well marked maximum rising, for about ten hours of the day, above an irregular min. period, which has in some cases faint secondary phases. The crest of the max. is fairly well rounded, but flattens out (showing less rapid changes) with progress southward.

For *July* the maximum period is above the nearly flat min. period for about fourteen hours; in most cases the crest is well rounded but it becomes flatter toward the south.

For the *Year* the minimum period is usually still more flattened out than in the cases just mentioned, and the maximum portions of the curves are nearly as pronounced as for July but do not extend over quite as many hours. The curves for the *Year* are unusually similar to those for July, and in each very little secondary influence is noticeable.

Southeastern U. S.—For *January* the maximum rise is well marked, but does not cover a period of over eight to ten hours, and the minimum is rather more regularly level than is usual in mid-winter. For the relatively high exposure at Atlanta (Curve 10) there is but slight absolute variation, although there is a noticeable max. succeeded almost immediately by a rapid descent to a narrow minimum.

For *July* the max. covers a wider period than for January, and is more strongly marked (except at Jacksonville), while the curve of descent becomes steeper and the max. retarded until a later hour. The minimum period is hardly as level as for January. At the high exposure of Atlanta a slight secondary minimum is present.

For the *Year* the maximum is well developed and the curve well rounded, with a gradual ascent and a slightly sharper descent, and extends for about twelve hours above the smooth, slightly sloping, minimum period. At the high exposure of Atlanta the curve resembles that for July but has a more rounded maximum with slight secondary phases.

Lower Mississippi River Region (Curves 11 and 12).—For *January* the curves are very irregular and suffer but slight

absolute changes; usually the max. occurs at 14^h to 16^h. The irregularity is greatest along the Mississippi River, at Vicksburg and Memphis, where the maximum is so slightly developed that the secondary maximum is nearly or quite as great as the primary; this is not due to the greater development of the secondary but the lack of development of the primary. For Vicksburg, the minimum has about the same absolute value in both phases, but for Memphis the afternoon minimum (at about 19^h) is slightly the lower of the two. On the lower Arkansas River, with a more east-westerly river exposure, the primary maximum at 13^h or 14^h is well developed, but the secondary phases are hardly perceptible, and the principal minimum is hardly to be distinguished since it is but little below the long, nearly level, period of minimum wind.

For *July*, there appears to be but a single well defined maximum culminating about the middle of the afternoon, at about 16^h, and a minimum is reached just before or about midnight. The slight traces of secondary phenomena can hardly be ascribed to other than accidental errors of exposure, etc.

The curves for the *Year* are very similar to those for July, but the amplitudes are not quite so great, and the minimum period is more nearly a uniform level. In all cases the descent from the culminating maximum is steeper than the ascent to it. The absolute maximum is at about 15^h and the minimum at or just before midnight.

Ohio River Region (Curve 13).—For *January* the maximum, at about 14^h, is well defined and with a rounded crest in some cases, and in others a pointed crest, but the slopes on either side are symmetrical. There is just a trace of a secondary maximum at some of the stations, which becomes best defined at Knoxville; while the minimum occurs for some of the stations before midnight, and for others after midnight, so that the usual times of both primary and secondary minima are represented in speaking of the principal minimum, and at Knoxville minima of about equal magnitudes occur for both primary and secondary phases.

For *July* the maxima are well developed, and usually with rounded, rather symmetrical crests; and the period of excess above the somewhat level period of deficiency is about fourteen or fifteen hours. The time of extreme maximum covers most of the afternoon hours, extending from 13^h or 14^h to 17^h or 18^h. There is but little more than a suspicion of a secondary maximum phase at about midnight, and although it can be noticed in some cases, yet it is entirely wanting in others. The minimum occurs a little before sunrise, and consequently just precedes the beginning of the ascent to the principal maximum.

For the *Year*, the maximum curves are remarkably symmetrical and have an absolute maximum at about 15^h, and while the amplitude is not quite so great as for July, yet the period during which the curve is above the very nearly level minimum is but little less than for July, and what shortening there is, is due to there being an earlier descent to the minimum level. The time of minimum is still in the early morning hours. Secondary phases are not noticeable.

Lake Region (Curve 5).—On the *Lower Lakes* for *January*, the curves are generally very irregular, but there is, in every case, a well defined, though short, principal maximum at about 14^h. The time of the principal minimum is variable; for Rochester and Cleveland it occurs only about four or five hours after the time of maximum, consequently at about 18^h, and for Buffalo, Detroit and Toledo it occurs shortly after or at midnight. Slight, secondary maxima occur for Rochester at about midnight; for Toledo two hours earlier, and probably for Cleveland at about 23^h.

For *July* a fairly well rounded maximum culminates at 14^h, but the time of minimum is by no means regular, for it occurs at about 4 hours before midnight in some cases, and 4 hours after midnight in others. In those cases in which the maximum is the best developed, the minimum occurs after midnight, both of which characteristics belong to the stations having greater land influence.

