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Meteorology

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Friday, March 4th, 1859.

Colonel the Honourable J. LINDSAY, in the Chair.

METEOROLOGY.

By Rear-Admiral Robert FitzRoy.

An apology should be made for presuming to address you on a subject so familiar as that of wind and weather, even when dignified (I will not say mystified) by the term meteorology.

Yet acquainted as all are, more or less, with the causes and consequences of changes in the air we breathe, or in the water, which is scarcely less important to existence, it may be interesting, and one may hope useful, to endeavour to illustrate some of their remarkable features clearly and comprehensively. If they should be less philosophically treated than might be desired, I must hope that allowance will be made for a practical man, who has not graduated regularly in science, and therefore must be deficient in the higher acquirements. It is as a practical observer of nature, especially at sea, aided but little by books, that I now venture to ask for your attention to some few points in meteorology which may be so far popularised as to be useful in every-day life.

But what is the precise meaning of the term "meteorology?" a stranger may ask. "It is the science treating of air and water, wind and weather, heat, cold, and climate," may be replied.

As time is limited to the reasonable space of one hour (long enough to exhaust the patience of most hearers), I will premise briefly what is proposed to be submitted to you this day, and the subjects which are intended for notice next Friday.

First, I would endeavour to give a general view of the atmosphere, in order that the explanations subsequently offered may be properly understood, and then I will make very brief allusions to some of the most useful instruments, not going into or attempting anything like a complete description, to those who are more conversant than I am with most of them, but simply alluding to particular points in which certain instruments *now* adopted are supposed to be better than those which were used some years ago, and drawing attention to some of the novelties in them.

After having given this general reference to the instruments, I would try to show how they may be made most practically useful in every-day life, by foretelling weather, advantageously to the soldier, as well as the seaman and traveller, besides the farmer, the gardener, and the medical adviser. I would then very briefly glance at the ocean with reference particularly to the endeavours to explore its depths, because it is a matter of immediate interest—and if time should allow, I would refer briefly to the effects of changes in the atmosphere, and particular winds, on climates generally; but this, probably, must be put off till next week, when what is commonly called "cyclonology," or the investigation of circular storms, in connection with the general winds, and the movements of the atmosphere, called sometimes (whether correctly or not) "atmospheric waves," a much-disputed question intimately connected with the barometer, will be considered. These being rather more scientific, may be deferred at present.

Speaking now of the nature of our atmosphere:—It is very commonly remarked that air is a fluid, and that all fluids are much alike. Air is a fluid, water is a fluid, gases are fluids. Very true—but there are these remarkable differences between the fluid, *water*, and the fluid, *air*. Water is almost incompressible and inelastic. It is composed of two gases, which are mixed together *chemically*, oxygen and hydrogen—the water, not being elastic, exerting no force to spread itself, except in common with other fluids by seeking its own level, with reference to the centre of the earth (or gravitating towards the centre of the earth). All fluids have that property in common, they all gravitate and seek to attain a uniform level. But air has the peculiarity of extreme elasticity. It is not only fluid as water is fluid, and therefore seeking to maintain its equilibrium (with reference to the centre of the earth), but it is always more or less under *pressure*, and if that pressure be relaxed, ever so little, it expands immediately. It has a constant tendency to *expand* in every direction. Water only spreads.

About 15 lbs (everyone knows) is the weight of the atmosphere pressing upon every square inch of surface at the level of the ocean. This pressure may be relaxed, locally and temporarily, by air being withdrawn, or lightened by heat around the locality, by being rarefied above it, when immediately the air around expands, seeking to fill up the space of lessened pressure. If you draw a part of the air out of a room, the rest of the air in that room will fill the remaining space, as air is capable of very great expansion. I do not know whether ascertained, but believe it is nearly indefinite. Why I would lay stress upon this point now is, because it immediately affects the barometer.

But this is not the only reason why, when air becomes more expanded and lighter, the barometer, which weighs the air, sinks, but also from the watery vapour, invisible, but in the air itself, as *gas*, expanding by heat and occuping more space.

By the expansion of this gas, air becomes lighter; and, bulk for bulk, a given space full of warm air with expanded watery gas (or aqueous vapour) is lighter than an equal bulk of dry air. This is another reason for the mercury in the column of the barometer falling in certain states of the weather, and rising in others. Upon this question, however, there has been much difference of opinion. Some authorities demur, and assign other causes. Some indeed think that the effect on the barometer is chiefly caused by *electrical* changes; but, while we *have* simple and general causes intelligible to all, and which we know, from experiments easily made, do take effect, I do not see why we should look only to the mysterious workings of electricity, although its (secondary) results are occasionally remarkable.

The effect of the atmosphere upon the thermometer—the ordinary motion of the column of mercury in the thermometer—everyone notices almost daily.

The barometer is used not only for the common purposes of a "weather-glass," but as a scientific instrument, and for measuring heights. I refer also now to the use of the "*boiling point thermometer*," to show the little reliance that can be placed upon this instrument, as compared with the barometer, for measuring great heights; and I mention it particularly, because within the last few years much stress has been laid upon the measurement of some very remarkable mountains by boiling water. Each degree of the thermometer is equivalent to about 550 *feet of ascent*, or one-tenth to 55 feet; therefore, the smallest error in the graduation of the thermometer itself will affect the height deduced materially.

In a thermometer which is graduated from 212°, the boiling-point, to 160°, similarly to those intended for the purpose of measuring heights, there must have been a starting-point, or zero, from which to begin the graduation. I have asked an optician in London how he fixed that zero, the boiling-point: "By boiling water at my house," he replied. "Where is your house?" In such a part of the town, he answered. I said, "What height is it above the sea?" to which he replied, "I do not know;" and when I asked him the state of the barometer when he boiled the water, whether the mercury was high or low, he said that he had not looked at it! Now, as this instrument is intended to measure heights and to decide differences of some hundred, if not thousand, feet upwards, at least one should endeavour to ascertain a reliable starting point. From inquiries which I have made, I believe that the determination of the boiling-point of ordinary thermometers is at present very vague, not only from the extreme difficulties of the process itself, (which are well known to opticians,) but from the radical errors of not allowing for the pressure of the atmosphere at the time of graduation—which may be much, even an inch higher or lower than the mean, or any *given height*, while the elevation of the place above the level of the sea is also unnoticed. Then there is another source of error, a minor one perhaps: the inner limit, the 180° point, is fixed only by arbitrary measurement, by comparison with another thermometer; it may be right or it may be very much out, as may be the intermediate divisions, for the difficulty of ascertaining degree by degree is very great; and it must be remembered that the measurement of a very high mountain depends upon those inner degrees from 200° down to 180°, and thereabouts. Hence the difficulty of fixing them upon the thermometric scale, and of making a reliable observation by boiling water, may be greater than has been generally supposed and admitted.

By one of the boiling-point thermometers to which I referred, may be seen at once how very small the degrees in the small space ranging from 180° to 212° must be, while even their starting point is not reliably fixed.

There is an application of the thermometer which would be used advantageously and frequently, if more generally known. I mean the common moistened or wet bulb thermometer, used with a dry one as a "Mason's" hygrometer. One thermometer being moistened, is kept cool by evaporation and shows its temperature. The two thermometers need not be placed quite together. You may hang either in one place and the other pretty near it, but not close, provided that they are under the same conditions, or in similar circumstances. The bulb of one should be kept moist, (not wet, but simply moist,) so that evaporation may go on, and then that thermometer will show the temperature at which water is taken up and converted into invisible vapour; while the other will show the temperature of the air. The difference between the two, doubled and taken from the lower, shows very nearly the "dew-point;" or that at which dew is formed (as on a bottle of water brought out of a cold place, when, according to the lower temperature of the water within, the deposition will take place, sooner or later, by the vapour in the air beginning to be condensed into moisture). Hence you may know whether the air is more or less moist, whether rain is likely to fall or not, or whether your room is too dry or too moist. It is a very simple instrument, and, if more freely used, might become very much more popular. At present it is generally thought rather too scientific, and so much notice is not taken of it as should be. In connection with the barometer, it affords an almost unfailing warning of the weather that is coming on, as I will show subsequently.

