RESTRICTED

WEATHER SERVICE *Bulletin*

ARMY AIR FORCES HEADQUARTERS WEATHER WING
NOVEMBER 1944 ASHEVILLE, N.C. VOL. 2 NO. 5

RESTRICTED

SEMINAR PROGRAM

*"Sir George Airy once said that 'the observing is out of all proportion to the thinking in meteorology,' and the remark is still pertinent, though perhaps not so painfully true as in Airy's day."**

Certainly much of the thinking that has been done is failing to penetrate to the forecast room in the weather station. Preliminary analysis of the observer and forecaster proficiency examination results indicates that practicing meteorologists have not kept pace with theories and practices of recent origin.

We know that continuous advancement, through the adoption of newly-developed techniques and through periodic review of proven methods, is essential for efficient operation of the Weather Service. This headquarters is attempting to stimulate use of new methods of forecasting and observing by means of the technical consultant program and by distribution of technical publications. It is evident, however, that such efforts are not sufficient in themselves: sincere and agressive endeavors must be made by each individual, forecaster or observer, before his knowledge and proficiency can be advanced. It is equally evident that some form of organized and supervised study is necessary to produce worthwhile results on a broad basis.

At this headquarters, a weekly seminar program for forecasters was instituted several months ago. Staff members, in turn, present novel meteorological subjects in a one-hour program each Monday evening. These seminars have already proven their value in bringing new concepts to the attention of the staff and in stimulating scientific interest. For the information and guidance of weather stations in the field, an outline of the headquarters plan, including a list of potential subject matter and details of organization, is being forwarded to each station weather officer.

I am certain that a parallel program organized in each weather station for observers and forecasters will prove equally beneficial.

W. O. Senter

W. O. SENTER
Colonel, A.C.
Commanding

*Presidential Address to Royal Meteorological Society, by Dr. David Brunt, 19 January 1944 (see pages 12 14 of this issue).

HURRICANE WARNING

141330Z, Army Advisory #25:

HURRICANE WARNING ORDERED FROM NORFOLK TO CAPE COD. HURRICANE'S SEVEREST INTENSITY LOCATED JUST SOUTH OF CAPE HATTERAS AT 141230Z, MOVING NORTH-NORTHEAST AT 20 TO 25 MPH: STRONGEST WINDS OVER 100 MPH NEAR CENTER. STORM WILL CONTINUE NORTH-NORTHEAST, GRADUALLY RECURVING TO NORTHEAST AND WILL CAUSE WINDS ABOVE 45 MPH, HATTERAS TO CAPE COD......PORUSH, Army Hurcn Wea Ofcr.

Tropical hurricanes often contradict official forecasts which have to be drawn from limited oceanic data, as East and Gulf Coast residents know from experience. But the notorious September storm which swept northward along the Atlantic beaches this year was hearlded by warnings given far enough in advance to restrict loss of life and property. This time, bombers of the AAF Weather Service had been flown in and around the hurricane all along its trajectory. Investigation of synoptic blank areas from aerial vantage points yielded first-hand information about hurricane positions and character, radioed at once to a weather central.

This success gave widespread attention to the assignment of weathermen and aircraft to regular hurricane reconnaissance duty for the first time this season (June-December 1944). The Army Hurricane Weather Office in Miami collects information from every source which will delineate "areas of suspicion" in the Carribbean, Atlantic, and Gulf. Then B-25's equipped with aerographs are dispatched so that Mitchell-borne forecasters can transmit wind speeds, cloud data, soundings, special phenomena, and locations as soon as they encounter the disturbance.

The storm which later caused so much damage to Middle Atlantic States was first "fixed" by reconnaissance on 8 September near Antigua, as a relatively mild tropical disturbance. But in a few days it intensified into a hurricane of frightening proportions and curved along the Atlantic coastline.

