before the time of the tornado, 10:40 p. m. The passage of the tornado was accompanied by a terrific downpour, the noise of which tended to deaden the roar of the tornado. This heavy rain continued for some time afterward and gradually slackening ceased altogether before midnight. The sky remained clouded for the rest of the night, the clouds hanging low and driving fast before a hard wind that followed the storm and persisted throughout the remainder of the night. After midnight it grew colder rapidly and the next day there was a light fall of snow.

DISCUSSION.

Since this tornado was followed by a sharp fall in temperature at the passage of the wind-shift line of a marked V-shaped cyclone (see figs. 7 and 8) it would be natural on first thought to explain the storm as the result of cold air running over the mountains in advance of the wind-shift line at the earth's surface, and entrapping below it some of the warm, moist air on the Piedmont. This would cause intense local convection, and the resulting turbulence might be sufficient to produce a tornado.

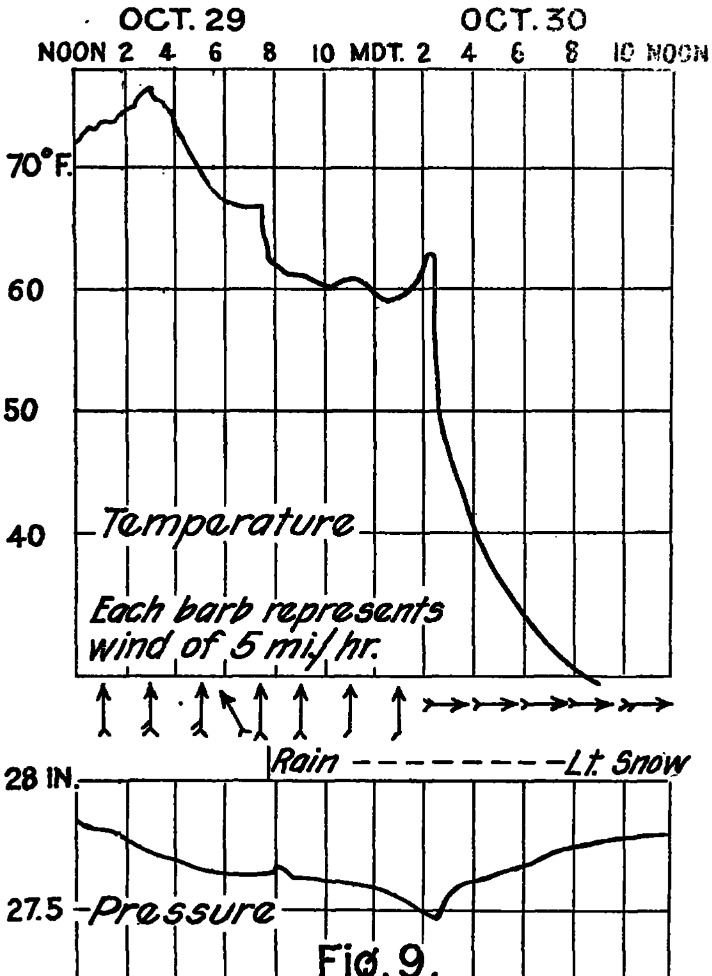

Fig. 9.
ELKINS, W. VA.

Such an explanation, however, does not seem to be justified by the facts. At Lynchburg, about 40 miles north-northeast of Gretna, there was no rise in pressure till 7 hours after the storm (see fig. 10), although some humps in the pressure curve might legitimately be expected if a considerable stratum of cold, dense air arrived aloft. At Elkins, W. Va., rain began at 7:40 p. m., the temperature fell 6° F. at about 7:50 to 8:00 p. m., and there was a temporary, sharp rise in pressure amounting to 0.03 inch at about 8 p. m. (See fig. 9.) This is the only intimation that there may have been a cold wind front aloft which could have reached Gretna at the time (10:40) the tornado occurred.

