local cause. The southern slopes of these islands, bearing little vegetation, exposed to the rays of a powerful sun and sheltered from the trade wind, produce a dilatation of the atmosphere in the neighbourhood, which rises along the slopes and overflows at the summit, overcoming and, to a certain extent, reversing the trade wind. Humboldt and others have been led by this phenomenon to believe that they were in presence of the counter-trade.

It would not occur to any one to pretend that the counter-trade does not exist. The masses of air drawn into the tropical regions by the trade winds of both hemispheres, must regain the regions abandoned by them, but the path which they follow is still unexplored.

After a season's work with kites in the Atlantic, I resolved to apply to the meteorological research of the atmosphere at great altitudes above the ocean, the system of *ballons-sonde* which had already been giving excellent results on the continents. With the assistance of Professor Hergesell I made several tentative experiments in the Mediterranean in the spring of 1905, chiefly with the view of making myself familiar with the difficulties which such operations present, and especially with reference to the recovery of the balloon when it has descended again on the sea. The final method of procedure was the following.

Two very light india-rubber balloons were inflated, one to a slightly greater extent than the other, with hydrogen of which a supply was carried in steel cylinders. The less inflated balloon carried the registering instrument, enclosed in a small basket, an instrument analogous to that used with the kites, but more complete, as well as a float suspended at the end of a line 50 meters long. The more inflated balloon was connected with the other by a line also 50 meters in length. Its function was, first, to facilitate the ascent by rendering the necessary assistance to the other balloon and, afterwards, to facilitate its descent with the registering instrument by quitting it at the altitude determined beforehand by the degree of inflation given, on which depends the height at which the balloon burst. The first balloon, now become a simple parachute, brought the instrument back towards the sea, above which it remained floating so soon as the float at the end of the stray line touched the surface of the water. In this way, the basket containing the instrument was kept clear of the waves, and the balloon remained visible at a distance of 8 to 10 miles. During the ascent it was necessary to make observations as often as possible with the sextant and the compass so as to fix the altitude and azimuth of the balloons at different instants with a view to establishing the route followed through the air, and thus to obtain the elements for arriving at a knowledge of the strength and direction of the aerial currents in the different layers traversed. It must be understood that the ship was following the system at full speed, in order not to lose sight of it, a result which was obtained, thanks not only to the excellent prismatic glasses used, but also to the keenness of sight of some of the observers. An operation of this kind was possible only in very clear weather, because the disappearance of the balloons behind a cloud would have made very doubtful the discovery of the place where they fell.

FIG. 1.—Filling the balloon and stopping up small holes.