Here are official reports from the Army flyers and weathermen who searched out the hurricane on reconnaissance duty:

11 September
by Lt. Otha Spencer, pilot,
Hurricane Reconnaissance Unit 2

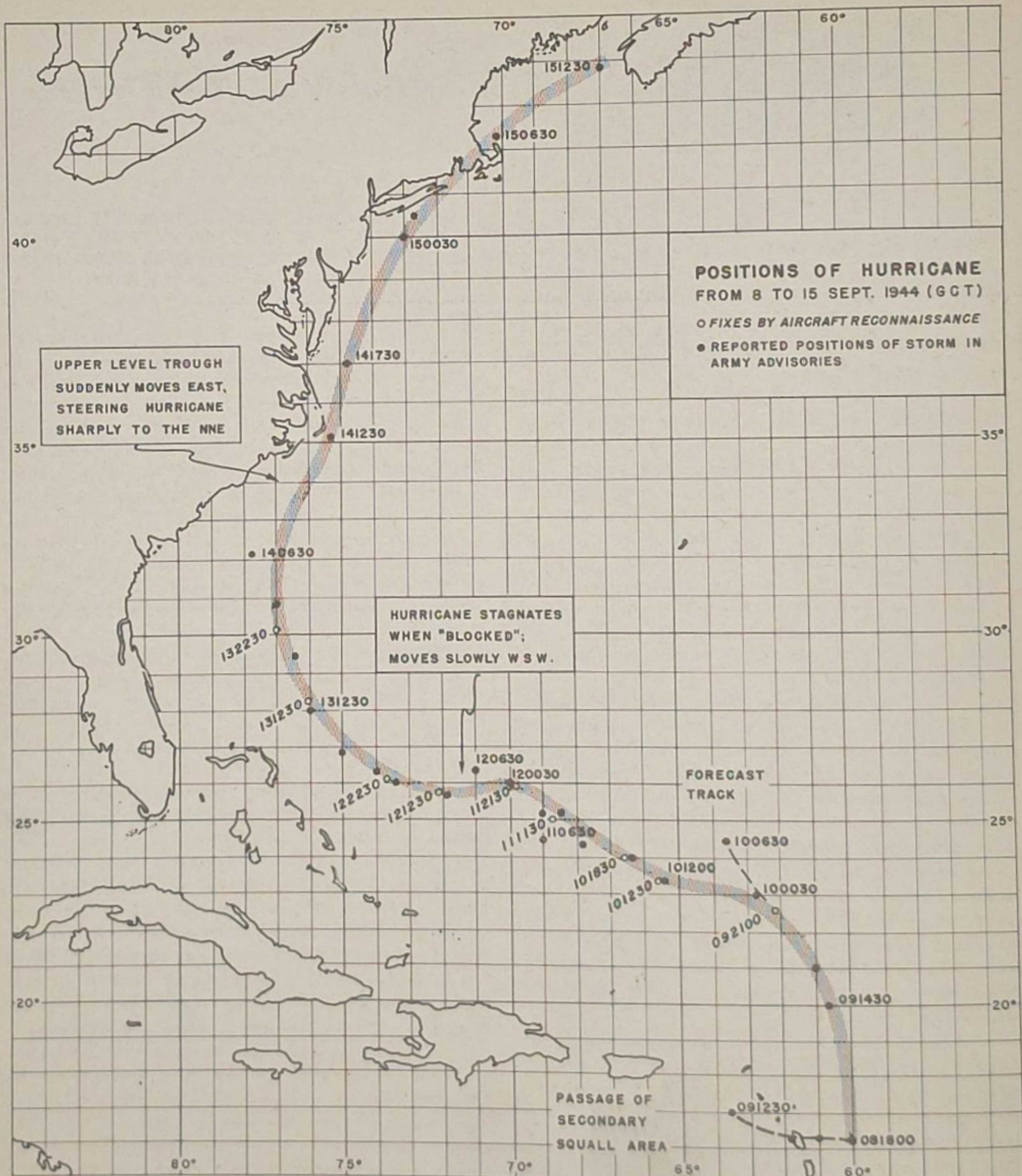
Just before dawn of 11 September we left Morrison Field flying east, primarily assigned to fix the storm's position. Our intention was to "box-in" the circulation: we were to hold our easterly heading until a strong north wind would be encountered, then turn south and fly on to the westerly current, next proceed eastward toward the south winds, and so on around the "center." This plan had proven effective on previous occasions, but we were to learn something new.

