THE OBSTACLES TO THE PROGRESS OF METEOROLOGY.¹

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LET not this title produce an unfortunate impression. I am not a pessimist. I see the great work that meteorologists still have before them and that their motto must be that of every student: "*Nil desperandum. Labor omnia vincit.*" Man must never despair.

We have all been so long accustomed to fairly accurate and very useful daily weather forecasts that we begin to look for perfection in long-range predictions. Let us be optimistic and believe that eventually these will come.

In addressing you many years ago I told you of the good work done by your own Franklin and Espy, and I spoke cautiously, but hopefully, of the future progress of our knowledge of the weather and of the atmosphere. In those days of small beginnings I assured those who wished for perfect long-range predictions that not only were they impossible at that time, but that mankind was not yet ready for them; they would do more harm than good, they would frighten more than they would help. But when the world is ready for them and able to profit by the truth, the whole truth, and nothing but the truth, then men will be found able to make forecasts as accurate as any one may desire.

All this is still true. In those days we dared only to speak of probabilities—now we say forecasts—but we are not yet justified in making predictions as to precise details of future local weather, such as the astronomer makes relative to the stars, or the electrician or the engineer makes as to the behavior of his machinery.

Why is it that our progress has been so slow? We have not been idle. Other nations have not done better or gone ahead

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of us. The trouble lies largely in the inherent difficulty of our problems and the comparative complexity of our atmospheric conditions. It is a common saying that the more we study the atmosphere the more complex it seems; perhaps it is not yet clearly apprehended in its entirety. Just as a young student of medicine takes to pieces an ideal mannikin and is astounded to realize the very complex structure and still more complex physiology of the human body, so is the meteorologist amazed as the difficulties of the problem before him open up in his daily work. In 1846, Loomis, Redfield, Espy, and Bache assured Professor Henry that the time was at hand for the possible prediction of our storms with the help of the Morse telegraph. In 1854 he began this work at the Smithsonian Institution, and in 1868 I took it up anew at Cincinnati, but we never promised perfect work immediately, nor indeed within a lifetime. Filled with faith in nature and man, we could only *begin* the work. We knew that the perfect fruition of our labors must be left to future generations and future centuries. You yourselves may not see it all in your day, but it will surely come to us—as it has come to astronomy, optics, chemistry, and many other branches of knowledge. A work has been begun that the world will not willingly let die.

During past centuries students have given great attention to *climatology*, the average pressure, temperature, and rain, the average winds, and even the climatic diseases that affect the life and health of animals and plants. These matters form the special features of each locality. If the average temperature should vary from century to century we might recognize a steady cooling or a periodic variation, and we would feel justified in making a corresponding forecast for the century to come. But in fact no such periodic variations have as yet been satisfactorily demonstrated. There are indeed thought to be a so-called eleven-year period corresponding to sun spots, and a longer period in temperature, called Brückner's period of thirty-five years—but the variations in temperature during these periods are too slight and as yet too uncertain to neutralize my previous statement. Why can we not definitely establish the existence of such periods in our local climates? Why? Possibly they do not exist; but even if they do exist, they are so completely covered up by the defects of our own observations and records that it would

require many thousands of such records as we have to assure us that their inherent uncertainties counterbalance each other, and that a computed period exists in nature and is not a mere appearance due to our fumbling with figures.

In general, throughout the world, observations have been at fault because instruments have been faulty, or exposures have been changed by the growth and disappearance of buildings and trees. Change after change prevails in all human matters, and such changes affect the work of the climatologist. It is hard to detect minute periods when the records at any one spot are usually kept up for only a few consecutive years and then a new observer, at a new nearby location, with new apparatus, and possibly with new hours and new methods, takes up the work.

Illustration (1). We have a long record of temperature and weather in this very city at the Pennsylvania Hospital. From the annual means of this record we may deduce several interesting coincidences and relations, correspondences and periodicities during past years, but every attempt at accurate forecasts of temperature, either daily, monthly or annual, based on these simple statistics turns out to be elusive—and this is true in all other cases that I know of. The errors of apparatus and changes of exposure combining with the irregularities of temperature are larger than the forecasted changes and the latter turn out to be unsatisfactory.

Illustration (2). About 1820 the German meteorologist H. W. Brandes excited a new interest in forecasting by compiling a few daily maps of the meteorological conditions throughout Europe. His work was equivalent to showing that large areas of land must be considered in all meteorological studies; this is the principle now adopted in all modern forecasting.