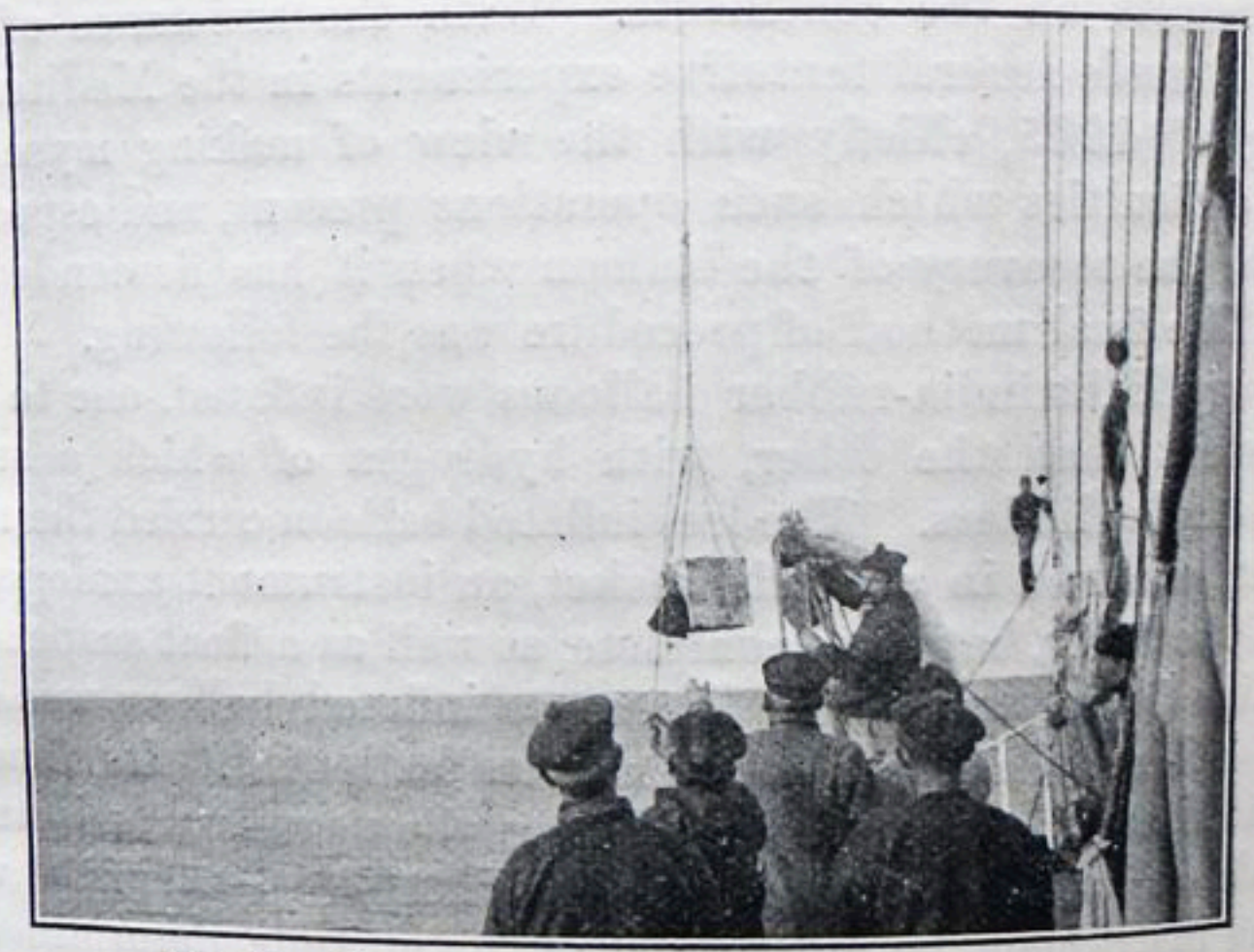

FIG. 2.—The instruments coming safely on board.

