XIII. *Obſervations on the Annual Evaporation at* Liverpool *in* Lancaſhire; *and on Evaporation conſidered as a Teſt of the Moiſture or Dryneſs of the Atmoſphere. By Dr.* Dobſon *of* Liverpool. *Communicated by John* Fothergill, *M. D. F. R. S.*

Read Feb. 13, 1777.

THE quantity of rain which falls during the courſe of the year, is a very uncertain teſt of the moiſture or dryneſs of any particular ſeaſon, ſituation, or climate. There may be little or even no rain, and yet the air be conſtantly damp and foggy; or there may be heavy rains, with a comparatively dry ſtate of the atmoſphere. The ſame depth of rain will likewiſe produce different effects on the air, according as it falls upon a flat or hilly country; for large quantities ſoon quit the hills or high grounds, while ſmaller quantities have more laſting and powerful effects on a flat country. Much alſo depends upon the nature of the ſoil, whether clay or ſand, whether firm and compact, or looſe and ſpungy.

Is not evaporation therefore a more accurate teſt of the moiſture or dryneſs of the atmoſphere, than the quantity of rain?

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It is well known, that air is an active ſolvent of water, and that its powers of ſolution are in proportion to its dryneſs. It is likewiſe well known, that in chemical ſolutions, the action of the *menſtruum* is greatly promoted by heat and agitation. If the temperature of the air then, and the ſtate of the winds, be aſcertained, which in the preſent caſe denote the heat and agitation of the *menſtruum*, the evaporation will be the true index of the dryneſs of any particular ſeaſon, ſituation, or climate.

To determine the annual evaporation in the neighbourhood of Liverpool, I procured two well-varniſhed tin veſſels; one of which was to ſerve the purpoſe of a rain-gage; the other was to be employed as my evaporating veſſel. The evaporating veſſel was cylindrical, twelve inches in diameter and ſix inches deep. The rain-gage conſiſted of a funnel twelve inches likewiſe in diameter, the lower end of which was received into the mouth of a large ſtone-bottle; and, to prevent any evaporation from the bottle, the pipe of the funnel was ſtopped with a grooved cork. Theſe veſſels were placed in the middle of a graſs-plot, on a riſing ground adjoining and immediately overlooking the town, about ſeventy-five feet above the level of the ſea, and with a free expoſure to the Sun, winds, and rain. The cylindrical veſſel was filled with water within two inches of the

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top; and if, in conſequence of heavy rains, there was danger of its overflowing, a quantity of water was taken out; but if, in conſequence of long drought, it ſunk lower, a quantity of water was then occaſionally added; and theſe additions or ſubtractions were carefully regiſtered. At the end of every month, the depth of rain was firſt calculated; and, as each veſſel received the ſame depth of rain, I had only to examine the quantity of water which had been added to, or taken out of, the evaporating veſſel, and the evaporation of the month was aſcertained.

The firſt column of the following tables points out the mean temperature of the air at two in the afternoon. The ſecond, the character of the month with reſpect to the winds, the number of dots expreſſing their ſtrength; and, to make this part tolerably accurate, daily obſervations on the winds were marked down, and the character of the month formed from a general ſurvey of theſe obſervations: our winds are Weſterly for near two-thirds of the year. The third column points out the evaporation of each month in inches and decimal parts of an inch. The fourth, the depth of rain during each month. And the fifth, the ſtate of the ſeaſons, E being prefixed to the evaporation of the whole three months, R to the rain, and T to the mean temperature.

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It is to be obſerved, that in making theſe experiments, 251 grains were allowed for every cubic inch of water; and that three pounds and twelve ounces of water give a depth of one inch on a circular area of twelve inches diameter.

TABLE I.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1772.

Months.	Temp.	Winds.	Evaporat.	Rain.	Seaſons.
January	38	. . .	1.27	3.26	E. 4.87
February	39	. . . .	1.25	2.35	R. 7.23
March	44	. . .	2.35	1.62	T. 40.
April	48	. .	2.53	1.85	E. 11.40
May	57	.	4.25	3.42	R. 8.39
June	67	. .	4.62	3.12	T. 57.
July	70	. .	5.53	1.59	E. 13.20
Auguſt	68	. .	5.35	3.65	R. 11.29
September	62	.	2.32	6.05	T. 66.
October	60	. .	3.18	3.42	E. 6.46
November	50	. . .	2.15	4.85	R. 10.48
December	44	. .	1.13	2.21	T. 51.
	54		35.95	37.39	

TABLE

TABLE II.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1773.