Illustration (3). Thus when the question of the possibility of changes on the earth corresponding to spots on the sun, was discussed by Koeppen in 1881 he compiled his data for the whole world, especially the northern hemisphere, and for all the years of accurate record since 1640 and even then Koeppen found no relation except one. The elusive nature of even this one has been demonstrated by Schuster, who shows it would require far more and far better material than Koeppen had to establish any sun spot influence. Prof. Simon Newcomb's work on this sub-

ject seemed to show that the influence of the sun's spots, or his general spottiness, on the temperature of the earth is insignificant; and yet there can be no doubt but that there is a general suspicion or belief that the solar spots have some relation, direct or indirect, to all terrestrial phenomena.

Illustration (4). As with the sun spot periods so also with lunar periods. If the sun or moon produces any direct periodic influence on the climate of any part of the earth, or on the earth as a whole, these periodical influences seem insignificant and it is quite impossible for us to recognize them in the presence of other disturbances which introduce all sorts of larger irregularities and perhaps temporary periods in the local observations. We are safe in saying that long range forecasts of any magnitude, and short time daily forecasts of any value, cannot be based on solar or lunar periods.

The improvement of climatological records is a minor branch of dynamic meteorology; but even this is not an easy matter: it does not depend wholly upon finances or on personal enthusiasm, nor on obedience to official orders.

Illustration (5). For instance dynamic meteorology needs the average temperature of large masses of freely moving air; hence we should put our thermometers on the tops of high buildings. But every year sees taller buildings erected in our important cities. It is as though the ground in Philadelphia, or New York, or Chicago, were rising up to the level of our self-recording thermometers. If we elevate these latter, the local citizens, hygienists and agriculturists complain that they want temperatures near the ground where men live and where plants grow and that a station two hundred feet above the ground does not suit them. Do they not forget that at the ground the temperatures around their feet are often quite different from those at their heads? That the temperatures on the shady side of the street differ from those on the sunny side, and that temperatures in a valley differ from those on the hillside? We meteorologists are studying the temperature of the free air in connection with clouds, rains and storms,—while they are thinking of crops or personal health and comfort.

The conservatism of climatologists and hygienists opposes the best interests of progressive forecasters and meteorologists, properly so-called.

Illustration (6). It is the same also with the wind pressure

and the wind velocity. The student of dynamics needs the data from the free air, and the clouds, therefore, he raises his anemometers high above the tallest buildings or puts his stations on the highest hills. The records of these instruments are so difficult to understand that many inventors have devoted years of experimentation to convert the anemometer readings into true wind velocities. But meanwhile the steady increase in the elevations of tall buildings, and the growth of trees at all country stations, make it impossible to consider the records of to-day as being truly homogeneous with those of twenty years ago.

Illustration (7). The case is even worse with regard to rainfall. The rain gage is certainly the simplest of apparatus, a mere cylinder set up to catch the falling rain and snow. We measure the depth of the water in the gage and that is all there is to the observation and record. But this simple apparatus, which has no inherent instrumental error, is open to such serious sources of error that its indications and the averages of years of observations may easily be misleading. These errors have their source in the two-fold influence of wind at the locality, and at the gage. Every building or hill is an obstacle to the wind. We place the gages near the ground in an open clear space, or on a post, or on the top of a tall building. The wind sweeps around and over the building, or the hill, and carries the rain or snow to the leeward so that only a few large drops fall on the spot where the gage is located. Equally so the gage itself becomes an obstacle when placed in a clear windy spot and all the smaller drops of rain are carried over it and beyond it, so that a perceptible percentage misses being caught and measured. The remedy for all this was long since pointed out by your own Professor Joseph Henry when Secretary of the Smithsonian, who cut off the wind from the mouth of the gage and now we have various devices for this purpose constituting the "protected rain gage." But how very rarely do the thousands of rainfall observers protect their gage records against this source of error, which, on the averages of 10 gages in England whose altitude is 200 feet where strong winds are likely to prevail, amounted to a deficit of about 50 per cent., diminishing thence to 6 per cent. for elevations of three or four feet in European gages, for rain only, but amounting to 100 per cent. in the case of light rain or snowfall and strong winds.