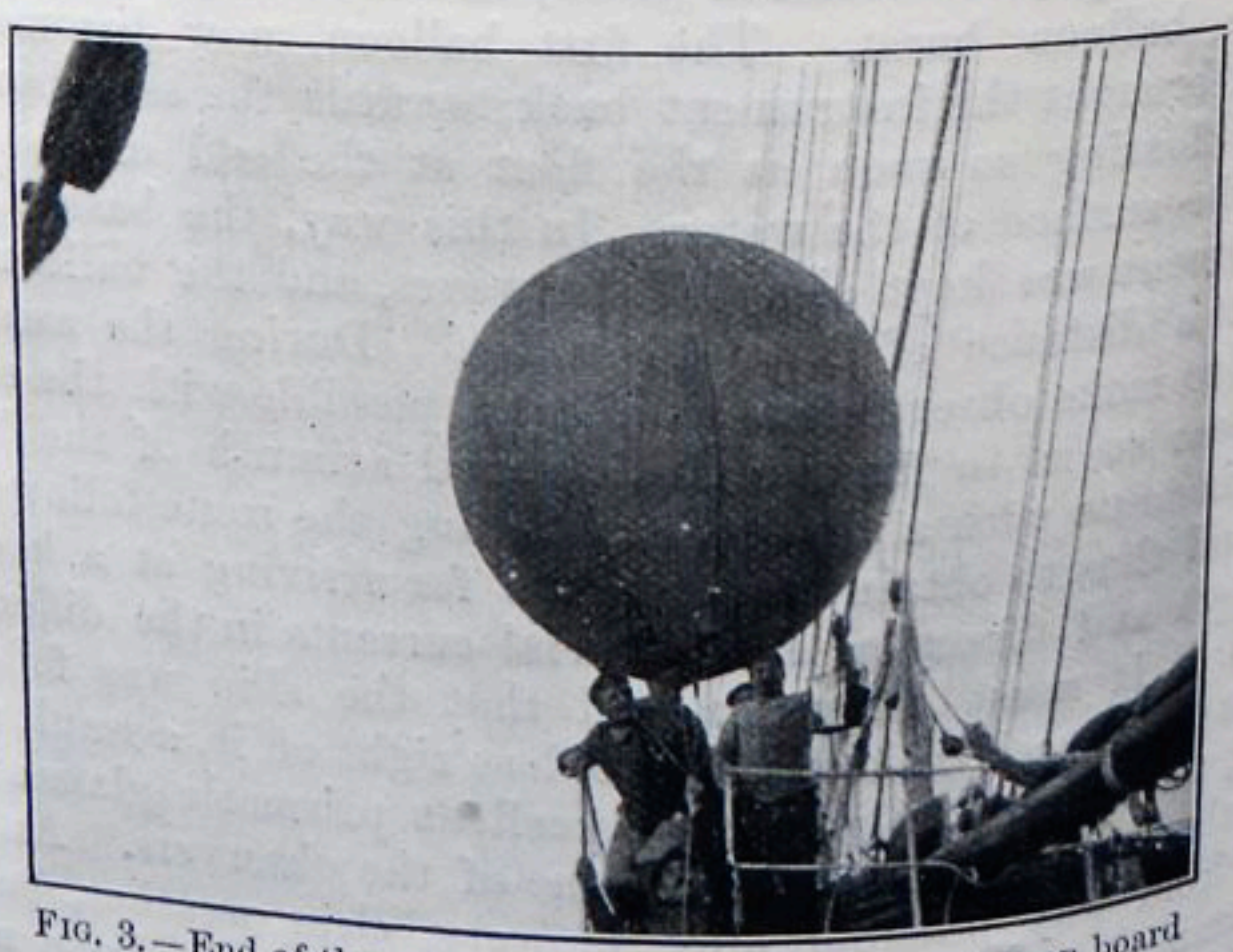

FIG. 3.—End of the experiment, the balloon returning on board with the baskets for the instruments.

In these conditions I made a cruise of 5500 miles in 1905 in the Atlantic, during which eighteen experiments were made with balloons up to a height of 14,000 meters, of which most were successful, and confirmed the conclusion of the previous year with regard to the counter trade-wind, arrived at with kites used at lesser elevations.

But this method presented various grave difficulties; first, the recovery of the balloon if it had been sent to a great height, and second, the exact fixation of the point where the ascent of the balloon would be stopped by the bursting of the subsidiary balloon. In fact, any fault in the india-rubber of which the balloon was made might advance or retard the time of explosion. From the year 1905 we have sought to remedy these difficulties, and have succeeded as follows.

In the first place, we can now recover the balloon with its instrument, no matter what may be the distance of the point where it reaches the sea. Relying on the fact that, from its culminating point down to the surface of the sea, the system passes through meteorological conditions which are sensibly similar to those which it had met with during its ascent, we have established a formula which permits us, if we have followed the balloons during the greater part of their ascent, to trace rapidly on the chart the route which the *ballon parachute* will follow during its descent, and consequently, the point of the sea where it will fall. The ship can now be steered for this point without the necessity of following the balloon. Our formula has afforded us the means of finding the balloon on all occasions when its course has not been disturbed by accidental causes. We made the first successful use of the formula in the summer of 1905.

In the second place, we can now arrest the ascent of the balloons at the desired height. The bursting of the subsidiary balloon is no longer used on my ship for this purpose. It presents some irregularities, which however do not affect the validity of the results obtained, because the barometer indicates with precision the altitudes traversed. The subsidiary balloon is now detached from the system altogether at the desired height by the action of the electric current furnished by a small dry cell on a spring, which takes effect the moment the pen of the recording barometer touches a conductor set for the desired altitude. In order to be sure that the cell will act at the great altitudes where the cold is intense, it is surrounded by a calorific envelope, which does not require to be very powerful, because the balloons, having a velocity of ascent of 300 meters per minute, attain these heights very rapidly. We made the first application of this method in 1905.

But the *ballons-sonde* are not the only apparatus which we have employed, along with kites, for investigating the phenomena of which the high atmosphere is the seat. In certain circumstances, for instance, when the sky is covered with clouds, or if the vicinity of inhospitable land makes it unlikely that balloons would be recovered, we have used captive balloons, sent to moderate heights. A *ballon-sonde* was fixed to the end of the very light wire of the kites, and when it had reached the greatest elevation which its ascensional force, diminished by the weight of the wire, permitted, a second balloon was allowed to slip up

along the wire which, when it arrived near the first, gave the system a fresh charge of ascensional force and permitted it to rise higher. In this way we sent a group of three or four balloons, selected from those which had served as *ballons-sonde*. Having already been exposed to very great dilatation in the high atmosphere, it was not thought safe to use them for this purpose again. The recording instrument was attached to the last balloon, which could then ascend along the wire with a velocity sufficient to afford adequate ventilation for the thermometer. In this connection I may observe that the use of *ballons-sonde* offers very considerable advantages over that of the kites, by the exactness of the temperatures registered, which is due to the ventilation which the thermometer, placed in a sort of chimney, receives during the ascent. The ascent also is effected at a much higher speed.

We have also launched pilot balloons, which sever all connection with those who dispatch them. They rise to prodigious heights and disappear for ever. They carry no instruments, but they furnish valuable information regarding the direction and the violence of the aerial currents in the highest regions of the atmosphere. The following is the manner of their employment.

The weather being clear and otherwise favourable, three observers, —forming a triple alliance—land on the shore of a continent or of an island. They take with them a small balloon inflated to a diameter of not more than one meter, and a theodolite, the telescope of which is especially powerful. The balloon may, however, be retained on board to be launched at a given signal from the shore.