	Temp.	Winds.	Evaporat.	Rain.	Seaſons.
January	44	. . . .	1.85	3.15	E. 5.74
February	42½	. . .	1.13	2.37	R. 6.17
March	50	. . .	2.76	0.65	T. 45.
April	54	. . .	2.89	2.47	E. 9.34
May	57	. .	3.79	4.56	R. 8.35
June	64½	.	2.66	1.42	T. 58.
July	67	. .	4.92	1.32	E. 14.02
Auguſt	70	.	5.75	2.21	R. 10.08
September	60	. .	3.35	6.55	T. 65.
October	55	. . .	2.79	4.57	E. 5.49
November	47½	. . .	1.15	6.69	R. 15.58
December	41½	. . .	1.55	4.32	T. 48.
	54½		34.59	40.18	

TABLE III.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1774.

	Temp.	Winds.	Evaporat.	Rain.	Seasons.
January	37	. . .	1.38	4.43	E. 5.92
February	$45\frac{1}{3}$	. . . .	1.67	2.42	R. 8.23
March	$49\frac{2}{3}$	. . .	2.87	1.38	T. 44.
April	$54\frac{1}{2}$	. . . .	4.56	2.23	E. 12.39
May	$59\frac{1}{2}$	. . .	4.31	1.65	R. 7.14
June	63	. .	3.52	3.26	T. 59.
July	$66\frac{2}{3}$	. . .	4.97	2.68	E. 13.51
Auguſt	67	. .	4.52	2.36	R. 10.56
September	$61\frac{1}{3}$	. .	4.02	5.52	T. 65.
Octobr	57	. .	1.95	1.68	E. 4.82
November	$46\frac{1}{3}$	. . .	1.12	2.69	R. 6.00
December	$41\frac{3}{4}$	. .	1.75	1.63	T. $48\frac{1}{3}$.
	54		36.64	31.93	

TABLE IV.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1775.

	Temp.	Winds.	Evaporat.	Rain.	Seaſons.
January	$44\frac{1}{2}$	. . .	1.51	3.21	E. 7.10
February	49	. . . .	3.02	4.62	R. 10.28
March	$48\frac{1}{2}$	. . .	2.57	2.45	T. $47\frac{1}{3}$.
April	$57\frac{5}{8}$	. . .	3.21	1.01	E. 15.09
May	61	. . .	5.02	0.85	R. 3.98
June	$70\frac{1}{2}$	. . .	6.86	2.12	T. 63.
July	$68\frac{1}{2}$	. .	5.03	5.31	E. 12.50
Auguſt	$66\frac{1}{2}$	. .	4.42	4.26	R. 12.57
September	65	. .	3.05	4.00	T. $56\frac{1}{3}$.
October	$54\frac{1}{2}$	. . .	2.12	7.01	E. 5.27
November	45	. .	1.63	3.03	R. 13.39
December	$48\frac{1}{3}$	. .	1.52	3.35	T. $49\frac{1}{3}$.
	54		39.96	40.22	

OBSERVATIONS.

1. It is evident from theſe tables, whether we attend to ſeparate months, ſeaſons, or years, that the depth of rain is a very erroneous index of the moiſture or dryneſs of the atmoſphere. On comparing the two months July and Auguſt of the year 1772, it appears that the tem-

perature of the air, the ſtate of the winds, and the evaporation, were nearly the ſame during theſe two months, and yet the rain of Auguſt was more than double that of July. The reaſon why the greater quantity of rain had no more effect than the ſmaller in adding moiſture to the atmoſphere, is obvious; for on conſulting my regiſter I find, that the rain of Auguſt fell in heavy ſhowers, and ran off the ground before it could be evaporated; while that of July, falling in ſmall drizzling ſhowers, gave more time for its evaporation.

Again, the temperature of the air, the ſtate of the winds, and the evaporation, were nearly the ſame during the firſt three months of the year 1773, with what they were during the laſt three months of that year; the ſtate of the air therefore, with reſpect to moiſture and dryneſs, muſt have been the ſame during theſe two ſeaſons; and yet the depth of rain, in one of theſe ſeaſons, was much more than double what it was in the other. If we attend to whole years the ſame obſervation is confirmed. The rain of 1775 exceeded the rain of 1774 more than eight inches; and hence it might be concluded, that the atmoſphere was more moiſt in 1775 than in 1774; the reverſe of this, however, is found to be the fact: for there evaporated from a conſtant and determinate ſurface of water in 1775, full three inches more

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than evaporated from the same surface of water in 1774. Consequently the dryness of the atmosphere or its power of solution, during the year 1775, exceeded that of 1774.