What false conclusions are we not liable to draw when study-

ing climatological data subject to such errors? It is to such misleading records as these that we must attribute the origin of that widespread fallacy that "forests increase the quantity of rainfall." They do indeed increase the catch of the rain gage, by diminishing its loss due to the action of the wind at the mouth of the gage, but the actual rainfall is not affected by forests. The winds that sweep over our western plains often swirl nearly all the rain and snow out of the gages; modern records with gages better protected from the wind by trees, fences, and buildings, give larger annual precipitation than formerly; but this does not mean that the climate has changed.

Illustration (8). These strong winds may have a very decided deleterious influence on our records of barometric pressure, so that here again is a weak point in the comparison of long continued records at some of the most interesting observatories in the world, namely, those located in very windy places, as on the mountain tops, or at sea coast island, and such spots as Point Reyes Light near San Francisco. Barometers are usually fastened against the walls or on solid piers in some room of a fixed building. The normal standard barometers are so constructed that every minute source of error inherent in the instrument may be carefully determined and allowed for, so that the pressure of the atmosphere within the room may be known to within a thousandth part of an inch or one ten-thousandth part of the length of the vertical column of mercury, which is usually about thirty inches long. But this so-called static pressure within the room is not necessarily the same as that in the free air outside the building, because the building is an obstacle to the wind. If the doors and openings are all closed and one window be opened on the windward side the barometer will be at once seen to rise by reason of the added pressure due to the wind pressing against that open window, whereas the pressure will fall if a window be opened on the leeward side. But if all ordinary openings and leaks are closed and the chimney alone is left open, this chimney becomes the important obstacle and the stronger the wind, so much the stronger the suction up the chimney, if the latter be properly built, or the pressure down the chimney if it be improperly built. The influence of an 80 mile gale is about half an inch of barometric pressure on the scale of the mercurial barometer, or a quarter of a pound pres-

sure per square inch. Studies into the influence of chimney-tops on the draft up chimney, and therefore on the pressure within the room at the fireplace were carried out most elaborately by a special committee of the American Academy of Science in Boston, about 1847, and with equal energy by your own committee, as reported in the *JOURNAL OF THE FRANKLIN INSTITUTE*, Vol. IV, 1842. Your object was to teach us how to improve our chimney drafts, but who thought of teaching us how to escape their deleterious influence on our barometric records? The mariner often speaks of the oscillations of his barometer at sea, "it pumps with every gust of wind during a hurricane," but our delicate aneroid, or self-registering barometer, is much more sensitive than the sluggish mercurial and what should be a delicate curved line, on our recording sheets, often seems a mere broad blotch of ink. Thus the study of the relation between the pressure that prevails in the free atmosphere and the corresponding free wind velocity, or free wind pressure, is complicated with uncertainty as to what the barometer is recording. It is quite common to build an observatory on the top of a mountain, or hill or a ridge, in such a sheltered position that the prevailing violent west winds striking the ridge bound over it and over the building which is thus sheltered by it. In other words the building is located within a small region where the wind pressure and the barometric pressure are both of them lower than they would be if the barometer were located in the free air, and were floating with the wind like a free balloon. We ordinarily say that a portion of the kinetic energy of the moving wind is given up to the ridge as an obstacle increasing the static pressure on the windward side, while the barometer records a deficit in the static pressure on the leeward side of the ridge.

To the unaided eye a very pretty evidence of the existence of such regions of low pressure is given when the observer notes a little cloud like a streamer attached to the mountain-top on the leeward side. This is a region of deficit of pressure into which outside air under higher pressure has been pushed and this air expanding and cooling, just as ordinary clouds are formed, forms a beautiful delicate "banner cloud" full of internal commotions.

In the Hartz Mountains of Germany a cloud is often to be seen forming what is called the Spectre of the Brocken due to

the expansion of moist air into these so-called discontinuous spaces.

I have spoken of some insidious instrumental and local errors that are still creeping into our climatological records all over the world. In former ages these matters have been equally serious, so that all records since the first organization of meteorological work, about 1640, by the disciples of Galileo and after his death, need to be carefully scrutinized before one dares to compare them together and draw fine conclusions as to changes in *climate*, or as to the relations between local climates and the various theories that have been suggested about the influence of the sun or the moon, or comets, the forests, or battles, or auroras, or the cultivation of the ground, or any other suggested cause of possible changes in the earth's atmosphere and climate.

