At 6 a. m. on the 26th the relative humidity was 90 per cent, the air temperature 32°, and the dew-point 30° on the roof of the Federal building in Grand Junction. Temperatures near the ground usually run 3° or 4° lower.

As it was probable that peaches, in their advanced stage of development, could not withstand dry air temperatures much below 31°, smudges were lighted in the Palisade district, but they were extinguished when the more effective natural heat preserver made its appearance.

The cloud moved in from the NW. and increased in size as it progressed, thus affording protection to all districts.

The thermogram clearly indicates the arrival of the cold NW. wind at 3:30 a. m., and the barogram shows increased pressure just after the aqueous vapor was condensed and its place filled with colder and drier air.

MAPPING THE OCEAN OF AIR.

551.55

By C. E. P. BROOKS.

[Meteorological Office, London, England, Nov. 8, 1920.]

The development of flying, and especially the establishment, actual or proposed, of various commercial flying services, involves an urgent call upon meteorologists to do that service for aviators which they have already done for seamen, namely, to chart the wind currents, in this case not for the surface only but also for the free air. The obvious way of doing this is to study the air movements at different levels directly, by the reports of aviators, by kite and balloon ascents and by studies of cloud motion. It is to the second of these, the kite and balloon ascents carried out at various aerological observatories and on aerological expeditions, that we must at present refer for most of our direct records of air movement in the free air. The most important of the observatories for which the observations have been summarized are those at Lindenberg near Berlin and Blue Hill in Massachusetts, at both of which a large number of observations have now been accumulated and partially tabulated.[1] For Lindenberg the observations are summarized seasonally as percentage frequencies under sixteen directions and five velocity stages, for every half kilometer level from the surface to 4 km.; this is the most valuable as it is also the fullest and most laborious way of presenting the results. The Lindenberg observations have also been employed in several valuable special investigations, such as that by A. Peppler on wind velocity and "veer" in cyclones and anticyclones.[2] The Blue Hill results are given graphically in the form of separate winter and summer wind-roses of frequency and velocity for heights of 650, 1,650, 3,300, 6,600, and 10,000 feet (i. e. surface and approximately ½, 1, 2, and 3 km. above M. S. L.). This volume also contains similar wind-roses for the trade wind region of the Atlantic Ocean, based on observations by Teisserenc de Bort and Lawrence Rotch on board ship[3] and another chart of considerable historic interest, illustrating aerial routes across the Atlantic eastward and westward, for an airship with an engine speed of 25 miles per hour. Observations with kites are now being taken regularly at several stations in North America and published as supplements to the MONTHLY WEATHER REVIEW.[4] J. Rouch[5] gives frequency wind-roses, with indications of force, up to 6 km. at Paris, and at 1 and 2 km. for various points in the western Mediterranean. Unfortunately these diagrams refer only to summer means, and their meaning is not made clear in the text.

The Italian Aerological Service has developed into a very active organization, publishing a *Bollettino Aerologico*, which gives in the form of a daily report tables and charts of the wind up to 5,000 meters obtained by the use of pilot balloons, with other data of interest to aviators. In the last report available, that for December, 1918, 63 stations were in operation, though all these did not send up balloons every day. This form is very useful for day-to-day purposes, but before the data can be utilized for "pilot charts" some form of frequency table or wind-rose is necessary, and it is only at the moment of writing that tabulations in this form have begun to come to hand.[6] Without such summarizing the results are difficult to handle, and to make full use of them they should be tabulated not only under directions, but also under different limits of velocity for each direction, with auxiliary tables showing the normal change of velocity and veer from surface conditions to different heights.

The only other summary of pilot-balloon results on a large scale which has been published is based on observations at Batavia. W. van Bemmelen[7] gives a table showing the resultant direction and velocity of the wind in each month for each kilometer up to 24 km. This form is valuable for theoretical investigations, but for aeronautical purposes is less useful than the detailed frequency form adopted for Lindenberg. It can, however, be employed for finding the best levels to make for when flying in any particular direction.

Mention must also be made of the German aerological expedition to the Indian Ocean and Lake Victoria Nyanza,[8] though the observations have not yet been tabulated into a form suitable for free-air wind-roses.