The Kew marine barometers, which are now much used in the navy, and frequently in the merchant service, are made of glass, iron, and brass. The old barometers used to be generally cased in wood, and had wooden cisterns with leather bags. It is supposed that a metal barometer, with a glass tube securely fixed in it, can be graduated with greater accuracy, and is more reliable in its indications, than a glass tube in a wooden case. The French, however, have been hitherto of a different opinion, and use the wooden case: but they are now instituting investigations, with a view of proving the question. The English opinion has been that wood, being hygrometric, alters its length, and therefore the graduations are liable to be incorrect. That is one disputed point. Then the method of securing the tube in the cistern is said to be more manageable in wood. The English opticians, however, who probably have more experience on their side, say that it cannot be well and permanently fixed in wood, because climate, moisture, heat, and cold alter the casing, the cistern, and the leather, so much that the instrument becomes deteriorated, and lets in air, while the position of the tube is more or less altered. In an iron cistern the tube is securely fixed, so that it cannot vary upwards or downwards. Some think it is too securely fixed, and therefore it is liable to be broken by concussion more readily than that of an inferior instrument. This, however, appears to be a necessary consequence of greater exactness, and if exactness is requisite the tube must be fixed securely. It is not generally known that this instrument is not graduated to exact inches; the inches are artificial, and so spaced as to show the correct height of the column (compared with a standard barometer, by trial and error), so that after the instrument has been graduated and thoroughly verified by the proper process, there are no corrections requisite to be applied to it except one constant, for scale or index error, and one varying, for temperature. None of the corrections depending upon the size of the tube and the relative size of the cistern, and for capillarity, which are necessary in some land standard barometers, are required in these, which, after being verified in a reliable observatory, such as that at Kew (established by the British Association for the Advancement of Science), become valuable as standards.

It may not be generally known that the only difference between such a barometer, and a barometer used on land, is that the upper part of the tube is alone carefully measured (or calibrated, as it is termed). Upon the nicety of that part of the tube the value of the instrument chiefly depends; the size of the other part is of little moment, for whether the interior bore is greater or less, makes very little sensible difference to a barometer made upon the Kew principle. Whatever constant errors exist, are proved by actual "trial and error," and allowed for in the graduation, which, as I said before, is *artificial*. The part of the tube contracted to prevent the mercury from "pumping" (or oscillating with the motion of the ship) may be 2 or 3 inches long, or it may extend the whole length. In most of the old marine barometers, the contracted part extends the whole length, but in this one it is only about 2 inches. Below this there is a "pipette," or a little funnel with the point downwards within the tube. The air, which may work its way in, never goes *through* the mercury; it always passes between the mercury and the glass, so, by having this funnel within or near the top of the tube, any air which goes up by the side is stopped at the shoulder and there remains; the mercury itself working up and down through the middle of the funnel. After a barometer has been some time in use, if any air has got into this part of the tube (and it cannot get beyond, or into the upper part, when it is thus constructed), or when there is reason to suppose that air has got into this part, you have only to turn the lower end of the tube upwards and tap it gently, when all the air will gradually go out, and pass into the cistern again, the barometer tube thus becoming freed from it.

During four years that the office has been established in which I am employed, such instruments have been sent out, and returned from voyages on board merchant ships, as well as men-of-war, sometimes for two or three voyages successively, and most of them without injury. In the first two years several were broken; but chiefly, I may say, through unduly rough usage, several being from the near concussion of guns on board men-of-war. In one instance the barometer was hung immediately under a heavy pivot-gun, which was fired just over it, when, of course, such an instrument could not stand the shock. Others were placed between decks where men in exercising ran against them, and it thus happened that many were returned "broken," from men-of-war, during the first two years. During the last two years, however, there have been very few breakages; while from merchant ships during the four years, not 5 per cent. of the whole number afloat, out of several hundreds that have been supplied, have been broken; so that as far as experience has gone, they have stood common work very well. They have been sent by railroad, in a manner which the old-pattern barometers could not have borne, and have preserved their merits. Not only is the cistern itself a fixture, as it were, requiring no opening and no adjusting, but the little funnel within the tube prevents the air from getting into the part of the tube upon which accuracy depends. Within even the last month, I have had the testimony of other authorities, in addition to that of the Astronomer Royal for Scotland, to the effect that these barometers are equal to any work for which standards are required on land or at sea.

Still I think another kind of barometer might be found better for men-of-war, with reference to the concussion of guns—that it might be made upon the syphon principle, and graduated on the glass itself.

The tube of a Gay Lussac mountain barometer is on the syphon principle; there being no air in the long tube, the mercury falls to a certain distance when the short tube, which corresponds to a cistern, is open. When this short tube, or leg, is opened, the mercury rises to a certain point according to the atmospheric pressure, just as in the cistern and column mercury acts in other barometers. The scales slide, and you measure from the level of the mercury in the long tube to that of the mercury in the other, so that all errors, excepting those caused by temperature or a defective graduation of the scale, are obviated. It is the simplest of all barometers in principle, but difficult to deal with at present, because the mechanical construction is critical. It is rather curious that these instruments, perhaps the best mountain barometers of the present day, are now made in England by a person who is employed by the principal opticians, while he is ostensibly keeping a hotel not many miles from London, though the sole maker in this country, who is now reliable.

These Gay Lussac barometers have been taken to many parts of the world, and have been found to answer exceedingly well, when duly cared for. Some however say they are too brittle, and cannot easily be carried by travellers.

My principal object in referring to them was to show that I thought a barometer upon nearly such a principle, with a very strong and graduated tube, might be made available for men-of-war, which require a barometer far stronger and less brittle than any of the instruments that are now in use. When Sir John Richardson went on his land journey to the Arctic regions, he wished to take a barometer that would bear rough usage in travelling, and he had one made on his own plan. It went with him and came back uninjured. He had some spare tubes. It was very strong, and would not run any risk unless hit very hard. It is graduated upon the tube itself, which is an eighth of an inch in thickness, and will stand rough usage. The tube has an iron screw securely fixed upon it, which goes into the cistern. The cistern can be carried in one place and the tube in another: the tube being in a wooden case by itself, and therefore not liable to be broken by having the weight of any mercury in it. The filling it properly, requires a long elastic tube or funnel to go down to the bottom of the glass tube, through which the mercury may be poured in carefully, beginning at the bottom, so that as it fills the tube it forces the air out before it. You fill it quite full, with the cistern screwed on and held up; then screw up, by the bottom screw—reverse, and take out the little screw, through the hole for which a certain quantity of mercury may be withdrawn by a small syphon till the mercury's level is at the *marked* neutral (or starting) point. With a little syphon made of glass, or wood (on the principle of that which is put into a cask), as much of the mercury as you choose may be withdrawn: or, the tube may be screwed more or less into the cistern, till the mercury is exactly at the mark. I do not say that a barometer thus roughly constructed (with *unboiled* mercury) can be compared with the accuracy of a more scientifically constructed instrument, such as our first opticians would make; but I believe that it would be very much more reliable for travellers (within certain limits of error) than boiling water thermometers, or Gay Lussac barometers, or any other means that we have at present, because it is strong, it is very portable, the limits of error are known, and they are not too great for use. I believe that one would get the actual pressure of the atmosphere anywhere within *two-tenths of an inch;* which, when measuring a mountain from 12,000 to 20,000 feet in height, would correspond to but a small quantity, namely, about 200 feet of altitude, a difference much less than the uncertainty of corrections necessary for temperature, and other circumstances, at a great elevation. The instrument before you is the identical one which Sir John Richardson travelled with and brought back uninjured.

Merchant ships which have been supplied by the Government with instruments during the last three or four years, and many men-of-war that have been supplied, had at first thermometers with metallic scales, which came back after a voyage in a rusted and illegible state. To obviate that a white porcelain scale was brought into use, which answers remarkably well. It is made like a plate, the scale being baked with the *larger* figures on it, the maker's name, and all that can be placed, without extreme accuracy being required, before graduation. The exact marks for the graduation of the scale are then cut in, or etched, and the marks blackened with nitrate of silver or some other chemical preparation. Thus, the scale not being put into the fire again after graduation, these thermometers remain without change of form, size, or colour. They can be easily read at night, and are perhaps the most useful that have been made.

Another kind was previously tried, namely, slate: but was found to be too easily defaced, and on the whole it does not answer so well as porcelain or earthenware, neither is it so easy to read at night; porcelain is altogether preferable.

Some thermometers, merely for scientific investigation, have a blackened bulb, and, if *in vacuo*, the air is exhausted out of a glass globe which incloses the bulb. The sun's rays striking upon such a blackened bulb, in the focus of a reflector, cause the greatest degree of heat at the time and place. It is for trying experiments in various climates with a view of ascertaining the intensity of the sun's heat under various circumstances, and is a contrivance that has only been effectually completed within the last few months.