The greatest climatic change that we know of is that which seems to have occurred when the earth passed through that geological epoch known as the glacial period, when snow and ice a mile in depth covered what is now known as our Lake Region and when similar phenomena occurred from time to time in Europe, in New Zealand, and even in Central Africa. We are at present wholly at a loss to demonstrate the value of the various suggested explanations of such great changes in local climate. How can we expect to reason from our little possible climatic changes of one degree F. or one inch of rainfall, or an occasional cold winter, back to those ages during which the whole face of the earth was changed!—and yet even then man was living on the earth?

The errors of instruments, and of their exposures, the shortness of each local record, the limitation to stations on the globe at the very bottom of our atmosphere, the limitation to habitable parts of the globe, depriving us of extended records on the ocean, or in the deserts, or in the polar regions, with only here and there an occasional record brought down from high altitudes by kites or balloons, are, however, but minor obstacles to the progress of meteorology.

Not long since (1892) Prof. Arthur Schuster, at the British Association for the Advancement of Science, discouraged by the slow progress of our knowledge of the peculiarities of our atmosphere, exclaimed, almost in these words: "Why not stop

all observing and recording and the daily predictions, for five years, and devote ourselves to *study*? Why not relieve our numerous National Weather Bureaus from their previous onerous statistical work and turn their best men into the study of the physics and mechanics of the earth's atmosphere? Why ask a blind man to observe and record without knowing why or what?"

Of course we would not forget that local climates and their influences on humanity, have for ages occupied the attention of mankind as *climatology*. There is a demand, a steady daily demand for daily data. At first forecasts of storms and weather were an application of our elementary statistical knowledge of general climatology, were not based on our knowledge of mechanics, because we know so little of this latter science as applied to the atmosphere. We believe that the fundamental laws of forces must be still better understood than now, before we have any right to expect detailed predictions at such long ranges as are possible in some other professions.

But let us pass from considering climatology or the average condition of the atmosphere and statistical conditions. Suppose that we really had perfect observations and records for ages past, would these alone enable us to make accurate long range predictions as to the future? No, indeed! not even though our kites and balloons do record whatever goes on ten or fifteen miles above us. Not even though our daily weather maps cover the whole of the United States and the oceans on either side of us, including the corresponding daily weather maps for all Europe and Asia. Daily maps for the whole Northern Hemisphere for both land and ocean were published formerly by us for about ten consecutive years, showing all about the successive conditions of the weather. We may always obtain sufficient observational material for these, but how can accurate predictions be made from the most perfect graphic maps and statistical figures? We may indeed estimate the probabilities, but the great obstacle that hinders perfect predictions is nothing less than our ignorance of many details as to the laws that govern the atmosphere and our inability to put even what little knowledge we have, into such a form that it can be promptly utilized by the forecaster.

I do not consider our present system of forecasts as being

faulty either in Europe or America. Such good men as are now engaged in this work, throughout the world, cannot do other than *good work*,—the very best that is now possible under existing conditions. I am not criticising the good that we have, I am asking you to seriously consider what can be done to help meteorologists throughout the world, onward toward perfection in the distant future.

Now and then you will find a man who by persistent practice and long familiarity with his billiard table, his balls and his cues and his strokes, can tell with delightful precision just when and where a ball will land; equally is this true of the pitcher in baseball, or the man at the helm of a great steamship, or the pilot of an aeroplane. These all get at the desired result after many trials and failures; they acquire a knowledge of the motions of things without much knowledge of the fundamental laws that govern moving bodies; they have a so-called practical knowledge without the theoretical. Hence the experience of the billiardist may be very useful in *some* new fields of work, such as baseball, but how can it apply to some distant field of work, such as the motion of a flood in the river, or the advance of a rushing blizzard? I recall vividly the agitation scattered throughout this country by the newspaper press of 1851-5, relative to the rotascope of Prof. W. R. Johnson, then of Philadelphia, and relative to "the mechanical paradox" of Prof. Jonathan Homer Lane, that brilliant light among the scientists of Washington, all which instruments are now well known as the gyroscope of Foucault. "A new force has been discovered," said one popular writer; "falling bodies are made to rise and move horizontally; Newton's law of gravitation is not universal," said another. And yet the puzzling movements were easily explained by the laws of rotation that had long before been expounded by Poisson. So little were these laws of motion then known to the professors and students of our colleges that many, like myself, were staggered as to their faith in the teachings of Sir Isaac Newton and began to inquire whether it might not be possible to undermine and upset all the wisdom of ordinary learned men. No, this is not possible. The future may enlarge or perfect our present knowledge of nature. We may impose new conditions and attain new results, but we shall merely clarify our present wisdom, we shall add to, but not upset, all the teachings of the past. He who pushes on

over the mountains and discovers new uplands, does not destroy the lowlands that he left behind.