In pre-dawn darkness the wind velocity could not be determined because the driftmeter was unreadable, but just as dawn broke the navigator obtained a pilotage fix over a recognized Bahamas Island. This observation, 250 miles from the hurricane, gave us our first wind vector from an "air plot," 330° and 20 mph. But now that the sea could be seen, a "double drift" was flown to obtain the instantaneous wind, 350° and 29 mph.

So far the flight had met nothing more than scattered cumulus, although the Bahaman waters seemed rougher than usual. The sunrise was exceptionally red, lending credence to "...red sky at morning, sailors take warning." A little later we came under a high cirrostratus overcast, noticing that the flat cumulus which had been lying beneath now rose above flight level. Stratus decks intertwined the vertical clouds. The sky ahead became very black.

At 1110Z, half an hour after sunrise, a wind from 10° at 42 mph reported by the navigator caused the weather officer to change our course. Flying to the south until the wind should shift to the east, we continually entered and left the driving rain and turbulence of cumulonimbi.

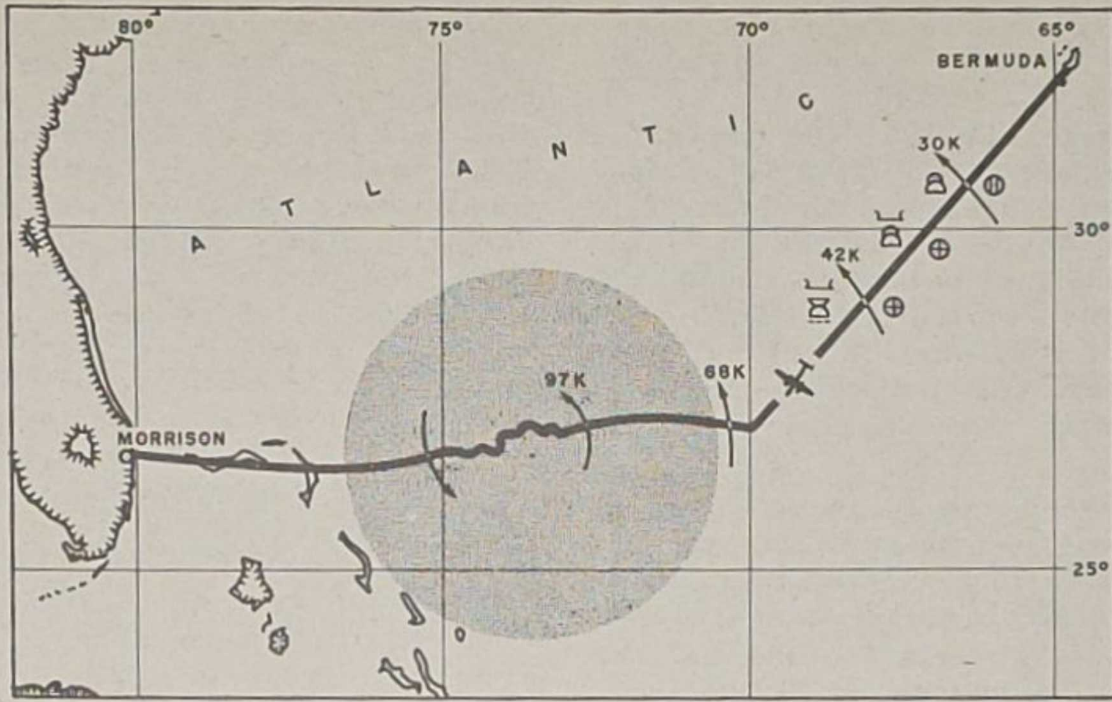
When the time came to turn east, that change in heading brought the plane into heavy rain and heavy turbulence. Several minutes later, the flight level had cleared up (7,000 feet), although rain was falling from above. The sea was very rough, and long streaks along its surface clearly indicated the wind direction. The air was only slightly turbulent at our level, but the sky looked dark and threatening in all directions. Later we overtook more clouds