Various anemometers, wind-gauges or wind-measurers, have been brought into use lately, and within the last few days two such instruments, on the most approved principles, have been sent out to Halifax and Bermuda by the Government (one by the Board of Trade and the other by the Admiralty). The principle upon which those anemometers measure the wind can be shown by a little instrument (intended for use on board ship) mounted on gimbals like a compass, in order that it may remain horizontal under any motion of the ship. It was found by Dr. Robinson (of Armagh) that the shape of a hemispherical cup (exactly the half of a sphere) offered a third greater proportion of resistance to the wind on the concave side than on the convex side, and that the velocity of such cups, when put in motion by the wind, is one-third that of the wind, nearly, the wind exerting a third greater force upon the hollow side than it does upon the convex side.* This fact being known, the measurement of the velocity and force of the wind is comparatively easy. The proportion is not quite exactly three to one, but very nearly so. Such an instrument may have a self-registering apparatus with clockwork or dials, like those of a gas meter, to register the velocity of the wind in a certain time; the force may be ascertained by comparison with a pressure-plate, or by calculation. The instruments that are sent out to Halifax and Bermuda upon the same principle are large and self-registering. There is an apparatus attached to them of wheels and rollers, with paper fixed on the rollers, so that in whatever way these cups move their indications are registered by the machinery below, connected with a clockwork moving cylinder covered with paper, and a pencil making the indications. All is so well contrived, that it is only necessary to look at and change the paper once a day (Osler's and Robinson's principles combined).

An attempt has been made to obtain a hand instrument, which is much wanted. At present the measurements of wind on board ship are merely estimated. Lind's wind-gauge, modified by Sir William Snow Harris, and altered subsequently, may yet effect the object in view, which is to get an instrument that you can hold up to the wind. A level which it has, shows when it is exactly horizontal; and the means of opening while holding it to the wind, and shutting it instantly at pleasure, are effected by a touch. It is Lind's wind-gauge, with a means of opening and shutting the orifices. The wind blows in, pressing the fluid to a certain distance along the graduated tube according to its strength; your thumb at the back keeps the instrument open till you choose to shut it, when you may read off. It is not perfect, but I believe it will be a tolerable approximation to a wind-measurer. The level is on the principle of the very simple "Peruvian level," that by which aqueducts in Peru and Mexico were carried out, namely, a hollow cane or bamboo half full of water with an opening and a float near each end, the floats carrying marks of an equal height, and the cane being placed so that the observer's eye might be in a line with those two marks (just as the eye should be in a line with the sights on a gun). When the two points are in one line with the eye the level line is shown. The late Sir Francis Beaufort was exceedingly anxious for some instrument of this kind. His scale, a very good one for merely *estimating* the force of the wind, became generally adopted, not only in this country but in America and France, yet he wanted something of this kind to verify and use with it. I do not say that the gauge described will quite answer our purpose, but something of the sort may give means of actual approximate measurement, instead of arbitrary estimation.

The atmosphere consists of very minute particles, far smaller than can

* The effect of friction is not considered, because, when well mounted and furnished with friction balls (rollers), there is in effect no sensible amount of retardation due to friction.

be shown by measurement, or that we can realize to our conception. A glass containing very small shot (dust shot), compared with another glass containing large shot, may help to illustrate what I mean when saying that different gases—the different component parts of the atmosphere—may differ very much in their mechanical nature, as to their particles (smaller or larger); and that the particles of one kind may mix among those of the other, between their interstices, while another substance, such as perhaps heat, may mingle with those various particles, as water mingles in such glasses with shot. A good deal of water can be mixed with such shot before all the interstices are filled—and so it is in the case of particles of atmosphere. I refer to this as a practical illustration of one gas mixing with another, and of vapour or heat being spread through a portion of air, without increasing its apparent bulk, being sensible to the eye, or the contrary.

Supposing that the air over any place at which the atmosphere is lightened or rarefied, by heat insinuating itself between the particles of air, they are expanded, become lighter, and occupy greater bulk, therefore equal cubes weigh or press less. A body of air then ascends; and it acquires a certain momentum which carries it on; but, having left a particular place, other air *must* come into that place, which cannot be a vacuum. Being raised by its comparative lightness, it ascends, and other air pushes in immediately from all space around to fill its place. In a room, for instance, rarefied air goes up towards the upper part, and cold air comes in from below, if there is an opening for supply.

Upon this simple general principle, the principal phenomena of wind in our atmosphere depend chiefly, I will not say entirely, because there are local, temporary, chemical, and electrical causes; but the great principle upon which the movements of the atmosphere generally depend are simply these: the rarefaction and rising of a body of air, the place of which is filled by other air coming in from the readiest source of supply.

Supposing that a diagram represents the world's surface from one pole to the equator and the other pole (a section through the globe from pole to pole); if the air is rarefied at the equator, and ascends in a body, we have shown that other air must rush in to supply its place. The trade winds continually blow towards the equator; the heated air thereabouts cannot go up beyond a certain distance, where it becomes cool, and is prevented by gravitation from going beyond a certain distance from the earth's surface. It can only go laterally. Pressed upon still by air rising from below, and by the constant * pushing in of other air, it flows over laterally, and makes its way *towards* the poles; but before it has passed beyond the tropics, there is a demand for it below, or underneath, from the places it is passing over (in about the northern extremity of the tropics, from 25° to 30°); and if the supply is at any time failing from the poles, the cooling and sinking of the air about that part (30°) will tend to supply the want at the equator: thus there will be (what I will another day endeavour to explain more distinctly) a double action; there will be a pressure downwards of the upper returning current, which has been cooled and dried to a certain extent, on its way to the pole, a pressure of this returning current about the latitude of 30°, and a pressure at the same time from the polar regions, which are generally supplying

* Vis a tergo.

the want caused by the sun's heat rarefying and making the air ascend at the equator.

This double, or concurrent, action is probably a chief cause of the constant accumulation of air, and a greater pressure of atmosphere about the (so called) "horse latitudes," near 30°, where the barometer all the year round stands higher than anywhere else in the world, on an average, if not in extreme cases. I allude to this with a view of showing how the simple principle of the rarefied air ascending, and its place being supplied by colder air, is carried out in the movements of winds, by supply from the colder places, or poles, and the upper currents of returning air. No air can escape from the attraction of the earth; it cannot go beyond a certain distance. Whether our atmospheric air extends further than ten or twenty miles can only be conjecture; perhaps beyond that distance there may be far lighter gas than our own mixed air; there may be much hydrogen, which is the lightest of all gases; but no experiments that have yet been made have proved with certainty what are the constituent parts of our atmosphere beyond five or six miles upwards.

I may here, with reference to some intended observations, allude in the same brief way to the combined action of the earth's rotation with the circulation of the atmosphere. As any body of air which we suppose to start from the equator is making its way northward, whether stopped at the latitude 30°, or carried on to nearer the pole, the earth itself is turning; and the consequence of these combined actions is, that instead of that body of air going direct towards the pole, as the earth turns, this said mass of air, having the velocity of the equatorial part of the earth (not of the polar part, which turns very slowly), moves eastward as it goes northward, and its actual course is towards the north-east.

On the other hand, the cold air from the pole, which starts southerly, meeting parts of the earth that are turning faster and faster, comparatively, is left more and more behind, and becomes while going towards south and west, north-easterly and easterly in effect. There can be no doubt (on the authority of Herschel and Dové, the two first meteorologists,) that such is the system of our winds; and that if referred to when using instruments shewing the pressure, direction, elasticity, and composition of the air, the facility with which nearly all that takes place in the atmosphere can be foretold or explained becomes satisfactory beyond expectation.

One subject, that of clouds, may be only briefly referred to now, as there will not be time for more. A cloud is formed before you, or what may be called and is a cloud, when an urn is smoking or rather steaming on the breakfast table. Steam which ascends from the urn is at first, when it is close to the urn, invisible; but it spreads, becomes visible, and then is dissipated altogether, if not condensed on a cold substance. A cloud is watery vapour, in a state *between* invisibility and water. Perfect gas or pure steam is not visible: what we generally call steam is that same vapour slightly affected by the chill of the atmosphere, or partly turned to a cloud. Steam, when unaffected by external air or cold, is quite transparent. Directly steam expands into air, it is more or less chilled, and the first effect is an appearance of cloud; but as soon as the particles can diffuse themselves, among *comparatively* dry air, the aqueous vapour is taken up, and you see no more of it. The large clouds we see in the air are comparatively near the earth, which is always much warmer than the air high above. A certain quantity of water can be held in suspension in an invisible condition within a given distance of the earth—that distance frequently varying according to the changes of temperature. A certain chill brings it down, perhaps at once, in rain, but between the state of rain, the actual deposition of moisture, and invisible vapour, there is that state which takes place when vapour is only chilled, as seen in clouds. A considerable amount of cold acting upon aqueous vapour existing in an invisible state in the atmosphere turns it into water, condenses it, and then down it comes as rain. If there is not a great amount of moisture, and if it is simply chilled, it becomes like mist or fog. It does not fall in rain, but is like the mist which you see rising from boiling water.