If one depends only on the daily weather maps and knows little or nothing of nature's laws he finds himself in a maze of limitations. He dare not prophesy; he ventures only to say that "judging by the general behavior of the atmosphere, during the past few hours, it may be expected that," or that "the indications are," or "the probabilities seem to be that so and so will happen." Must we then imitate the self-confident sooth-sayers, haruspices, augurs, fortune-tellers? Shall we look to the birds and animals and plants, for a little of their wisdom?

Do we not know that our atmosphere is an inert machine, controlled by the same laws that govern all machines? It is simply a very complex air engine, in which the air is warmed by the sun, and cooled by radiation. The denser air pushes the lighter air aside and keeps up the circulation. Can not man's intellect unravel the complex of combinations that are changing every hour of the day and every day of the year? Of course this immense machine is a whirling globe, revolving daily and feeling the influence of its own centrifugal force. It is rushing around the sun annually through the inter-planetary space, so that it is affected by shooting stars, solar electrons, inter-planetary æther and exceedingly thin unknown gases.

Consider for a moment the fact that the atmosphere is a mixture of gases and vapors, each of which has its own peculiarities so that we must especially consider the presence of water and ice and their vapors. All its constituents are subject to the laws of thermo-dynamics, by reason of which gases cool, when rising and expanding, and warm by descent and compression; they are all subject to the laws of hydro-dynamics, by reason of which cyclones, tornadoes, blizzards, trade winds and calms, must occur; they are all subject to the laws of radiation and absorption of heat, by reason of which low lying fogs are formed and also the great stratum of relatively warm air that surrounds the globe about ten miles above sea level.

The laws of radiation of gases and motion, of pressure and vapor diffusion, are understood at present only well enough to enable us to progress very slowly in the fundamental part of the physics of meteorology. In the ordinary physical laboratories of our universities, our best men, with expensive and accurate

apparatus, study these laws separately, or by simple combinations among themselves. But the meteorologist can not experiment with the atmosphere as a whole, as he would like to do. However, he can experiment with relatively small portions of the atmosphere and deduce conclusions that can be applied on a large scale to the data given by the daily weather map.

Of course our progress in the work must be slow but steady. Do not the remains of animals found in the depths of the earth show that the Creator spent ages in gradual approach toward the construction of such perfect birds of flight as the condor, the eagle, the carrier pigeon? Man has spent only the past thirty years in his persistent efforts to rival these creatures. They are flying by virtue of their material construction, their inherited wings and muscles and nerves, but man must learn to fly by virtue of some intellectual conquests. He must not expect to do in a few years that which the birds required ages to do. They have only an *art*; we must first understand the science.

It is the study of nature and nature's laws that must constitute the basis of all our future progress in every science. These laws are hidden from the eye and the ear, from the touch, the smell and the taste, they are not revealed to us by our material senses, but only by intellect and reason. Our imaginations suspect their existence; we begin with the conviction that there must be a cause or a reason for every phenomenon. We try various hypotheses and after testing them all, some of them become established as realities shown to accord with all the observed facts. It is this intellectual ability that constitutes the basis of man's power over nature: without it man cannot develop the mechanical principles that apply to this atmosphere.

Behind every perfect practical art and every ordinary act there is a higher science that must be understood if we would have full command of the world around us. This material world is so permeated with evidences of a wonderful creative power that we must recognize ourselves as following far behind trying to discover how things were done and how puny man must do if he is to accomplish his plans. Our minds can not think, our brains can not act, except in harmony with the properties of the atoms of which our bodies are composed; all our thoughts must be in harmony with the mechanical laws that govern those same atoms as they circulate in the inanimate nature around us. There

is not a mode of motion which the mind can imagine as possible but what is actually found to be present among the atoms studied by the chemist and the physicist.

Was Sir Isaac Newton satisfied to know that an apple falls from the tree to the ground, or that a stone flies from the whirling sling when it is let loose? Ah no! His imagination penetrated beyond these well-known material phenomena. He imagined various general laws that might govern the motions of the apple and the stone, and demonstrated to the satisfaction of all men that *inertia*, *momentum*, *gravitation*, *centrifugal force* prevail throughout the universe; that they control the motions of atoms, the phenomena of light and the revolution of the planets about the sun.