Responsibility for Army hurricane warning rests with the Commanding Officer, Weather Wing. Under his authority, Major Irving Porush issues Army Advisories on hurricane positions from Miami. AAF Hurricane Warning Service was first established by Lt. Col. Henry Harrison in 1943.

and encountered moderate turbulence. *Vertical currents were steady and continuous, and in that sense were different from ordinary convective activity.* Rain was so heavy at this point that the plane leaked badly: the pilots and weather observer were drenched, and water streamed down the instrument panel.

At 1208Z the double-drift wind was at 245° and 60 mph. Turbulence became heavier and the B-25 proved difficult to hold in level flight, much less to keep on course. The ocean could be seen in little snatches when the undercast parted momentarily. The water was streaked as we had never seen it before; green towers with huge white



The flight path indicated was flown by Captain Alan Wiggins' Hurricane Reconnaissance Unit on 12 September, from Bermuda to Morrison Field.

patches of foam boiled along in the wind stream.

For the next hour we took up a heading to the north on the weatherman's advice. In-cloud visibility that was nil in every direction precluded a wind determination, so the plane was let down at a small diving angle. When the craft did not break into the clear at an indicated altitude of 3,000 feet, flight was levelled off anyway in fear of an excessive altimeter error in the low pressure area.

At one interval when a rift appeared in the clouds below, the navigator recorded 23° of drift but could not complete the measurement before instrument conditions prevailed again. That fragmentary evidence indicated that one component of the wind was 90 mph, but the consensus of those who had seen the state of the sea placed the full wind speed at almost 120 mph.

Turbulence increased to the point where it was continuously heavy and sometimes severe. Equipment was torn loose. Once when the plane was wrenched into a climbing attitude, the indicated vertical velocity was 1,000 feet per minute when the airspeed meter read 250 mph. The aircraft would yaw violently even when the wings were level---a novel experience for both pilots. The turn indicator moved from side to side in rapid succession while the ball-bank device oscillated crazily.

We determined then to get out of the storm before the B-25 was torn apart. The plane was turned to the west and flown for a full hour before the sea surface again became visible. Crewmen were exhausted after the constant beating they had received. The plane itself suffered no major structural damage, although several large cracks in the ring cowling of one engine were in evidence.

12 September

by Captain Alan Wiggins, flight commander, Hurricane Reconnaissance Unit 1

By this time we spoke of the "Great Atlantic Hurricane" in deference to amazing reports by another reconnaissance unit of an intense tropical hurricane which now was 200 miles east of the Bahamas. A TWX from Major Porush was the signal for us to take off from our temporary base in Bermuda, under orders for flight to 70°W, 27°N and then due east to Morrison Field, Florida.

The first hour out of Bermuda was uneventful, but no one expected the calm sea and clear skies to remain that way much longer. Very soon the ocean surface became disturbed with heavy white-capped swells, 20-30 feet from trough to crest. Broken cumulus appeared below the aircraft, pushing up to 5,000 feet. The navigator reported a steadily-rising wind speed, then at 30 knots.

In a moment the storm area became visible, directly on course. High cirrostratus extended in a solid bank beyond sight to right or left of the westerly heading. Sea swells became heavier, and the whitecaps began to streak out in long streamers of foam. Estimates by crew members of the wave height varied from 50 to 100 feet.

Soon we entered under the layer of high cirrostratus, discovering that it was too thin to obscure the sun. Black vertical clouds towered from far below up into the high deck, intertwined by dark stratiform layers. The sea surface took on a decided change as large green areas appeared in the wake of each whitecap. Wind: 42 knots.

In another half hour the navigator reported a fix over 75°W, 27°N; whereupon a new, due-west course for Morrison Field was taken up. The worst of the hurricane now seemed to be just before us, so we took advantage of the few minutes remaining for a double drift reading. The observation measured 68 knots from the south, requiring that the magnetic heading be corrected by 20°.