For the *Year*, a moderately sized maximum with gentle, regularly sloping, sides culminates at about 14^h. The minimum period covers about half the twenty-four hours, and the absolute minimum follows closely the relations just given for July, but the absolute change is so much smaller than for that month that the whole minimum period varies but little from a fixed level.

For the *Upper Lakes* for *January* there is a principal maximum at times varying from 12^h to 15^h and the crest is the more pointed, the better the water exposure. While the principal minimum occurs in the early morning hours (4^h and 8^h) for most of the stations, yet at Duluth a secondary minimum occurs at 17^h or 18^h, and this is of the same magnitude as the primary. The minimum period is very irregular and broken in all cases, and there are traces of secondary phenomena, which are well marked only in the case of Duluth, where the maximum nearly equal to the primary occurs near, or shortly before, midnight, and the minimum as just mentioned.

For *July* there is a well marked, rather rounded maximum at 15^h in most cases, but at 14^h at Alpena, with minimum at about 3^h for Alpena and Chicago, but with the principal minimum just before and at midnight at Milwaukee and

Duluth. For these last mentioned places a secondary maximum occurs at 3^h or 4^h and a second minimum at about 6^h, while for Duluth there is a slight tertiary maximum at 22^h and minimum at 20^h. For the early hours of the descent from the maximum the slope is steeper than in the ascent.

For the *Year*, the maxima of the curves are nearly as well developed as for July, but the amplitude is not quite so great, and the period that the maximum is above the nearly level minimum period is only about 12^h, which is less than for July. In most cases the minimum occurs at about 3^h or 4^h, but the whole minimum period is nearly the same, although for Milwaukee it is very irregular, and secondary phases are probably present.

Upper Mississippi River Valley Region (Curve 14).—For *January* there is a rather sharp-crested narrow maximum rising for about 9^h above a somewhat irregular though level minimum period, and having a small amplitude. The minimum usually occurs at about sunrise, although a near approach to the absolute minimum occurs at about sunset or a little later. Traces of secondary phenomena are present about three hours after midnight for Dubuque, and three hours before midnight for Keokuk. At the high exposure of St. Louis there is a low flat-crested maximum during the time from 9^h to 15^h and a secondary sharp-crested maximum of nearly the same amplitude at midnight; the principal minimum is at 18^h and secondary at about 6^h. The extreme amplitude is very slight, during the whole month.

For *July* there is a well developed maximum at from 14^h to 16^h and in most cases a secondary maximum at about midnight (sometimes a little before, and sometimes a little later). The times of minima are variable but usually at 6^h and 21^h, or a little later; in some cases the first is the primary and in others the secondary. The secondary phases are slight in comparison with the primary.

For the *Year*, there are well developed maxima at about 14^h and very slight secondary maxima at St. Louis, at or just before midnight. The minima occur at or about daybreak, with very slight secondary minima at St. Louis at 20^h. The minimum period is quite level. Secondary phases are hardly noticeable except at St. Louis.

Great Plains (Curves 15 and 16).—For *January* in the north, the maximum period culminating at 13^h or 14^h or 15^h is short (about 8^h above minimum level), but well marked; and the main minimum is at from 5^h to 8^h. Most of the stations show secondary maxima, near midnight, and secondary minima at about 18^h or 19^h and of nearly equal level with the principal minima. In the *south* the principal maximum extends over a longer period and is more flattened at the

crest, which reaches from about noon to four hours after, but has not a greater amplitude than in the north. Secondary maxima rather better marked than usual are present, just before midnight at Abilene and Palestine; and the secondary minima for these stations at 18^h and 20^h are a little *lower* than those at about sunrise in the morning, so that the secondary phase really becomes the primary in these cases.

For *July*, the maxima culminating at 14^h or 15^h are large and well rounded, with the exceptions of Abilene and Palestine which have flat irregular crests; and the curve of the minimum is a sharply defined trough (at 5^h or 6^h) in some cases but rather flattened out in others, no law appearing to hold good. Secondary phases are present except in the extreme south, and in Dakota. At Palestine the usual secondary minimum is lower than the primary, and so in this case becomes the primary. Abilene and Palestine have flattened irregular crests at the principal maxima, and these show a slight recession at about noon.

For the *Year* the curves are quite similar to those for July except that the maximum period (culminating at 14^h or 15^h) is not so long or the amplitude so great. The minimum is at 5^h or 6^h. Secondary phases are lacking or are barely perceptible, except at Palestine, where the usual secondary minimum is so low as to really become the primary. The crest of the maximum is much flattened out at the south, showing little change for several hours about noon and later.