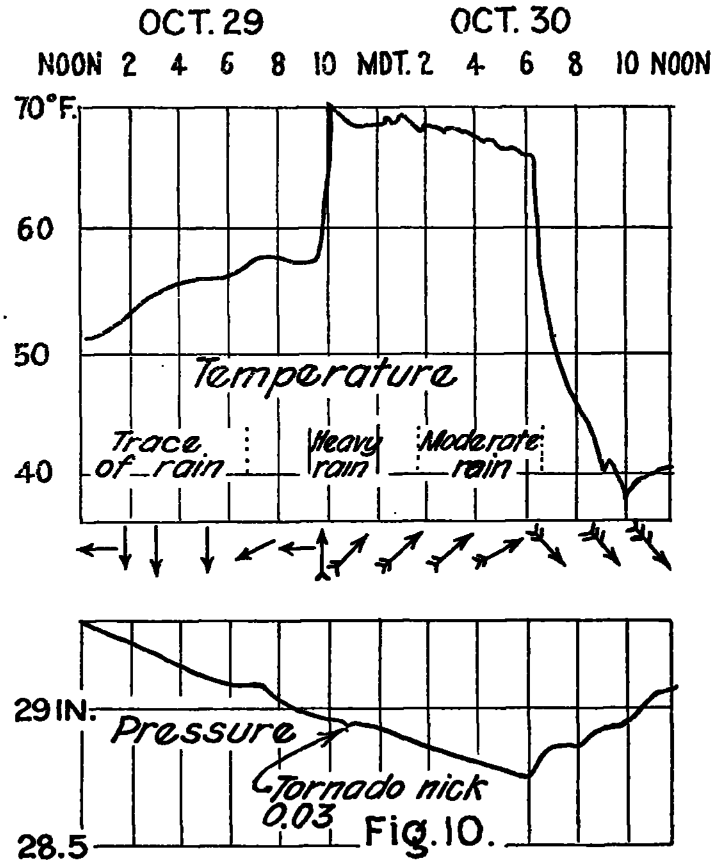

Fig. 10.
LYNCHBURG, VA.

Other conditions indicate that this tornado may be explained without assuming the arrival of a widespread cold wind running over the mountains. The stagnant cool air left from the anticyclone which was over this region the 28th was dissipated rather slowly; and at Lynchburg and probably westward to beyond the Blue Ridge some of this air remained till the evening of the 29th. (See fig. 7.) It is evident from the high temperatures and southerly winds at all surrounding stations, and from the cloudiness and light rainfall at Lynchburg during the day, that the warm, south wind was riding over this mass of cool air. Gretna seems to have been on the southern edge of the stagnant air until shortly after sunset, when "it cleared and a warm, gentle, spring-like wind began to blow." This light wind riding up over the cold air still at Lynchburg probably made the rainfall beginning there at 9:05 p. m.

At about 9 p. m. a severe windstorm of several hours duration began at Gretna; and 25 minutes later this wind reached the surface at Lynchburg, causing a remarkably rapid rise of temperature (see fig. 10).* When the temperature had reached its maximum of 70° F. at Lynchburg the first thunder was heard at Gretna (10 p. m.), and 40 minutes later the tornado occurred there. Whence came the cold air necessary to produce such an

* Cf. abstract on next page.

intense thunderstorm and tornado? The cold air which was over the Piedmont around Lynchburg could not have ridden back over the advancing southwest wind and produced a thunderstorm coming apparently *from* the southwest. Anyway, there is normally little opportunity for such cold surface air to get above any of the over-running warm air.

The most reasonable explanation seems to be that the cold air remained in the valley behind the Blue Ridge for an hour or two after it was blown off the Piedmont, and that when this cold air was pushed out bodily, beginning in the southwest, it spilled over the Blue Ridge on top of the much warmer wind on the Piedmont. The storm produced in this way might be exceptionally intense and would be confined to a relatively small strip of moderate length. At Lynchburg the rain from this storm amounted to 0.58 inch from 9:05 to 11:45 p. m., and it was followed later by a characteristic shower of 0.13 inch on the arrival of the wind-shift line.—*C. F. Brooks.*

ABNORMAL CHANGE OF AIR TEMPERATURE AT TOKYO AND SINAGAWA.

By K. SIGETOMI

[Abstract.]

In the August, 1918, issue of the Journal of the Meteorological Society of Japan (pp. 49–54) there is an account of abnormal changes of air temperature at a number of Japanese stations on March 20, 1918. At Sinagawa, 9 km. south of Tokyo, the temperature rose 7.8° C. in 50 minutes, and there was a smaller change at Tokyo. An extreme case is mentioned in which the rise was 9.8° C. in 20 minutes at Tokyo in 1912. On March 20, 1918, the land was overlain by a cold wedge of air, thickest in the north; and above this cold air there was a warm current from the south. As the outer margin of this cold mass of air varied back and forth; there were correspondingly extreme changes in temperature—now to the warmth of the southerly wind and then to the cold of the northerly one. The morning weather map and the thermograph and wind records at 10 stations are reproduced.