Clouds ahead seemed to be based at about 3,000 feet, so the aircraft was set in a shallow dive to permit contact flight for better meteorological observations. During the letdown our plane entered the cloud bank at an indicated 3,800 feet. Mild turbulence and rain became evident, but nothing to excite alarm. The altimeter was reset at 28.80" (ground stations later reported pressures of 28.00"), instrument lights turned on, and descent continued.

We broke into the clear when the altimeter read 2,800 feet, but the raging greenish-white sea was much nearer than that. Drift to the right was very great, and vertigo struck me with each glance at the sea. Green streaks on the tempestuous sea had no visible beginning or end Flight was continued contact for the next 15 minutes, but all the while it became darker and more rough. Keeping the wings level was very difficult and the bomber rolled from side to side, but vertical turbulence was not in evidence.

A wind determination proved impossible when the first 45° turn to the right brought an envelopment in clouds and heavy rain. Even a slow left turn to the original heading did not break us out again, so the plane again was let down slowly.

The altimeter set at 28.80" indicated 1,500 feet when we reached the cloud base, but the roaring sea was actually only about 800 feet below. Forward visibility was absolutely zero while we flew at the ceiling base, but the ocean could be seen skidding by at a terrific pace below. We took a drift run here that indicated a wind velocity of 170° and 97 knots.

As soon as we finished this procedure, the ceiling suddenly dropped down to the sea; our bomber hit a wall of clouds and rain. Water poured through the Mitchell's Plexiglas seams to drench every occupant.

Then came the roughest weather anyone of us had ever experienced. The sturdy B-25 began to pitch and lurch; to climb and dive at the same time. The instrument panel shook so hard that I became dizzy in trying to watch the instruments. The magnetic compass swirled through 360° while the rate of climb indicator jumped from 2,000 feet per minute *up* to 2,000 feet per minute *down*. Only the gyro compass and the flight indicator seemed reliable.

I was worried about sluggish responses of the control surfaces. On the frequent occasions when a wing would drop down as much as 60°, even use of full opposite rudder and aileron did not bring back level flight for several seconds. In the meantime, the compass heading would have gone 20-30° astray. A slow turn toward the planned direction was nullified each time because the wing would always sag again. Even during these erratic maneuvers, however, the plane was under general control.

But then all hell broke loose: a sudden jolt and we had climbed a thousand feet. Before my foot could reach the elevator, another jolt precipitated the bomber below the original level. Airspeed dropped from 210 to 150 mph---then jumped around between 150 and 180 mph. The controls seemed to stall out; no air flow could be felt across them although the airspeed indicator still showed 150 mph.

Panic seized me because I knew that all control had been lost. The only thought was then to reach a safer height above the sea, but application of full rated horsepower and every other resource produced no additional lift or speed. Our radio operator transmitted the last observation as an "Urgent" message to Miami.

Fatigued from fear and strain, I called the navigator to suggest turning tail to the wind. I remarked that the airspeed fall and wing stalls might be caused by the terrific crosswind. However, both weatherman and navigator believed that our present course was best.

Occasional glimpses of the sea seemed to confirm their advice not more than five minutes later. Even more comforting, drift readings proved that the wind had switched to the north: we were getting 26° of left rather than right drift. Navigator gave a course correction to compensate for the change in wind.

Then: blessed relief. We flew into stratus clouds that were very stable. Instruments settled down to normal and airspeed picked up to 190. Climb at full power promised safety, despite sharp jolts that marked each cumulus embedded in the stratus. We broke out of the stratiform top at 7,000 feet. Above us a high cirrostratus overcast shut out the sun at first, but later we roared through a cumulus into comforting rays of the setting sun.

14 September

Prominent meteorologists of the Weather Division flew into the hurricane at 2000Z when its center was 60 miles northeast of Cape Charles, Virginia. They traversed a band of descending air about 50 miles wide within the outer portion of the storm. Later, in proceeding toward the center, a region of rapidly rising air was encountered. These convective currents were so uniform, however, that their turbulent effects on flight were not dangerous despite the tremendous horizontal wind speeds involved.