2. If we take the medium of four years observations it appears, that the annual evaporation at Liverpool amounts to 36.78 inches.

Dr. HALLEY observed at London, that water placed in a close room, where neither the winds or Sun could act upon it, exhaled only eight inches during the whole year. He makes no doubt but that the free access of the winds would have trebled the quantity carried away; and that this again would have been doubled by the assistance of the Sun. Dr. HALLEY, therefore, fixes the annual evaporation of London at 48 inches [a]. If this calculation be admitted, it follows, that the annual evaporation of London exceeds the annual evaporation of Liverpool 11 inches; but were the experiments to be made in London, in the same circumstances with those made at Liverpool, it is probable, that this would be found to be more than the real difference.

The learned CRUQUIUS observed at Delft in Holland, that there exhaled from water set in the open air, but in a calm and shady place, about 30 inches; and it is not to

(a) Phil. Transf. N° 212.

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be doubted, ſays Dr. BROWNRIGG in his very valuable work, *The Art of making common Salt*, but that double this quantity, or 60 inches, would have exhaled, had it been placed where the Sun and winds could have had their due effects[(b)]. In another part of this publication, Dr. BROWNRIGG fixes the evaporation of ſome parts of England at 73.8 inches during the four ſummer months, May, June, July, and Auguſt; and the evaporation of the whole year at upwards of 140 inches[(c)]. Theſe are calculations, however, which do not appear to correſpond with experience; for the whole evaporation at Liverpool, inſtead of 140 inches, was only 36.78 inches. The evaporation likewiſe of the four ſummer months, on a medium of four years, inſtead of 73 inches, was only 18.88 inches.

3. Dr. HALES calculates the greateſt annual evaporation from the ſurface of the earth in England, even that from a ſurface of hop-ground, at 6.66 inches[(d)]. If we compare this with the annual evaporation from a ſurface of water as determined by experiment, we find, that the latter exceeds the former about 30 inches; and that the annual evaporation from a ſurface of water, is to the annual evaporation from the ſurface of the earth in this part of England, nearly as 36 to 6, or as 6 to 1.

(*b*) Page 185. (*c*) P. 189.
(*d*) Veg. Stat. vol. I. p. 55, 56.

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4. On comparing the depth of rain with the annual evaporation of this part of Lancaſhire we find, that more falls in rain than is raiſed in vapour, even though the whole were a ſurface of water; for the rain is to the evaporation as 37.43 inches to 36.78 inches: and we farther find, that the quantity exhaled from the ſurface of the earth is little more than a ſixth part of what deſcends in rain; we muſt therefore have very large ſupplies from other regions, from the ſurrounding ſea, and from the ocean of warmer climates. Hence we ſee, why our South and South-weſt winds are ſo often accompanied with rain; for as the air ſweeps along the warmer latitudes, it involves a large proportion of moiſture, which is conſtantly and copiouſly exhaling from the ocean; and this moiſture being retained in a ſtate of ſolution till it reaches the colder climates, is then either collected in clouds or immediately precipitated in rain, according to the different conditions of the atmoſphere.

Theſe foreign ſupplies, however, are uniformly reſtored to the ſources from which they were derived: for that proportion of rain which riſes not in vapour, after moiſtening and refreſhing the earth, forms ſprings, brooks, and rivers, and is thus perpetually returning to the ocean whence it was taken; ſo truly philoſophical are the words of the preacher when ſpeaking of this vaſt circulation:

circulation: "All the rivers run into the ſea, yet the ſea "is not full: unto the place from whence the rivers "*come*, thither they return again."