Discussion.—Sudden rises in air temperature not infrequently accompany the arrival of a warm wind, the lower boundary of which has gradually descended till it reaches the surface with apparent abruptness. Similarly, if a wedge of cold air is slowly pushing under a warm wind, there will be an abrupt fall in temperature when the cold air arrives. On the boundaries between such currents there is usually a mixture fog. The persistence of the occurrence of such abrupt changes for a period of many hours shows how slowly two currents of air of radically different temperatures affect one another when the denser one is below the lighter. For some notes on similar occurrences in the United States, see (1) page 463 of this issue of the REVIEW, (2) note on Three ice-storms, Science, August 8, 1913, and (3) Ice storms of New England, Annals, Obs. Harv. Coll., volume 73, part 1, 1914.—*C. F. B.*

MAJOR CONTROLS OF THE CLIMATES OF THE UNITED STATES.[1]

By ROBERT DE C. WARD, Professor of Climatology, Harvard University.

Climate in general.—Climate is accurately and briefly defined as *average weather.* But means, or averages, may be made up of very different values of the elements which go into them, and therefore a satisfactory presentation of climate must include more than mere averages. It must also take account of regular and irregular daily, monthly, and annual changes, and of the departures, mean and extreme, from the average conditions which may occur at the same place in the course of time. This extension of the definition of climate is especially important in any region where irregular cyclonic variations of weather conditions are frequent, as in the so-called "temperate" latitudes of both northern and southern hemispheres. Therefore, just as weather types change from day to day, and from season to season, under varying controls, so climate is the resultant of many variables. One climate differs from another because of a different combination of these controls. While it is a relatively simple matter to enumerate the factors which combine to produce any given climate, it is difficult, if not impossible, to determine, quantitatively, the relative importance of these different controls, so intimately are they connected and so complex are their effects.

The major controls of climate.—The sun is obviously the fundamental control of climate. The general distribution of temperature over the earth's surface, as well as the diurnal and seasonal changes, depend upon variations in the intensity and in the duration of sunshine. This solar control of climate is commonly known as the control by (1) *latitude*, and stands first. If the sun alone were concerned, all places on the same latitude circle would have the same climate,[2] for the intensity and amount of sunshine depend upon the angle of incidence of the sun's rays, and upon the length of the day, and both of these depend on latitude.

Such a condition is very decidedly modified by the distribution and influence of (2) *land and water;* (3) *mountain barriers*, (4) *altitude*, (5) *prevailing winds*, (6) *ocean currents*, and temporary (7) *storms*. The reaction of the physical features and conditions of the earth's surface upon the atmosphere results is what is termed *physical climate*. According to the dominant control in each case we may have *continental, marine*, or *mountain* climates. In the first, land is the essential control; in the second, the ocean; in the third, altitude. An extreme development of the continental type is a *desert* climate. A transitional type between continental and marine, is a *littoral* climate.[3] The relative importance of the above-mentioned major controls of climate, and the types of climate which result from their interaction, inevitably vary greatly in different places according to the geographical location, and the physical, topographic, atmospheric, and other conditions peculiar to each district. For the United States the outstanding facts regarding each of these major controls are here briefly stated.

Latitude.—The difference in latitude between the northern and the southern portions of the United States is the fundamental control which determines the important fact that the mean annual, the seasonal, and the monthly isotherms as a whole show prevailingly lower temperatures in the north than in the south.[4] Yet these isotherms do not run east and west across the continent, as they would were latitude the sole control. Their deflections from the latitude lines show the influence of other controls, such, e. g., as land and water, mountains, ocean currents, winds. If winds have a free sweep across a country they inevitably

[1] Read before the American Climatological and Clinical Association, Boston, Mass., June 5, 1918.

[2] *Solar climate* is the term for a climate which is controlled solely by the amount of solar radiation which any place receives by reason of its latitude alone.

[3] For fuller details regarding the characteristics of these different types of climate, see R. De C. Ward: "Climate considered especially in relation to man," 8°, 2d ed., New York and London, G. P. Putnam's Sons, 1918.

[4] See, e. g., the charts of monthly and annual isotherms in Bartholomew's "Atlas of Meteorology," 1899, Pls. 7 and 8; also the mean annual, January and July isothermal charts in the series of "Climatic Charts of the United States," U. S. Weather Bureau.