Nearness to the storm center was indicated by a thinning of the cloudiness and appearance of the sun.

HURCN WEA OFCR's REPT

A routine hurricane reconnaissance flight on 7 September found light *southwest* winds, an altostrotus overcast, and light rain at 55°W, 13°N: in that latitude such weather means a low center to the north. This disturbance was not evidenced on forecasting charts, however, until the approach of a deep "wave in the Easterlies" was detected next day from 24hr. pressure falls (4mb.) and backing winds aloft in the Lesser Antilles. Thereupon a reconnaissance mission was dispatched, but it reported only a slight wind shift from 80° to 100° with speeds to 30 knots along 60°W.

Army, Navy, and Weather Bureau forecasters predicted westward motion of this tropical disturbance into the Carribbean. Notwithstanding these august opinions, the storm moved to the north-northwest and intensified. The first indication of the storm's actual movement was given by a navy pilot, who on 9 September reported a southwest wind at 30 knots and heavy rain northeast of Antigua.

At 2100Z on the ninth, an Army weather B-25 obtained a definite fix by flying entirely around the storm. Wind determinations on this flight showed a complete cyclonic circulation with speeds to 49 knots at 5,000 feet. A continued north-northwesterly movement at the rate indicated by past positions would have carried the storm center near Bermuda in the next 36 hours.

However, further Army reconnaissance on 10 and 11 September demonstrated a change in the hurricane track to the west-northwest. This phenomenon was explained by presence of a warm high to the northeast and a wedge aloft to the north and west. Blocking of the storm caused retardation to 10 mph. At the same time, the area of hurricane winds enlarged and spread to 150 miles east of the center and 75 miles west. Violent storm effects were experienced in the enormous area from Hatteras to Bermuda and south to the Greater Antilles.

As the blocking wedge disintegrated on the 12th, the hurricane accelerated and recurved to the north. The major trough into which the storm was to recurve had lain almost stationary over the central U. S., but this depression moved rapidly eastward in time to steer the hurricane north-northeastward across Cape Hatteras. The speed of motion jumped to 40 mph when the storm came under the influence of the trough's 40 to 50 mph steering current as reported by east coast winds aloft stations.

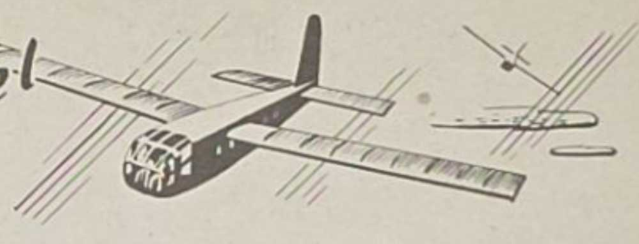
New York City and Atlantic City were forced to endure the highest surface winds on their records: 82 mph from the north. The latter station had one hour in which 76 miles of wind passed. Hatteras' anemometer failed at 66 mph but its pressure went lowest, down to 948 mb.

Scheduled ATC flights between Miami and Bermuda were not interrupted by movement of the hurricane center across the route. Flight courses were altered to take advantage of tail winds within the cyclonic circulation, yet the aircraft were flown far enough from the center to avoid difficult weather. This planning was out of the question in other years when regular hurricane reconnaissance did not exist.

151330Z, Army Advisory #30:

ALL CLEAR NORTH OF NEW HAVEN. TROPICAL STORM HAS ASSUMED EXTRATROPICAL CHARACTERISTICS, PASSING OFF THE NORTHERN COAST OF MAINE AT 151230Z MOVING EAST-NORTHEAST ABOUT 40MPH. NO FURTHER ADVISORIES WILL BE ISSUED ON THIS STORM. PORUSH, Army Hurcn Wea Ofcr.

GLIDER WEATHER *Sequel*



by LT. WILLIAM WIDGER, JR.