5. About a century ago, the ingenious Mr. TOWNLEY, of Townley in this county, made ſome accurate obſervations on the depth of rain which fell annually in the neighbourhood of the hills which divide Lancaſhire and Yorkſhire; and on taking a medium of fifteen years, he determines it to be 41.516 inches[(e)]. The depth of rain, therefore, at Townley exceeds the depth of rain at Liverpool about four inches. This is probably, however, leſs than the real difference; for there was a ſource of error in Mr. TOWNLEY's experiments with which the world was not at that time acquainted. Mr. TOWNLEY's rain-gage was fixed full ten yards above the ſurface of the earth[(f)]; which circumſtance, according to ſome later obſervations, makes a very material difference in the reſult of the experiment[(g)]. Were the obſervations to be repeated at Townley, and the rain-gage placed upon the ground, there can be no doubt but that the depth of rain would conſiderably exceed 41.516 inches; for I find from a great number of experiments, made during the laſt three

(*e*) Phil. Tranſ. abridged by Lowthorp, vol. II. p. 46. (*f*) Ibid.
(*g*) Phil. Tranſ. vol. LIX. art. 47.

years

years with two veſſels of equal dimenſions, one placed on the ground, and the other eighteen yards higher on the battlement of the hoſpital; that the quantity received in the lower veſſel exceeds that in the higher more than one-third and leſs than one-half.

6. An ingenious friend, on peruſing theſe obſervations, aſked, "Whether the fact of evaporation going on "equally well in an exhauſted receiver, was not an un-"ſurmountable objection to that theory concerning eva-"poration, which ſuppoſes a chemical ſolution of water "in air?" With a view to aſcertain this fact I made the following experiment.

Two china ſaucers, each containing three ounces of water, were accurately weighed. One of them was placed in the open air; the quickſilver in the thermometer ſtood during the experiment between 48° and 50°, the day tolerably clear with a moderate breeze. The other was put under the receiver of an air-pump; the air was exhauſted, and the piſtons occaſionally worked, to draw off any of the water which might be ſuppoſed to be converted into vapour. After four hours the ſaucers were again accurately weighed; that in the open air had loſt one drachm and eight grains; the weight of the other was not ſenſibly diminiſhed.

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From this experiment it appears, that air is a chemical ſolvent of water, and as ſuch is undoubtedly to be conſidered as one cauſe of the evaporation of water. Heat is another cauſe of evaporation, and when raiſed to a ſufficient degree may produce this effect without the intervention of air, and the evaporation conſequently go on copiouſly in an exhauſted receiver, agreeably to the experiments of the ingenious Dr. IRVING(i).

The following obſervations are added as a farther illuſtration of this ſubject. Water may exiſt in air in three different ſtates. 1. In a ſtate of perfect ſolution. 2. In a ſtate of beginning precipitation. Or, 3. Completely precipitated, and falling in drops of rain.

In the firſt inſtance, where the water is in a ſtate of perfect ſolution, the air is clear, dry, heavy, and its powers of ſolution ſtill active, though it already contains a conſiderable proportion of water. In the ſecond, the air becomes moiſt, foggy, its powers of ſolution are diminiſhed, and it becomes lighter in proportion as its water is depoſited. It is a ſingular and well-atteſted fact, that it never rains in the kingdom of Peru; but that during part of the year the atmoſphere is conſtantly obſcured with

(i) Phipps's Voyage to the North Pole, p. 211.

vapours, and the whole country involved in what they call *Garuas*, or thick fogs[i].

It is not neceſſary to point out the cauſes which thus diſpoſe the air to depoſite its diſſolved water; nor to conſider with what bodies air hath a ſtronger affinity than with water; neither to inquire how far the electrical fluid is engaged in the proceſs. It is ſufficient to obſerve, that ſo long as theſe cauſes have a general action on the air, they diminiſh its powerof ſolution, and give a damp and foggy ſtate of the atmoſphere; that when they operate for a conſiderable proportion of the year, they produce a moiſt climate; and that when they more generally do not, and the air retains its moiſture in a ſtate of perfect ſolution, the climate is dry. Conſequently, that the moiſture or dryneſs of a climate, do not ſo much depend upon the abſolute quantity of water which is contained in the air, as upon the air being in a ſtate of perfect or imperfect ſolution. During long continued ſummer droughts, a very large proportion of water is diſſolved in the air; notwithſtanding this, the air is ſtill dry, and continues to be ſo as but as the water remains in a ſtate of perfect ſolution; long no ſooner are the powers of ſolution diminiſhed, than what was before a dry, now becomes a moiſt climate.

(*i*) D'Ulloa's Voyage to South America, vol. II. p. 69.

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In the third inftance, the diffolved water may be either flowly precipitated and fall in drizzling rain, or it may be more powerfully difcharged in brifk rain; or there may be partial and fudden precipitations from particular regions, while other parts of the atmofphere ftill retain their water in a ftate of perfect folution. Heavy thunder-fhowers are the moft remarkable inftances of partial, fudden, and copious precipitations.

Liverpool, Nov. 20, 1776.