Similarly did Sir Robert Boyle reveal the law that liquids and gases press outwards in all directions and that this pressure is equal at every point of the inclosure upward or downward or sideways.

The progress of knowledge in every direction has led us from the visible phenomena of everyday life, through the telescope up to the stars; through the microscope down to the microbe; through the prism and iceland spar up to that inter-planetary substance called æther that brings us light and heat from the sun. Through chemistry we have learned about the combinations of atoms and molecules; through the steam engine we have learned the laws of thermo-dynamics; from the old electric battery we have ascended to the study of the electron, and the ultimate corpuscles of all matter; through photography we have come to study radium and the X-rays. Now all such study is done by manipulation in laboratories devoted to these subjects. But it is also brain work; it is the spirit of mathematics that guides us into the airy realm of the mechanics of molecules and the structure of all matter. The intellectual process called logical reasoning, which is generally mathematical, leads us up to the laws of the forces of nature, which laws themselves are, so far as we now know, perfectly non-material, not to say intellectual and spiritual.

Mathematics is really the laws of thinking as distinguished from mechanics, which is the laws of forces. We speak of thinking as an intellectual process wholly confined to the mind or brain, but the atoms of the brain are regulated by the very same

laws of mechanics, so that thinking is but expressing in words the mechanical processes going on among the atoms of the brain, or if you will, the matter of the whole universe. We and nature are one. As successive generations of men devote their intellectual powers to the mechanics and mathematics of nature, we shall gradually unfold all the secrets of nature and elucidate all the phenomena of meteorology that now seem so obscure and difficult.

A recent address by Professor Moeller, of Brunswick, Germany, who has written much on the problems of the movements of the atmosphere, has enforced the need that is felt in that country of courses of study specially designed for students who wish to devote themselves to meteorological researches and the increase of our knowledge relative to the atmosphere.

Possibly the first step ever taken to specifically provide for future researches on the atmosphere was by that earnest philanthropist Thomas G. Hodgkins of New York, who willed his fortune to the pursuit of this one study in all its relations to mankind. Therefore the Smithsonian Institution as his executor has aided and published a large variety of atmospheric researches and may be expected to publish still more in the future. Even the Carnegie Institution has done a little for meteorology by printing one volume on dynamic meteorology by the most advanced, enthusiastic and stimulating of all living students, Victor Bjerknes, of Christiania, Norway.

It is not merely a publisher that is wanting. It is the laboratory with its corps of thinkers and experimenters—men who have done and are able to do still more,—the so-called mathematical physicist, full of enthusiasm and profiting by the stimulus of a few companion students.

In the special field of electricity ideals could be mentioned, such as the Cavendish Laboratory at Cambridge, England. Here J. J. Thomson and his group of students remind one of the ancient peripatetic school of philosophy held by Socrates at Athens, so far as concerns the close communion of spirits; or the glorious Academia del Cimento at Florence, where the disciples of Galileo had buildings and apparatus adapted to the close study of natural philosophy. Something of this kind I would see devoted to the advance of atmospheric.

Am I looking too far ahead? Shall not some of us now living see the establishment of some such school devoted to the

physics and mechanics of the earth's atmosphere? Our great universities have their schools of mathematics, chemistry, physics, engineering, etc. Annually they turn out innumerable successful candidates for the degree of Doctor of Philosophy. These young men by their published theses show that each knows all of some one special subject and has added thereto discoveries or improvements of his own. They become adepts in such researches and are quickly sought by the various business concerns that need their knowledge and their talents. Almost all the progress of modern times has been due to the works initiated by such men and by their teachers in special laboratories. It is precisely such men and such talents for research that I would secure for the study of obscure atmospheric problems. I would have them furnished with an extensive laboratory especially adapted to atmospheric studies. A study now often confounded with aerology, but which I would rather call atmospheric. I do not specifically suggest an establishment devoted to the aeroplane or aerial navigation. This is a specific engineering problem, that many nations are providing for on account of its prospective importance in warfare. Possibly the aeroplane will become as useful to meteorology as the kite and balloon have been. But atmospheric has other needs than those of an aerial navigation. To be sure, we do need observations made in the atmosphere itself, but still more do we need a building wherein to imitate atmospheric phenomena so that they can be measured and subjected to mathematical study.