Many U.S. glider pilots feel that the British Air Ministry's technical note, "Glider Weather" (March 1944 Bulletin), contains several recommendations which do not apply to AAF procedures. This reaction was observed by a weather instructor at the Advanced Glider Training Center, Lt. Widger. He compiled authoritative Troop Carrier opinion to "Americanize" the requirements laid down for weather forecasts appropriate to glider operations.

Of course glider operations require terminal weather that is at least contact; but when tactical considerations require it, glider flight in clouds or reduced visibility enroute to a target is feasible. Gliders *on single tow* may be flown through overcasts when the visibility is sufficient for the pilot to see several feet of his tow rope. Skilled aviators are able to maintain correct position of the glider by this reference alone. Fatigue results rapidly from the mental concentration necessary to successful gliding without sight of the towing aircraft, but glider flight has been achieved through overcasts by this technique for considerable periods.

"Double tow" gliding, and nighttime operations in general, require that the tow plane be visible to the pilots of motorless craft at all times, principally so that the correct position can be maintained. However, a limited number of AAF gliders (particularly CG-13's) have been equipped with automatic pilot or position-indicating instruments. Although these devices do not work well in moderate or severe turbulence, they do make possible single tows through stratiform overcasts by day or night.

The AAF uses nylon tow ropes of high elasticity, reducing the chance of tow-rope fracture. This hazard was probably emphasized by the Air Ministry in reference to the British use of hemp ropes. Troop Carrier experience reveals extremely few valid examples of nylon rope failure, even in turbulent conditions. Most so-called cases of tow-rope fracture were ascribed later to accidental release of the tow connection at the powered aircraft.

These factors may make possible the use of cloud cover in tactical missions. Anyway, a ceiling of 1,000 feet is seldom needed inasmuch as combat glider formations usually fly below 500 feet.

Contact weather conditions are the rule for glider flights in the United States, but tactical training flights are sometimes made in this country when weather is below the contact minimums.

Gliders are not equipped with de-icing equipment, and so are particularly subject to icing hazards. Glaze and rime are most dangerous when they form on aerodynamic surfaces, destroying lift and necessitating higher landing speeds. Both effects seriously threaten the success of glider operations, and Weather Service forecasts should point out the areas and levels where icing is expected.

Windshield obstruction can be overcome *in emergencies* by breaking the glass. Spatter of mud from tow ropes in operations off a wet field is a consideration other than ice and mist in avoiding obscured view.

Turbulence has two very significant effects: first, it causes sickness among air-borne troops just before the gravest demands will be made upon their physical and mental resources; secondly, turbulence may cause the load to shift or become entirely unfastened, thus altering the flying characteristics of the glider. In any glider operations, turbulence should be avoided whenever possible.

When the Air Ministry memorandum laughs off high wind speeds over landing areas, reference is made to British equipment only. The Horsa (British glider) is properly landed in a steeper angle of approach than the average powered aircraft. But the AAF's CG-4A has a landing approach which is much flatter than that of most powered craft, and the CG-13 has one which is comparable to power landings. Landing at relatively slight angles, a characteristic of AAF gliders, makes a knowledge of winds over the target area between the surface and the maximum flight altitude vitally important.

DAYTIME VISIBILITY

by MAJOR WALLACE HOWELL

"How far will I be able to see?" is obviously a fundamental pre-flight worry, because visual reference to the ground guides takeoffs, landings, and all CFR flying. Unfortunately, the forecaster's information of least precision is often his knowledge of current visibility. Observers report this atmospheric property in a numerical value to be sure, but without *objective assistance* the value given is related inextricably and unsatisfactorily to the particular marker seen and traits of the observer himself.

"Objective assistance" could mean use of an instrument if one were available, but in visibility measurements of today it has to signify a standard *procedure*, designed on the basis of physical laws to reduce local, personal, and interpretive error. A clear and precise meaning to numerical values for visibility exists only when variations in properties of the marker used and subjective reactions of the observer have been minimized. Even if an observer "can see the water tower in Winthrop two miles away," the visibility is not determined uniquely or with generality unless the illumination falling on the object, its size, its albedo, and the meaning of "can see" have been considered in a standard way or eliminated as variables. The most convenient way to do this is to agree upon certain standard conditions (within practical limits) under which all observations of visibility will be made.