If you go into a laundry when there is much washing going on, you probably find the whole of the upper part of the room full of steam. That steam is cloud, which cannot get away—being confined in the room; if it could get away into the air it would be taken up by the drier air and apparently dissipated, just as a sponge takes up a certain quantity of moisture. The air is generally in a state that will enable it to take up a certain quantity of moisture (more or less according to temperature and other conditions); but as aqueous vapour in the air is invisible under ordinary circumstances, and when condensed by sufficient cold becomes rain, there must be immediate states between the two, which intermediate states are the varying conditions of clouds which we see above our heads, in every condition and form.

Fog and the cloudiness in a room full of steam are similar varieties of aqueous vapour.

Many gentlemen in this room have ascended high mountains and passed through clouds. They found that the clouds, when they were in them, were just like fog, that they got above, and completely out of them, and that the chilly air alone seemed to keep vapours in a visible state.

This appears to be a simple explanation of appearances which some have connected entirely with electricity, and have tried to explain more elaborately; but it has been generally found that nature's works on the greatest scale are precisely similar to her operations on the smallest, and that, what is true of water or vapour of any kind, in a small room, is, if the right principle be fairly carried out, true of all the operations of nature respecting aqueous vapour and wâter on the largest scale in the universe.

I must refrain from further occupying your time now. The subject is one upon which there is inducement to enlarge. Another day I will endeavour to refer more clearly to these subjects in immediate connection with Dové's "Law of Gyration," or rotation theory, and the (so-called) atmospheric waves.

One may call a simple diagram, a circle divided by a diameter from north-east to south-west, the thermometer compass. While the wind is shifting from south-west, by west, north-west, and north to north-east, the thermometer is falling, but while shifting from north-east, by east, south-east and south, towards south and south-west, the thermometer is rising. Now the barometric column does just the reverse. From north-east the barometer falls as the wind shifts through the east to south-east, south, and south-west, and from the south-west, as the wind shifts round northward to north-east, the barometer rises—it rises to west, north-west, north and north-east.

The effect of the wind thus shifting round and traced upon paper by a curve seems certainly wave-like to the eye; but I believe it to be simply consequent on the wind shifting round the compass, and indicating alteration in the barometric column.

If the wind remained north-east, say three weeks, there would be no wave at all—there would be almost a straight line along a diagram (varying only a little for *strength*). The atmospheric line, in such a case, remains at the same height, and the barometer remains at 30 inches and (say) some three or four tenths, for weeks together. So likewise when the wind is south-westerly a long time, or near that point, the atmospheric line remains *low*, towards 29 inches. It is thought heterodox to say, *now*, that "atmospheric waves" are an optical delusion; but—as generally understood, such a misconception is asserted.

Such a diagram as alluded to above shows how the barometer and thermometer may be used in connection with each other in foretelling wind and consequently weather that is coming on, because as the one rises the other generally falls, and if you take the two together and confront with their indications the amount of moisture in the air, at any time, you will scarcely be mistaken in knowing what kind of weather you are likely to have for the next two or three days, which for the gardener, the farmer, the soldier, the sailor, and the traveller, must be frequently of considerable importance.

Among the objects to which meteorologists should chiefly devote themselves seems to be the selection of practically and immediately useful points, in the first instance, and purely scientific ones, for future objects subsequently. Among those most useful, probably simultaneous observations, once or twice in the 24 hours, by general concert of a great number of observers, will be found the most immediately available, because they give a bird's-eye view of the world's surface at a given time, and again synoptically for successive definite times, days, or weeks, perhaps months, from which may be learned what is the regular or irregular succession of weather, what may be expected, and what are the various causes and connected circumstances. Such a plan is now in progress, and we may hope in two or three years to know, at all events in the Atlantic, and the countries bordering on this nearest ocean, what is the usual course of changes and *sequences* of weather during certain cycles—to know beforehand what may be expected, and what changes certain occurrences will inevitably bring after them, so as to become enabled to turn such warning knowledge to practical general use.

Chairman.—I am sure every one who has heard Admiral FitzRoy's exposition of the subject must be deeply impressed with the ability which he has brought to bear upon it, and also the extreme clearness with which he has put the subject before us. When an officer whose time is fully occupied and deeply engaged in the public service (as Admiral FitzRoy's is) favours us, as he has done to day, our thanks may well be in proportion to his devotion to our service. I may offer him also, at the same time, the thanks of the Council of the Institution for occupying so much of his time in explaining the subject.

Friday, March 11th, 1859.

REAR-ADMIRAL SIR GEORGE BACK, D.C.L., F.R.S., in the Chair.

I will endeavour now to explain some of the principal and general movements of our atmosphere,—looking at the world as a whole, and referring to generally prevalent movements, not to merely local peculiarities.

Pray suppose that you are looking at a section of a globe from pole to pole as if looking at our world from a position at some distance outside of it, and taking in the view of a whole hemisphere, and then remember that the effect of the sun's heat, the constant effect throughout the year, is to warm and elevate, or *continue* raising all the body of air in the neighbourhood of the equator from many degrees, say ten or twenty, on one side to many (perhaps more) on the other.

Around the whole circumference of the world it is that zone of the atmosphere upon which the sun exerts the greatest and most constant power, the effect being to keep the air in that particular region continually rising. But it cannot rise beyond a certain distance, because the counter effect of gravitation towards the earth's centre acts. It also gets chilled and cold, after rising some miles from the earth's surface; but being continually pressed upon from below, by air still more recently heated, the upper air must flow away *laterally* (like water seeking its level) in the higher regions of the atmosphere, where it may be said to overflow. Meanwhile, to the lowest spaces adjacent to the ocean or land whence such air has risen, other air will press in from either side to fill what would otherwise be a comparative vacancy; such other air being cooler, and drawn from afar, whether from south or north, or elsewhere. Now that air which has been first warmed, expanded and raised,—then cooled in the upper regions—must go somewhere. It cannot go upwards beyond a certain limit. The consequence then is that it overflows, as has been shown, on each side, part going northward in a direction nearly corresponding with the shape of the earth's surface, or parallel with it; part going similarly towards the south—thus keeping up a continual movement of air towards the poles, *from all parts of the equator, all round the world*, while there is another tendency constantly of the lower air, from the poles towards the equator, *near the earth*. A grand and immediate effect of these constant currents, or as one may say of this circulation, is the phenomenon of the trade and (so-called) anti-trade winds prevailing within certain limits, the former from near the equator to 20 or 30 degrees on each side of it, all round the world, and the latter in middle latitudes, excepting where spaces of land intervene and, from their heat or cold, occasion local or exceptional differences. Speaking *generally*, these trade and anti-trade winds around the world, upon which navigators depend so much, are caused by ascension of the equatorial air, and a supply of its place by other air pressing towards the equatorial places of departure.

Now that cold air (cooler air) flowing in, must of course come from some great source of supply! Where is that source of supply, one may ask, in sufficient quantity? If you compare the size of the world in its equatorial regions, the bulk of it around the equator, with the *small area* near each pole, and consider that the world is constantly turning, the central part being very large and moving rapidly in proportion to the polar, where it has very slow motion, it will appear evident that the mass of heated and expanded air near the equator must be very much larger than the body of air near the poles. It is not only very much larger in quantity, but it has a rotatory motion, very rapid, nearly equal to that of the equatorial earth, which air near the poles has not. The nearer the pole the less the rotatory movement of the earth, the nearer the equator the more rapid that movement; and the atmosphere, which goes nearly with the earth, moves similarly. The result of these combined movements, those of the earth and air, is that warm air which moves towards the pole from the central zone has another impetus, with the velocity of the equatorial regions, and as it goes towards the pole while the *earth turns eastward*, moves faster and faster than the earth does as the polar regions are approached. If you throw anything out of the window of a railway carriage in motion, it partakes of your motion, and instead of dropping behind, it drops abreast of the carriage. So with air that rises from near the equator in its movement towards the poles; and the consequence is, such a prevalence of westerly winds in middle latitudes, that they are justly termed anti-trades. These prevalent winds are at first south-westerly, then westerly or north-westerly in the regions between the tropics and those of the arctic and antarctic circles.