(1) Suppose one wishes to find out all about water-spouts, or thunderstorms, or tornadoes. Must he go *to* them and *into* them? No; he can cause small ones to form in such a laboratory under specific conditions that he can control. I have seen a beautiful experiment of this kind performed in Paris. One has only to rig up a horizontal whirling wheel and place a dish of warm water on the floor directly below it. The vertical spiral spout is quickly formed and the student with his little pieces of measuring apparatus can determine the pressure, temperature, moisture and wind, at every point within it. He is supposed to have previously prepared analytical formulæ that pertain approximately to just such a water-spout and he now compares his observations with his theory. Doubtless he will have to modify his formulæ until he attains those that will apply on a large scale to the air in a natural water-spout. He thus acquires

confidence in his knowledge of mechanics and his ability to demonstrate its agreement with nature.

(2) The beautiful clouds change their structure and their features with every approaching change in the weather. We can reproduce many of these in a proper laboratory and determine more precisely just what these changes mean.

(3) The formation of rain, snow, hail, and frost must be imitated until we know how and why they are formed.

(4) The beautiful smoke rings, or vortices, sent straight upward by certain cannon that are used to prevent hail, must be studied in a laboratory until we are able to show why it is that neither they nor the explosion of dynamite have any influence on thunder clouds or hail.

(5) The absorption of the solar rays by the air, the earth, the ocean, and the fields of snow, and in general the distribution of temperature on the globe, even the formation of glacial epochs, can be investigated experimentally, as well as by the present imperfect theoretical hypotheses.

(6) We can go further than small local phenomena. Models must be made of the whole globe or of its two hemispheres, bedecked with close imitations of our continents, mountains, oceans, clouds and atmosphere. These must revolve all together in imitation of our daily rotation, and we must be able to measure everywhere on our models, the pressures, temperatures, winds, the little eddies like our hurricanes, that move along the surface of the earth and the advance of great blizzards, or floods, or droughts. (All of which I explained in the *Monthly Weather Review* of December, 1907, and in the *Bulletin of the American Mathematical Society*, in July, 1907.) Thus we shall elucidate the motions of areas of low pressure and rain, eastward around the globe, from Japan to Russia, or from Cape Horn to Australia. We shall understand the influence of the Andes and Rocky Mountains, or of continents and oceans, on the general circulation of the atmosphere. We shall go on further and study the behavior of our upper atmosphere that is so very different from the lower half, in which our ordinary phenomena originate.

Time would fail me to describe all the beautiful, but confessedly difficult experiments, that can be made with gases and vapors in the laboratory for atmospheric; with all these experiments there must go on a truly difficult mathematical work.

Thirty years ago, the best mathematicians told me that our problems were too difficult for them, but now younger men have attacked them, and the experimental laboratory will enable us to test these newest results and will give us confidence in the application on a large scale of the results of experiments on a small scale.

If the preparations for such experiments were not so laborious and expensive, I should to-night have illustrated this plain talk by showing you some of them so that you might realize that I am not promising work beyond man's ability to perform.

In conclusion, I must say that what I most long to see, and what I believe is of fundamental importance, in atmospheric, the want of which is a real obstacle—is the existence of a laboratory building specifically adapted to atmospheric experiments and the association therewith of able students trained in mathematics, physics, and mechanics. When all this is realized the intellectual work that will there be done, will gradually remove all obstacles to the eventual perfection of our knowledge of the atmosphere.

Does this seem like a long look ahead? Not so. The time is ripe for the institute. Many eyes are looking for its appearance. It matters little whether the ideal be realized by our own Weather Bureau at its important research station on Mount Weather, or by the German Weather Bureau, at Lindenberg, or by Mr. Rotch at his private station on the Blue Hills near Boston, or under the auspices of some wealthy university, which latter would seem to be a most congenial spot. Or whether the Smithsonian and Carnegie Institutions shall add it to the galaxy gathered about them. *All are welcome.* There is room for several such laboratories of atmospheric and for many busy men in this class of work. Every man and every institute will be helpful in its own way. Each must plan for many years of labor, as is the case in astronomical observatories and all other scientific institutes. Man has to *make haste slowly*, when he studies nature.

If ever the state should honor those of your citizens who have done so much for meteorology, the names of Benjamin Franklin, William Ferrel, Alexander Dallas Bache, Walter Rogers Johnson, James Pollard Espy, Robert Hare, and Elisha Kent Kane, will be inscribed on the portals of some future laboratory devoted to atmospheric.