Of great importance also is the long series of autographic records, commencing in 1890, at the summit of the Eiffel Tower in Paris,[9] at approximately 1,000 feet above the ground, but similar direct observations are not likely to be available elsewhere or at greater heights except on mountains, where there is always the probability of local disturbance of the general conditions.

As regards the observation of cloud movements mention must be made of the researches of Hildebrandsson,[10] but these deal chiefly with the highest cloud levels and have only limited applications to aviation at present. Summaries of the directions of motion of clouds at various levels are made in many climatological discussions; these results, however, have a certain disadvantage compared

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[1] For Lindenberg see e. g. Assmann R: *Die Winde in Deutschland*, *Braunschweig*, 1910. For Blue Hill, Rotch; A. Lawrence and Andrew H. Palmer: *Charts of the atmosphere or aeronauts and aviators*, New York, 1911.

[2] Peppler, A.: Windgeschwindigkeiten und- Drehungen in Zyclonen und Antizyclonen, *Beitr. Phys. frei Atmosph.*, Leipzig, 1912, 4, p. 91.

[3] *Travaux scientifiques de l'Observatoire de Météorologie dynamique de Trappes*. Tome 4. Étude de l'atmosphère marine par sondages aériens, Atlantique moyen et région intertropicale. Paris, 1909.

[4] Owing to the extension of aerological work in the Weather Bureau, there has now accumulated a very large mass of observational data, both from kites and pilot balloons, the discussion of which will probably represent the best information on the upper air over the United States. Such a discussion is now in preparation.—EDITOR.

[5] *Préparation météorologique des voyages aériens*. Paris. Masson & Cie, 1920.

[6] Gamba, P. Risultsti dei lanci di palloni-sonde e palloni-piloti effettuati nel R., Osservatorio Geofisico di Pavia nel 1909, . . . 1910, . . . 1911, . . . 1912. Roma *Ann. Uff. centr. meteor. geodin.*, 1911, 33, 176; 1912, 34, 160; 1913, 35, 112; 1914, 36, 156.

[7] The atmospheric circulation above Australasia according to the pilot-balloon observations made at Batavia. Amsterdam, *Proc. K. Akad. Wetensch*, 20, 1919, p. 1313.

[8] Lindenberg, *K. Preuss. Aeronaut. Observatorium*. Bericht über die aerologische Expedition nach Ostafrika im Jahre 1908.

[9] Angot, A.: Études sur le climat de la France. Régime des vents. Paris, *Ann. Bur. Centr. Météor.*, 1907, pt. 1, p. 76.

[10] Hildebrandsson, H. H.: *Résultats des recherches empiriques sur les mouvements généraux de l'atmosphère*. Upsala, 1918. (Translation in MO. WEATHER REV., June, 1919, 47:374–389; discussion by W. R. Gregg, ibid, September, 1919, 47:649–650.)

with pilot balloons, because the latter refer to the best flying weather and the former to conditions more or less disadvantageous.

There is no doubt that as pilot-balloon observations are multiplied frequency and velocity wind-roses for various levels in the free air will be constructed for other stations, but the data available are at present scanty, and several years must elapse before sufficient observations exist for reliable direct results at a network of stations.

An alternative method, which though indirect is at present much more feasible, is based on the theoretical study of the relations of wind force to pressure gradient. A synchronous pressure chart at mean sea level corresponds to a certain actual distribution of surface winds; it also represents by the direction and closeness of the isobars the "geostrophic" wind, which is what the wind would be were there no surface friction. In practice it is found that the theoretical wind based on the measurement of the isobars at sea level gives a good approximation—when numerous observations are considered—to the actual wind prevailing at a height of between 1,000 and 2,000 feet. Hence by measuring the gradient on a series of daily weather charts we can obtain tables or charts showing the frequency of geostrophic winds of different directions and velocities, and we may assume that these represent conditions at, say, 1,500 feet above ground.

Such a study of the geostrophic winds over London based on the 35 years, 1881–1915, of over 1,000 observations for each month, is published month by month in the *Meteorological Magazine*, and a similar study of the geostrophic winds over the North Atlantic is in progress, and the data have appeared in part on the pilot charts for that ocean. But much more than this needs to be done. The geostrophic winds need to be tabulated, not for isolated stations, but for a connected network of selected points. With a sufficiently close network the relationships of the geostrophic winds to geography and configuration can be made out and interpolation for any desired point will present no difficulty.