The converse action, which is the easier to understand at first sight, takes place from the pole towards the equator. The mass or body of air or wind, starting from near the pole, moves towards the equator with little or no circular or rotatory movement, because the body of air within the arctic regions is *comparatively* slow in rotation, that part of the earth moving very slowly compared with the equator. Any body of air from polar regions then moves towards equatorial parts to fill the spaces being continually vacated there; but as it so moves the earth is turning to the eastward and the result is a diagonal, a more or less diagonal movement of any such body of air across the world's surface, causing north-north-east or south-south-east, or north-easterly or south-easterly, or easterly winds; *more* easterly as you get nearer the equator; so that the wind which we feel here as a north-east wind actually left the arctic region as a northerly wind, and, probably, when it has passed further south, will become sensibly more easterly. The simple effect of the polar current becoming more easterly towards the equator may be shown easily by moving a pencil from either pole of a common globe, on a stand, towards the equator direct, while the globe is turned eastward. The line traced by hand makes a diagonal (or rather a spiral) line nearly between the two directions. (It is spiral on account of the globular form.) This effect is easy to see; but the other movement, from west to east, and the reason why a body of air moving from the equator towards the pole goes faster than the surface of the earth over which it moves, is not so evident *at first*. It is only after reflection one sees clearly that, the rotatory movement within some degrees of the pole being slow—compared with the rapid motion near the equator—if the air rising from the equator moves with the momentum of that part of the world, as it goes further towards the pole it must move faster and faster over the earth's surface in an *easterly* direction, and the result must be the general or prevalent westerly winds in middle latitudes, which have been lately and justly called by Sir John Herschel and others, the anti-trades.

Referring again to a globe, its poles and equator, we see that extensive central masses of air rise from equatorial regions, move *above* laterally and towards the poles, and that polar currents move nearer the earth's surface towards the equator. Owing to the convergence of the meridians (that is, their approaching nearer and nearer), all the meridians meeting at the pole, from larger spaces at and near the equator, the polar supplies are deficient, and are made up for by parts of the equatorial current, as will be shown. All the body of air round the equatorial region, large and expanded as it is, has a *tendency* to move towards the poles; but it *cannot do so*, there is not *space* enough for it; the law of gravitation acting through this fluid air, seeking its equilibrium, prevents its *rising* beyond a limit; when resisted and cooled it becomes compressed, and then struggles with the polar counter-current for room near the earth's surface. Suppose that a body of air at the equator (which has the above described double tendency, namely, to move eastward and towards the pole), starts from an equatorial place, and moves more and more westerly (from the westward) over the earth's surface as it goes towards the pole, because its motion in middle latitude is faster than the motion of that part of the earth from the west, and it goes, therefore, faster than the earth,—it becomes compressed into smaller space, and also—meets with the polar current making its way towards the equator,—by the turning of the world making a diagonal (or spiral) course which is north-easterly, and afterwards easterly when it gets near the equator. There are thus two conflicting currents or bodies of air, one making its way northward and becoming compressed, having its vapour condensed and (as it were) squeezed out of it by the dry polar current which it meets, and the other making its way towards the equator. The effect of the antagonistic currents of air in raising the barometer about the "horse latitudes," and the return of part of the upper current, when cooled and condensed, to the equatorial regions, has been already described in the first paper. We see the effects of these two conflicting currents in ordinary changes of weather in this country (nowhere more plainly) the wind continually going round by north, east, south, west, and north—round and round again in successive changes, comparatively seldom going round the other way, the retrograde motion being exceptional to the *general* rule, like the exceptional eddies which one may see in the currents of a river when streams are meeting one another, the eddies generally turning one way, but occasionally from some local circumstances, turning contrariwise, as exceptions to the general rule of direct change, which is as the hands of a watch move.

Perhaps these views are not easy to make quite evident at first, more particularly that part relative to the equatorial or heated current going faster than the world, and therefore making westerly winds as it gets toward the pole; but it is the explanation given by Herschel and Dové. Dové bases upon it what he calls the "Law of Gyration," and to him is due the credit of having proved, if not detected, this law, by comparing most perseveringly, during the last thirty years, observations from all parts of the world; and he has shown that this law of gyration applies equally to all parts of the world; that it is not peculiar to the Atlantic or the Pacific, or north or south latitudes, but it is the general law throughout the world, exceptions occurring only over or near countries which are covered with snow or ice, or are localities where the sun's rays strike periodically and cause great heat. Such local circumstances interfere with the regular or normal movements of the winds.

From the "Law of Gyration," it is easy to trace the contests and effect of the two principal winds, which are quite different in their character, the one being warm and moist, having a great deal of watery vapour held in it as gas in an *invisible* state. Sometimes this vapour will be chilled or cooled by approach to the polar current near it; perhaps above, perhaps on one side, causing the vapour to become visible in the shape of cloud, or, when more cooled, precipitating it as rain; at other times, it is invisibly retained in the atmosphere.

Everybody may have noticed, when the wind has shifted from south-west to west or north-west, particularly during bad weather, that the first shift to the northward, or from the south even towards the west, is generally accompanied by a sharp squall, a good deal of rain, and perhaps hail, after which the weather clears up. This is the usual course in our latitude.

The circulation of atmospherical currents need not be only horizontal—it may be at an angle with the earth's surface—or even vertical; but the first effect of any cold current impinging upon the warm equatorial, is to cause condensation of its vapours in the shape of cloud, if not rain, hail, or snow. After this first effect, being dry (comparatively), it acts like a sponge; it takes up the rest of the vapour that there may be in the air. There is no longer precipitation, but all the vapour that it can sponge up (as it were) goes away invisibly; and after a short time, there is a clear sky with a polar wind.

Thus, the first effect of the cold air is condensation, and the subsequent effect of the dryness of the air is the sponging up and hiding the vapour (as it were) in itself: dry air from the polar regions being capable of containing a great deal more vapour in an invisible state than the warm air which comes loaded with aqueous vapour from the equatorial regions—loaded, indeed, with nearly as much as it can carry.

The struggle between these currents over various parts of the earth's surface, occasionally causes the circular storms, now usually known by the term Cyclones, or rotatory gales.

Whether so called or named typhoons, tornadoes, hurricanes, or whirlwinds, circular or rotatory, more or less, they all are, not exactly, but in an elliptically curved form, more or less irregular rather than circular. The outline of such a circulation of wind in one locality, say a few hundred miles in area, may be represented by moving a piece of card paper, with arrows to show directions of the wind, across a part of the earth's surface, as shown on a large map,—the North Atlantic, for example, between England and Newfoundland. The course of the arrows shows how the wind is circulating in that space ; so that, while the wind is at one point westerly, at another it may be easterly,—here southerly, and there northerly: supposing such a piece of card-board to represent a body of air in circular motion, and at the same time moving *bodily* onwards, as these great meteors (for so they may be called) do move,—that is to say, while circulating around their centres, they are also moving onwards across the earth or ocean's surface.

If such a circular paper be moved towards the north-east from near the Gulf Stream, or from the neighbourhood of the West Indies, across the Atlantic (as we know, from ships' logs and collected observations, such rotatory storms do move), the wind will be represented circulating round, while the meteor, or cyclone, travels on bodily towards the north-east. When first touching Ireland the wind would be south-east, but, as it moves on, the wind there becomes south, and afterwards south-west (the air in such a meteor is supposed to be going round, so that there are different winds in different parts, which may be some hundred miles separated). At London such a cyclone might begin with an east wind—which, as it passed on, would become south-east, south, then south-west, west, and then north-west, and north—owing to the polar current driving the meteoric eddy southward again.

The turn or apparent sequence of the winds is, in these cases, what sailors call right-handed, or with the hands of a watch ; but the meteor itself, or the body of air in motion, moves round contrary to the hands of a watch, while the appearance to the eye seems to be the reverse. Take London again for example. Supposing the beginning of the movement is at London, with an easterly or south-east wind, and that it shifts thence to the south, and south-west, and west, and then by north to north-east,—the effect to our eye is that of the wind shifting "right-handed," as we say it does, or "with the sun," but the wind in the cyclone itself has been going round actually in the opposite direction, or against the sun and contrary to the hands of a watch,—which is, perhaps, the best reference for illustration.