Great Plateau (Curves 17, 18, and 19).—For *January* at the *south*, there is a single abrupt, narrow, steep sided, but slightly round crested maximum with level or slightly sloping minimum but no secondary phases; near the *center* there is still a principal though less marked maximum, varying from 12^h to 16^h, and usually secondary or even tertiary phases. While the minima are about equal, yet the customary secondary minimum phases (in the early evening) are usually slightly the lowest and thus become the primary. At the high station of Winnemucca the curve is irregular and has three sets of phases; while at the *north* the curves have relatively slight amplitudes and are irregular, having at least two sets of phases, and the usual secondary minimum becomes the primary in about half the cases.

For *July*, in the *south*, the maximum (at 14^h or 15^h) becomes relatively great in Central Arizona, but is not usually large elsewhere, while a sharply defined minimum occurs at 6^h to 8^h; and but single phases occur where the amplitude is so excessive, while for the other stations secondary phases occur, but the minimum at about sunrise remains the primary minimum with a single exception, in which case the minimum occurs at midnight. Near the *center* the maximum period (culminating at

15^h to 17^h) is of rather long duration but the amplitude is not excessive, and the principal minimum occurs at about 6^h to 8^h. The high station of Winnemucca is the only one with pronounced secondary phases. In the *north*, the characteristics of the curves are similar to those near the center, except that at Ft. Assiniboine and Helena there is a secondary minimum at 21^h to 22^h and maximum at 24^h.

For the *Year*, in the *south*, the maxima (culminating at about 15^h) are about an average between those for January and July, and a single minimum occurs at 6^h or 8^h, except for Phoenix which, as in July, has an absolute minimum in the afternoon: the minimum period is rather level. Near the *center*, but a single moderately sized maximum occurs at about 15^h and the minimum is at 6^h to 8^h. Winnemucca has two maxima, a slight secondary one near midnight; and the morning minimum, although it remains the primary, is not much different from the secondary. At the *north*, the maxima are usually fairly well marked (crest at about 15^h) and cover a long period with no secondary phases except at Ft. Assiniboine.

The curves (p. 442) showing the daily march of the wind velocities for January and July for characteristic stations of twenty regions in the U. S. are numbered from 1 to 20 and the following list will identify stations by name:

	Daily Wind, miles per hour.							
	JANUARY.				JULY.			
	At 0 ^h .	Max.	Min.	Daily average.	At 0 ^h .	Max.	Min.	Daily aver.
1. Block Island,	15.9	16.8	15.5	16.2	10.4	12.7	9.7	10.9
2. New York City,	10.0	11.5	9.7	10.4	6.6	9.1	5.7	7.3
3. Key West,	11.1	11.7	9.9	10.8	8.8	11.1	8.8	10.3
4. Corpus Christi,	10.1	10.4	11.8	9.4	12.6	15.7	11.5	13.7
5. Cleveland,	10.7	12.0	10.2	10.9	7.8	8.4	5.1	9.0
6. Tatoosh Island,	16.6	17.0	15.3	16.4	8.8	8.2	5.9	7.1
7. San Francisco,	5.2	7.7	5.0	6.2	8.9	17.9	6.7	11.4
8. San Diego,	4.3	8.4	3.5	5.1	2.8	10.7	2.8	5.8
9. Albany,	5.9	8.5	5.3	6.6	4.2	8.0	3.6	5.6
10. Atlanta,	10.3	11.2	9.4	10.5	6.5	7.8	6.1	6.8
11. Little Rock,	5.6	6.9	5.3	5.9	2.4	6.3	2.3	4.1
12. Vicksburg,	6.8	7.4	6.2	6.7	4.0	6.2	3.8	4.7
13. Louisville,	8.4	9.7	8.1	8.9	4.0	8.4	3.8	5.7
14. St. Paul,	5.2	7.2	5.1	5.8	3.9	8.2	3.9	5.6
15. North Platte,	0.9	9.7	6.4	7.5	8.2	10.6	6.5	8.8
16. Palestine, Texas,	8.7	10.5	8.3	9.3	6.7	7.9	5.4	6.8
17. Ft. Apache,	4.6	9.2	3.3	5.3	4.4	10.1	2.9	6.0
18. Salt Lake City,	4.0	6.0	3.7	4.5	4.5	8.9	2.8	5.7
19. Ft. Custer,	6.4	7.5	6.4	6.7	6.3	9.3	4.7	6.9
20. Roseburgh,	2.5	4.6	2.5	3.0	1.5	8.1	1.3	4.0

In the little table are given for January and July the wind in miles per hour at 0^h (midnight), at the time of maximum and minimum wind, and for the average of all the hours of the day.

These curves begin and end at 0^h (midnight) and are all in the same scale. At the top of the diagram giving the curves the two hour spaces are indicated by short lines, but the miles per hour have been indicated only in general by vertical scales

at the sides of the curves because it would make the reproduction of the diagram less simple to place the scales properly opposite each curve. The miles per hour of wind at 0^h is given at the beginning of each curve.