The theodolite used by Professor Hergesell, if established on solid ground, permits the observer to follow the balloon without losing sight of it, whilst his two assistants read and note, every half minute, the angles furnished.

Finally, in 1906, we have attempted, and with success, a third method which allows a certain amount of exploration of the atmosphere, notwithstanding the presence of clouds, but with a clear horizon. It is then necessary to furnish the balloon with means capable only of taking it to such an altitude that it can regain the surface of the sea at a distance which does not exceed the limits of visibility. The ship is then stopped on the spot where the balloon was started, and attentive observers watch all directions in order to detect its return from above the clouds. The only experiment of this kind which we have made, succeeded perfectly, and the balloon, which had reached a height of 4800 meters on a day when the sky was completely covered by very low clouds, was detected and recovered at a distance of twelve miles.

Now, what results have been furnished by this new use of balloons over the sea? It is, after the first exploration made with them in the region of the trade winds during the cruise of 1905, towards the high atmosphere of the arctic regions that I have carried on my investigations to increase these results. I therefore took measures, in concert with Professor Hergesell, so as to be able to make the best use of the opportunities offered by my cruise of 1906. The balloons, the instruments,

and the methods afforded a better guarantee of successful results than in 1905.

But I was much hampered in the execution of one part of my programme by the persistent fogs over the sea to the westward of Spitsbergen, although in the bays and on land the weather was magnificent. Thus the dispatch of *ballons-sonde* which the preliminary experiments in the Mediterranean had rendered perfect of execution was stopped by this unsurmountable difficulty. Twice only was it possible to dispatch them. Nevertheless the information received is not without value, since our registering instruments have brought back curves from an altitude of 7500 meters in latitude 78° 55′ N.

In presence of continual fog at sea and the impossibility of launching usefully *ballons-sonde* in the neighbourhood of inhabited lands, we have frequently employed our *ballons-sonde* as captive balloons, as I have already explained.

But our best results have been realised with pilot balloons: these instruments, which are small enough to be embraced by the arms of a man, have been followed with a special theodolite to the extraordinary altitude of 29,800 meters (97,700 ft.), if it is assumed that their velocity of ascent increased a little with the change of density of the atmosphere in the most elevated regions; or at the very least to an altitude of 25,000 meters (82,000 ft.). Further, the one which attained this height was, at the moment of its disappearance, at a distance of 80 kilometers (49½ miles) from the observers. So remarkable a result is explained by the transparence of the atmosphere in the Arctic regions, a transparence which under other circumstances permitted us to follow distinctly on the snow of a glacier, at a distance of 40 kilometers, the movements of a party of four persons whom I had sent on a mission of exploration in the interior of Spitsbergen.

The information furnished by the pilot balloons which carry no instrument because they are sacrificed, concerns questions of capital importance for meteorology; the direction and the velocity of the upper currents. Now our pilot balloons of 1906 have taught us that there exists in the Arctic regions in the neighbourhood of the 80th parallel, at a height of about 13,600 meters, certain winds of 60 meters per second (132 miles per hour), a force for which we have no equivalent at the surface of the globe. Their direction was S. 68° W.

The theodolite which we employ permits the two assistants of the one who observes the balloon while keeping it continually in the axis of the telescope to note at every moment its position in space, its altitude as well as its path, and the velocity of the currents which it traverses from its departure to its disappearance.

We made thirty explorations of the high atmosphere in the arctic region of Spitsbergen in 1906, and twenty-six in the Atlantic ocean or in the Mediterranean in 1905; and the results of these cruises show that if the principal states of the world were willing to diminish a little the expense of international quarrels by submitting them to the judgment of a tribunal less costly than that of war, and if they preserved more of their resources for the veritable interests of humanity, it would be

possible with powerful means, very soon to ascertain the laws of meteorology, the key of which seems to be found in the higher atmospheric regions. It remains only to add that Germany has just sent to the Atlantic and the Indian oceans a special ship, the *Planet*, to continue and extend my aerial explorations. On the other hand, Messrs. Teisserenc de Bort and Rotch have fitted out and used during 1905 and 1906 a ship of their own for this purpose.

I am also very pleased to mention the share taken in my three Arctic expeditions by one of your Scottish meteorologists who has become a distinguished oceanographer, Mr. W. S. Bruce, the leader of your fine Antarctic expedition of the *Scotia*, one of the most fruitful of those which have explored that region in the last few years, and one whose success is the more pleasing to your country because it was carried out at very moderate financial expense. It is to be hoped that the future will permit him to continue his scientific work. This year Mr. Bruce again accompanied me with two assistants to the Arctic regions to undertake the exploration of a large island off Spitsbergen, Prince Charles Foreland. He carried this work out under weather conditions as unfavourable for the work of survey as for navigation.

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