In the southern hemisphere there has been some confusion, owing to our seamen always calling this direction right-handed, or with the sun, and the opposite direction left-handed, whether in the southern or northern hemisphere, although when beyond the tropic in the southern hemisphere, and looking towards the sun, he appears to move "left-handed," as sailors call it. In dealing with circular winds of any kind, it is better to refer to the hands of a watch, rather than to the sailors' expressions, "right or left handed," "with the sun," or "against the sun."

There is a very simple rule in connection with these rotatory winds, which is, in the northern hemisphere, when facing the wind, the centre of its circulation is square to your right, and when in the southern, square to your left hand. All the terms, tornado (twisted), typhoon, cyclone, hurricane, and whirlwind, are but different words expressing the same rotatory movement or circulation, of vastly increased strength at times, but not always excessive in force and duration.

We do not usually feel the total circular effect; we only feel part of it; the wind shifting only from some point to some others, because the whole meteor does not often go over any one place; a part of it goes across in general, and, therefore, places on one side of its centre are affected differently from those on the other side, where the wind will appear to shift differently. It is generally found that cyclones, instead of passing horizontally, or parallel to the earth's surface, are inclined at an angle (more or less acute) with the horizontal plane, and we therefore feel only parts of them; there may be several such circulations passing or following in the same direction, and revolving similarly, like eddies, with their lower surfaces on one side of the circulating meteor only, touching the earth's surface, the other parts circling in the atmosphere above our heads, so that we only feel a part of the change, and not the whole of it.

When the centre passes over any given spot there is a sudden change from one direction completely to the other, with probably a lull between. If only an extreme or limb passes, there is a gradual change through nearly half the compass—and very seldom is there an instance of greater sensible change than this, through about half the compass, excepting when successive storms follow one another and cause complications.

Professor Espy of the United States has written much of importance on this subject, and has put forward what has been by some supposed to be a different theory; but in fact his theory is a corroboration of Dové's, and supports such general views as are here offered. Professor Espy says that in a circular storm the wind blows from all directions towards the centre, and it can be demonstrated mathematically that the consequence of the wind blowing from over large areas, some hundreds of miles in extent, towards a centre, will be a whirl near the centre, and a comparative lull in the centre, which is what actually takes place. You find the strongest point of the whirlwind near the centre, but not in it; and the further you get from it, the more the wind diverges from the circular course. You may see a similar convergence in a trough of water with a hole in the bottom. If you open that hole the water begins to pour out, and the water near the opening which causes the movement moves fastest—the outer part moves more gradually. In air there is a somewhat similar effect, as there must be an elevation of the central part consequent on rarefaction or evaporation, which draws air from all other quarters: or there must be a *compression* consequent on two bodies of air passing each other and twisting the air forcibly between: as you see in a river, when one body of water passes another, a succession of eddies caused by such a lateral pressure of currents passing each other. So it is in the atmosphere, only that there these eddies are much more complicated, various, and extensive, on account of the extreme *elasticity* of the air, which not only yields to pressure, but has always a tendency to expand again greatly afterwards—a resilient elasticity not found in water, which is almost incompressible and inexpansive.

With reference to this subject, I would refer to a printed passage written by myself as far back as 1838. "Are not storms exceptions to the general winds or atmospheric currents, not the causes of them? Some persons have laid too much stress upon such exceptions, and have rather overlooked the general principal features—those of the conditions which *prevail almost constantly.* Common winds occur throughout the year, except during short intervals; but hurricanes, or even ordinary storms, are comparatively rare. May not opposing or passing currents cause eddies or whirls on an immense scale in the air, not only horizontal, but inclined to the horizon, or vertical. In laying a ship to during a storm there are other points to be considered besides the veering of the wind, such as the direction of the sea, with or against a current. I never myself witnessed a storm that blew from more than fifteen points of the compass, either successively or by sudden changes. In most, if not all of the storms to which I can bear testimony, currents of air arriving from different directions appeared to succeed each other or combine together. One usually brought the 'dirt,' to use a sailor's phrase, and another cleared it away, driving much of it back again, often with redoubled fury. One of these currents was warm and moist, another cold and dry, comparatively speaking. While one lasted the barometer fell or was stationary; with another it rose. At all places I have visited, or from which I have obtained notices on the subject, the barometer stands high with easterly, and comparatively low with westerly, winds on an average. Northerly winds in the northern hemisphere affect the barometer like southerly winds in the southern hemisphere."

With reference to foretelling weather, I will quote two or three very short passages, also from my own writing. "It should be remembered that the state of the air foretells, rather than shows, present weather (an invaluable fact too often overlooked)." I refer to foretelling weather now, because it is immediately connected with the general law of rotation, or Dové's law of gyration. "The longer the time between the signs and the change foretold by them, the longer such altered weather will last; and, on the contrary, the less the time between a warning and a change, the shorter will be the continuation of such foretold weather. If the barometer has been about its ordinary height, say near thirty inches at the sea-level, and is steady or rising while the thermometer falls and dampness becomes less, north-westerly, northerly, or north-easterly wind, or less wind, may be expected. On the contrary, if a fall takes place with a rising thermometer and increased dampness, wind and rain (or snow) may be expected from the south-eastward, southward, or south-westward. Exceptions to these rules occur when a north-easterly wind with wet (rain or snow) is impending, before which the barometer often rises (on account of the *direction* of the coming wind alone) and deceives persons who from that sign only expect fair weather." "Three things appear to affect the mercury in the barometer:—1. The direction of the wind; the north-east wind tending to raise it the most, the south-west to lower it the most; and wind from points of the compass between them proportionally as they are nearer one or the other extreme points."

What it is that causes these peculiarities immediately connected with the direction of the wind, whether it is entirely owing to the air, the southerly or equatorial wind, becoming lighter from its warmth, or from some electrical condition which is not traced out as yet, is not clearly proved. If connected with electricity, as is probable, we cannot yet deal accurately with it. Here only those facts are admissible which are distinctly verified.

"North-east and south-west may be called the wind's *extreme bearings*." If the wind remain for two or three weeks in either of these quarters, the mercury will remain at its highest or lowest point, the atmosphere appearing steady, with a north-east wind. "The range of difference of height of the mercury due to change of direction *only* from one of these bearings to the other (supposing strength, or force, and moisture to remain the same) amounts in these latitudes to about half an inch, shown by the barometer as read off. 2. The amount, taken by itself, of vapour, moisture, wet, rain, or snow in the wind or current of air (direction and strength remaining the same) seems to cause a change amounting, in an extreme case, to about half an inch; and (3.) the strength or force alone of wind from any quarter (moisture and direction being unchanged) is preceded or foretold by a fall or rise according as the strength will be greater or less, ranging in extreme cases to more than two inches." The barometer is affected to the extent of two inches by the *strength* of the wind, it is affected about half an inch by the quantity of moisture in the air, and perhaps another half-inch by the *direction* only of the wind. As these usually act more or less against each other, and in smaller proportions, the barometer is seldom so greatly affected; and its ordinary changes are not so marked. Such rules have been contracted on the scale of a barometer for the use of fishermen and coasters, in the following manner:

On one side being—	And on the other side—
Rise for N.E^{ly}. N.W.—N.—E. Dry or Less Wind.	Fall for S.W^{ly}. S.E.—S.—W. Wet or More Wind.
Except* Wet from N.E^{d}.	Except* Wet from N.E^{d}.

* (Being the only exception.)

"Allowance should invariably be made for the previous state of the column during some days as well as hours, because its indications may be affected by remote causes or by changes close at hand. Some of these changes may occur at a greater or less distance, influencing neighbouring regions, but not visible to each observer whose barometer feels their effect. There may be heavy rains or violent winds beyond the horizon and the view of an observer, by which his instrument may be affected considerably, though no particular change of weather occurs in his immediate locality." "Sometimes severe weather from an equatorial direction not lasting long may cause no great fall of the barometer, because followed by a duration of wind from polar regions, and at times it may fall with polar winds and fine weather, apparently against these rules, because a continuance of equatorial wind is about to follow. By such changes as these one may be misled, and calamity be the consequence if not thus forewarned."