This program is perfectly feasible for the greater part of the northern hemisphere, including Egypt and India, also for Australia and the Argentine, but the work is laborious, as to provide a sufficient basis the daily weather charts for at least 10 years have to be examined and measured, and for its satisfactory accomplishment longer periods should be utilized so that international cooperation is advisable.

Two points must be remembered in connection with these pressure maps. The first is that as the air becomes less dense with increasing height, a definite barometric gradient causes winds with a proportionally greater velocity. The second is that the wind velocity corresponding to a definite gradient increases as the latitude decreases, until close to the Equator any measurable gradient at all causes theoretically infinite velocities, so that the calculation of gradient winds becomes impossible and between the latitudes of 20° north and south we must at present rely for our knowledge of the upper winds on direct observation and not on calculation.

Similar in principle, but far less laborious in practice, is the process of obtaining the *resultant* geostrophic wind. This is the result which would be obtained by averaging a large number of individual geostrophic winds at any place, the east winds being treated as negative west winds and the north winds as negative south winds. Practically the same result is obtained by measuring the average barometric gradient from a chart of mean pressure distribution. For the wind at a height of 1,000 or 1,500 feet it suffices to use a *good* detailed chart of the pressure at mean sea level, in which the isobars should be drawn for every millibar or millimeter on a projection which gives a reasonably uniform scale for different latitudes and longitudes. But for greater altitudes it is necessary to take into account the temperature of the air. For cold air is heavier than warm air, and hence in a column of cold air, pressure (i. e., weight of the overlying column of air) decreases more rapidly upwards than a column of warm air. For this reason pressure lapse with height is more rapid in higher than in lower latitudes, so that at a height of several kilometers there is in temperate and subtropical latitudes a well-marked poleward pressure gradient, causing the great preponderance of westerly winds at these levels.

Now it is found that except in very cold regions there is on the average a fairly uniform decrease of temperature from the surface upwards, amounting to about 6a per kilometer. On this basis, given a chart of the average distribution of pressure and temperature over any portion of the earth's surface, we may proceed to work upwards, calculating the pressure distribution at 1, 2, 3 kilometers, and so on, with reasonable accuracy up to 5 kilometers (16,000 feet), which is as a rule as high a level as aviators are likely to require for some time to come.

This process was first carried out by Teisserenc de Bort in connection with a study of the circulation of the atmosphere. He published charts showing the calculated isobars in January and July at a height of 4 kilometers,[11] and showed that they agreed well with the average direction of motion of cirrus clouds, though the latter are in general at a much higher level. No similar charts for the whole world have yet been published, but Col. H. G. Lyons has prepared [12] charts of the pressure distribution over the Mediterranean during January, April, July, and October at the 1, 2, 3, and 4 kilometer levels, and recently H. U. Sverdrup [13] has published mean annual maps of the eastern north Atlantic showing the topography of the isobaric surfaces of 1,000 mb., 900 mb., and so on up 300 mb. The latter form is unsuitable for the purposes of aviation but could be converted to the more usual form with little difficulty.

Thus we see that a good beginning has been made both along lines of research in the direct observation of kites and pilot balloons and in the study of geostrophic winds at various levels. The general lines of the atmospheric circulation are already charted and we have now to look forward to the gradual filling in of details, until we can construct charts with first hundreds and then a thousand or more of arrows representing the winds at various levels all over the world.

DISCUSSION.

By C. LE ROY MEISINGER.

While the paper above is very interesting in the suggestions it makes for researches which may be applied to the benefit of aviation in all parts of the world, it should be strongly emphasized that averages of the meteoro-

[11] Hildebrandsson, H. H., and L. Teisserenc de Bort.: *Les Bases de la météorologie dynamique*. Tome 2, p. 214.

[12] Monthly Meteorological Charts of Mediterranean Basin, M. O. 224, 2 ed. Introductory Sheet.

[13] Sverdrup, H. U.: Der nordatlantische Passat. *Veröff. Geophys. Inst. Univ.* Leipzig, Bd. 2, H. 1. Leipzig, 1917.