Reference may again be made here to a useful rule. Supposing that a storm is rising, and that a seaman wishes to know where the greatest strength of wind is. If he *faces* the wind, in northern latitude, the centre of the circulation, or cyclone, will be square to his right; and in the southern hemisphere, if he *faces* the wind, the centre will be square to his left; therefore he knows in which direction to go to avoid that part where the greatest strength is, and must shape his course according to circumstances. He can hardly have a simpler rule. His position with reference to distance from the centre, whether it is near the ship or far off, can be ascertained by watching the falling or rising of the barometer, and the way in which the wind shifts. It only requires a sketch upon paper—a rough figure, with an hour or two's observation of the veering of the wind, to know exactly in which direction to steer, without studying any elaborate rules, which sometimes perplex more than they assist the seaman in the hour of need.

Before leaving this part of the subject, I would again advert to the excellence of the Aneroid as a *weather-glass*, if well made. Compensation for heat or cold has lately been introduced by efficient mechanism. In its improved condition, when the cost may be about 5*l.*, it is fit for measuring heights as far as 5,000 feet with approximate accuracy; but even at the price of 3*l.*, as a *weather*-glass only, it is exceedingly valuable, because it can be carried anywhere; and, if now and then compared with a good barometer, it may be relied on thoroughly. There is a place at the back with a screw-head, which may require to be touched occasionally, to reset the instrument, if out of adjustment. I have had one in constant use for ten years, and it appears to be as good now as at first. For a ship, considering the concussion by the fire of guns, for use in boats, to put in a drawer or on a table, I believe there is nothing better for a common "weather-glass."

The dryness or moisture of the air should be noticed in connexion with foretelling weather; "for ascertaining which the readiest and surest method is the comparison of two thermometers, one being dry and the other *just* moistened, and kept so. Cooled by evaporation, as much as the state of the air admits, the wet, or rather the moist bulb thermometer shows a lower temperature, nearly equal to that of the other, when the atmosphere is extremely damp or moist; but lower at other times, in proportion to the dryness of the air and consequent evaporation, even to a difference of twelve or fifteen degrees in this climate during the heat of summer, and twenty degrees or more elsewhere." I have heard of 25° difference in Australia, and parts of Africa, between two such thermometers. From three to seven or eight is usual in England, and six or seven is considered a healthy difference for rooms in which people are living. The two thermometers need not be connected by one frame; but they should be suspended near each other, and in similar circumstances as to shade, and exposure, whether to air or radiation of heat from any substance within a short distance.

Much has been said, during the last few years, about what are usually called "atmospheric waves," to which I would again refer. If wind veer round the compass, in the course of two or three days (more or less), or is many days in making a circuit—invariably, as it goes round, the barometer rises or falls according to the direction of the wind. Supposing a diagram to represent 36 hours, and divided into spaces of three hours each along the upper horizontal line; while below, points of the compass are shown, from north around by east to north again, and continued to south; and at the side a scale of inches and decimals, from 28 to 31. We may next suppose that the wind has gone round the compass once, or say once and a-half, as happens occasionally; and that it has been an extreme case of depression, as in a storm. Then, if from 30·3, with the wind at north, a shifting occurs, first towards the north-east, and then onward in the same direction around the compass—as the wind so shifts to the north-east, and is about to shift towards the east and south, the barometer foretells it, or falls beforehand. When the wind is north-east the mercury is lower, probably, than when it was at north. As it gets to the east the mercury falls, and gets lower still at south-east, and falls still more to south and south-west, where it is probably the lowest, because it feels the effects of the south-westerly or equatorial current most then, and may be down, let us suppose, to 28·2 inches. As the wind shifts round to south-west, west, north-west, the column in the tube rises, till, perhaps, the wind is north, or even north-east, when it may be as high as 30·8. It has been known in this country as high as 30·9. As the wind goes round again to the east, and south-east, and south, the barometer falls as before, and a line or curve traced upon paper, representing these falls and rises, or oscillations of the barometer, during a certain time, say these 36 hours, has an appearance like the outline of a wave of water; but as these apparent waves, or undulations, take place *exactly* as the wind shifts, and proportionally to its strength—and as, if the wind remains in one quarter for some days, or say two or three weeks together, the curve becomes almost a direct line, remaining at about the same elevation, it seems that there is an intimate and immediate connection between such a curve, or wave line, and the oscillation of the mercury, though not necessarily between the curve and any undulatory movement of the atmosphere above our heads. If a body of the atmosphere above us swelled upwards, like a wave, and fell again, as some suppose, as it were in "crests" and "troughs," how should we reconcile it with the fact of there being various currents passing over each other in the atmosphere in various directions? Aeronauts who have been up in balloons know that from one stratum of air they passed into another, and another, and perhaps a fourth also, moving in different directions. There cannot be *vacancies* between the undulations of various strata of air. These different bodies of atmosphere could not be undulating like waves while having spaces between them, and interferences of cross movements. Waves of ocean have only elastic air above them, which does not impede their rise and fall materially; and they are only superficial.

The effect of such a raising of any part of the mass of air would be that the lighter or equatorial portions, or winds, would rise the highest, and would expand; but, according to the "Wave Theory" (here controverted), the reverse is the fact; you have the lowest part of the apparent trough of the wave, with the lowest barometer, that is, with the air, which is the *lightest* and most *expanded*, and ought (therefore) to rise up the *highest;* and you have, coincident with the heavy dry air, the highest part, or what is called the "crest," of the wave. Considering then these facts, and the exact correspondence of the movements of the mercury with the wind's direction, besides noticing the extreme variability traceable in such an atmospheric wave, (which can hardly be conceived to be motionless for weeks, as in the case of a steady north-easterly wind, and then going into extraordinary irregularity during a day or two,) we are led to the belief and assertion that what are commonly called "atmospheric waves" are rather delusive; that there are waves in any line indicating oscillations of the barometer, but not traceable in the atmosphere itself, as usually understood by "trough" and "crest" outlines.

Before referring very briefly to the effect of winds upon our own climate generally, I would allude to a few considerations connected with the ocean. It may not perhaps be generally known that over the ocean, in most parts of the world, the average temperature of its superficial water is nearly that of the air near its surface. In the tropics, the temperature of the sea water ranges from 70° to 80° or more, and the air is much the same. In some limited parts of the world the surface water is as warm as 86°, for instance, near the Galapagos Islands; and in some very confined localities, even *more than* 90°, as, for example, in parts of the Red Sea and Indian Archipelago. But, although so warm on the surface, it is very much colder at a few hundred fathoms below, the cold increasing to perhaps 35°. It was long considered that 39° must be the greatest cold that could be found in the lower ocean, being nearly that at which water is condensed; but reliable observations, during the last few years, have shown temperatures apparently as low as 35°. The effect of this great variation of temperature, and therefore in quality of water, or the varying state of the water itself, the action of the winds upon the surface, also of evaporation, of rain, and lunar action, combine to cause constant movement analogous to, if not a circulation of the ocean, like that of the atmosphere, though on a much more limited scale, and perhaps not sensibly affecting very great depths. There is, for instance, the well-known current called the Gulf Stream, which runs from the Floridas across the Atlantic towards Europe, with a temperature ranging from 80° to 60°, and underneath which there is a current which several observers, including Captain Cochrane, have found to be as low in temperature as 36°, or less. Off the Cape of Good Hope there is a similar remarkable mixture of extremes of temperature within a very short distance of each other. The Lagulhas stream, running from near Madagascar, by the coast of Africa and the Cape of Good Hope, has a temperature of 70°; but near the Cape meets with cold water from the Antarctic regions, at a temperature ranging from 40° to 50°; and these currents occasionally intermingle, sometimes near the surface, sometimes below it, so that one may dip a thermometer in the water at one hour, and find 45° or 46°, and an hour or two afterwards find from 65° to 70°. Similar places occur in the Pacific Ocean, and one very marked, near the Galapagos Islands, on the north-west and south-east sides of the group.

The effect of such warmth of sea-water, particularly that of the Gulf Stream, upon our own climate, and the waters that are near the shores of other countries upon land adjacent to them, need hardly be referred to even in passing, except to remark that wind blowing over a body of warm sea-water is warmed and otherwise affected perhaps chemically.* Those countries which are exposed to the sea-winds of the lower and middle latitudes all round the world, in the northern as well as in the southern hemisphere, bringing moisture and warmth with them, are milder in climate and more favourable to vegetation than those countries which are exposed to dry land winds, whether hot or cold. Tropical, or other east winds, from over an expanse of ocean, carry vapours and rain. But they differ in some respects from the westerly. Polar currents in general carry but little moisture, excepting where they have passed over, immediately before reaching the land, a considerable expanse of ocean, whence they have taken up evaporated moisture, and therefore acquired a character more like that of ordinary sea winds, though not so moist and beneficial in nature. Generally speaking, sea winds are more or less charged with vapour, but land winds are usually dry and very different in their qualities, according to the country traversed.

It has been much discussed in Scotland within the last two or three years whether the Gulf Stream has really so much effect upon our climate as has been usually thought, and it has been chiefly questioned because experiments have been made with thermometers close in-shore, within twenty or thirty fathoms, where the water has been affected more or less by rivers, or the land near it, and has not been found nearly so warm as the winds or water of the Atlantic—but this seems to be rather a fallacious ground of argument. There is no doubt that along the coast of Norway, as well as the coasts of Scotland and the Hebrides, the warming effect is such that all ice is kept out of the harbours there. The climate is mild all the year round, even at the North Cape; while on the western, or the opposite side of the Atlantic, ice comes down in-shore to a very much lower latitude, even below Newfoundland.

The Consul-General for Norway (J. R. Crowe, Esq. now in London) says, that within the last few hundred years ice has increased along the east coast of Greenland very much, according to authentic records which he has consulted. There were colonies, several centuries ago, on the east shore of Greenland, then an open coast, which were destroyed by being blocked up by ice, and have never been heard of since.

The space between Iceland and Greenland is now blocked up entirely, although some centuries ago it was quite open; while between Iceland and Nova Zembla there is still a very large space of open water, and for 200 miles round the Naze, or North Cape of Norway, *no ice is ever seen*. The Gulf Stream is found to communicate its effects across the Atlantic by more or less narrow streams, or threads, of warm water, even to the eastward of North Cape, where none of the harbours are frozen up throughout the year, and where fishermen work in lighter clothes than they use further to the southward.

In some countries, where the wind blows almost constantly in one direction, vegetation is abundant on the side against which the wind blows from the ocean, an inexhaustible source of moisture, while on the other side there is scarcely any vegetation at all; as in Peru, Patagonia, parts of Arabia and Africa, various islands, parts of Asia and of Australia, where all the moisture from the sea winds has been condensed and

* *e.g.* Ozone.

extracted; and in passing across extensive land, the other sea-side, as in Peru, receives only dried air from the land, and the country is more or less barren. So in many other places, wind carrying moisture affects one side of a hill or mountain, and does not affect the other equally. Our own climate being exposed to south-westerly, westerly, and southerly winds for about three-fourths of the year, is remarkably favoured in this respect, as these winds are not only moist, but warmed in passing over the warm waters of the ocean, both tropical, and of the more expanded part of the Gulf Stream.

There can be no fear of any material change in our climate under such peculiar circumstances, but it may be very questionable how far the northern regions,—those in the latitude of Iceland and from Newfoundland across to Norway,—how far these countries may be affected by the increase or diminution of ice in the Arctic regions; and this is a question which may also have its weight with reference to our own seasons.

The temperatures of the depths of the ocean have been ascertained by thermometers peculiarly constructed, self-registering, and showing maximum as well as *minimum* temperatures, or minimum only, which is probably sufficient, and admits of the instrument being *narrower*, a considerable advantage in *sounding*. Such instruments must be strong enough to resist the pressure of the ocean at two or three miles depth, where there may be a force exerted to compress them, exceeding two hundred, perhaps three hundred, atmospheres (of 15 lbs. to the square inch).

The specific gravity of the ocean has been tried lately, in nearly all parts of the world, by small glass hydrometers; and the general result is that the specific gravity of the salt water is very much the same in all places, except where affected by recent heavy rains, or by water from the mouths of large rivers ; the differences in the specific gravity being found to be less usually than the common errors of observation with the hydrometer, which may occur if it is put into water without being carefully wiped. From the mere carelessness of not thus cleaning it, a difference of two or three divisions of the scale may be caused. The instrument is however *very accurate if correctly used.*

The general result seems to be established that the ocean is almost everywhere at the surface within one or two divisions of 1,027 (calling distilled water 1,000 grains), the sea-water averaging 1,027 grains in weight. The difference between various parts of the ocean, taking the whole world, being not more than 2 or 3 of these divisions from 1,027, or from 26, in short, to about 28, which is, as I said, rather less than the difference between using the instrument carelessly and accurately. In the Red Sea a specific gravity considerably higher than 1,028 is said to have been found; and some of the eastern seas show similar exceptional instances (*said* to extend to 1,080 in the Red Sea.)

Interest has been caused lately by what is called Ozone, which has been thought to affect health considerably. Whatever may be the real chemical or philosophical explanation, the known facts at present appear to be that ozone is chiefly found on or near the sea, and that winds which blow towards the land from the nearest sea bring the most ozone. Lieutenant Chimmo has lately observed that in the Hebrides, and on the north-west coast of Scotland, there is more ozone than he found in other places, including the great ocean, and, on comparing notes from different parts of our own coasts, it is remarkable that the wind which accompanies the greatest indications of ozone is that which blows from the nearest and largest sea. When Mr. Jansen, of Holland, and Dr. Mitchell, of Edinburgh, made observations in India, in the Atlantic, and in Algeria —Mr. Jansen's being between Batavia and England—they found, by independent methods, that over the sea, clear of the land, there was most ozone, and that over land or hills near the sea—hills against which the sea-winds blew—there was more than in the valleys or in other places which were separated from the sea, and that inland, about towns, and in inland places generally, there was exceedingly little.

This seems to point to a connection between ozone and chlorine gas, which is in and over sea-water, and which *must* be brought by any wind that blows from the sea. I will not here make any further reference to its peculiarities, except one—its possible affection of the gastric juice—as it is a rather too purely chemical question. I will only repeat, that at present the results of various different observations of ozone show that the greater prevalence of it is with wind that blows from the nearest sea; and that it prevails more over the ocean and near it than over land, especially land remote from sea.

It is intended in the course of the next twelve months to endeavour to obtain simultaneous observations of wind, weather, and other meteorological information, over the whole Atlantic, and round the coasts of this ocean, by enlisting the aid of observers in every quarter, for one or two observations only, in each day; with a view of getting at the exact state of each portion of the atmosphere, over our nearest ocean, during one particular time, on certain days, and then mutually comparing those successive and synoptic *views*, as it were, of the atmosphere, in order to discover the usual or normal sequence or succession of winds and weather, as more particularly affecting seamen and agriculturists. A memorandum has been circulated, and instruments specially suited have been lately forwarded to Halifax, Bermuda, and other places. The following extracts are from that memorandum:—

"The Royal Society and British Association for the Advancement of Science, having made official application to Government in favour of the establishment of anemometers at certain selected stations, the Meteorological Department of the Board of Trade and Admiralty has prepared two such instruments, and arranged for their conveyance to Halifax and Bermuda. It is proposed to request the principal authorities at each place to give aid in placing the anemometer and arranging for careful attention to it once a-day during the limited period of intended investigation of atmospheric laws throughout the Atlantic ocean.

"This period will commence at Midsummer next, and continue uninterruptedly until the following midsummer. During this interval of twelve months a collection of meteorological information will be sought from every part of the Atlantic Ocean—from ships, and from observers on its coasts and islands.

"It seems only necessary to state the object in view, and how the undertaking originated and is supported, to ensure hearty co-operation."

The scientific questions at issue that will derive so much advantage from the great collection of observations that is now being made in America, France, Holland, and this country, should not be allowed to extend indefinitely, lest the data should grow overwhelming. Up to the present time the practical results, as far as navigation, and what one may call "weather wisdom," are concerned, are satisfactory. On board ships, attention to signs of the weather, to winds and currents, and magnetism,—and consequent avoidance of accidents, besides saving life,—have been remarkable.

On our own coasts there is now, in almost every fishing village, some kind of barometer, and attention is paid to its signs of weather. Fishermen do not often now go out at hazard, but watch the instrument and the sky, and judge for themselves. If practical results of meteorological investigation can be turned to account even thus in the present day, besides gathering materials for scientific men hereafter, those who co-operate is the work must have reason for conscientious satisfaction, which indeed in their highest reward.

CHAIRMAN.—The elaborate and instructive lecture which Admiral FitzRoy has given us has been listened to with the greatest interest and attention. Seeing the beneficial results that have followed already from such labours, I have no doubt that at some future day, when further carried out, not only many ships, but very numerous lives, will have been saved, in addition to all the commercial and purely scientific advantages derived. I beg to call upon you now to join me in a vote of thanks to Admiral FitzRoy for his lecture.

The motion was carried unanimously.