The primary consideration in the measurement of visibility is that the *greatest distance at which the object can be discerned at all* must be reported. If the observer feels instead that he must see the marker "clearly", then its "clarity" becomes a matter of personal judgment or whim. The observation approximates a scientific recording of an atmospheric property much more closely when the only personal descision required is whether the reference point is visible.

There is a natural inclination to feel that, from the pilots' viewpoint, it is not enough for an obstacle to be *barely* visible. But in determining the minimum conditions of visibility under which operations are permitted, full account has been taken of the changes in distinctness which an object undergoes before it disappears. Furthermore, interpretation of weather conditions in terms of flying safety is solely the responsibility of operations authorities. Conservative observations are only inaccurate; not safe.

Weather Bureau Circular "N" says authoritatively, "Visibility in a definite direction is the *maximum distance* to which prominent, suitable objects like trees and houses, located in that direction and viewed against the horizon sky, are visible... For an object to be regarded as visible, it must be recognized by an observer who has previous knowledge of its character from having seen it when the atmosphere was clear."

This quotation implies that the observer should be familiar with the visibility markers at his station so that he will be able to recognize them at the limit of their visual range. Italicizing the words "maximum distance" emphasizes that recognition is a more appropriate criterion than distinctness or clarity.

Visibility reference points should be as dark as possible, because sunlight can play tricks with the visual range of light objects. For example, a vertical white panel will appear darker than the horizon sky if viewed in the direction of the sun (shady side to observer), but brighter than the sky if viewed away from the sun. At some azimuth, then, a light object will be exactly as bright as its background and consequently be invisible even at short range.

The color of the object, once thought to be important, is quite insignificant. A colored object becomes sensibly the same color as the horizon sky when near the limit of the visual range. Hence, only its over-all absorbing power for visible light ("darkness") is of importance. A purple object is quite as satisfactory as a gray one of the same albedo.

A uniform angular size for reference points is desirable, but often impractical. In any event, no marker is suitable which subtends an angle of greater than 20° or less than 0.5°. Figure 1 demonstrates that the "Contrast Threshold" (least value of contrast detectible by the eye) increases very rapidly when the angle subtended by the objective is below 1°. This is the same property of human sight which makes the black dots in a half-tone cut merge to form the grey tone of the picture, and which makes a thin line appear lighter than a thick line printed in the same ink.

This effect is so pronounced that instructions to observers in many meteorological services direct that visibility marks must be large enough to subtend an angle greater than 0.5°. Figure 1 shows that an object big enough to subtend a 1° angle or greater would be still more desirable.

An object a yard across at a distance of 100 yards subtends an angle of very nearly 0.5°. It is apparent that a smokestack a few yards across at a distance of two or three miles, or a radio antenna mast on the far side of the airport, are very poor visibility objectives. It is interesting to check these statements by noting the appearance on a foggy day of a dark-colored hangar from which several poles or masts extend. As the fog thins, the hangar becomes quite clearly visible before the poles can be seen at all.

Lest the opposite extreme be overstepped, it should be noted that if the object is so large that it shades an important portion of the sight path, the distance at which it can be seen will be increased beyond the standard visual range. This effect may be expected if the object subtends an angle of more than 20° or so, and objects of greater size than this should not be chosen as visibility points.

For very small objects, an additional effect contributes still more to the error: the diffusion of light around the borders of the object. It is unimportant for objects having an apparent angular size greater than 0.1°, however, so such diffusion is greatly overshadowed by the phenomenon of figure 1.

The value of the contrast threshold varies only slightly over the range of brightness usually found in daylight conditions. However, the threshold increases rapidly in twilight, and by full moonlight rises to the extent that the visual range is only 1/4 its daytime value. One must turn to other methods of observing the visual range as soon as twilight prevails.

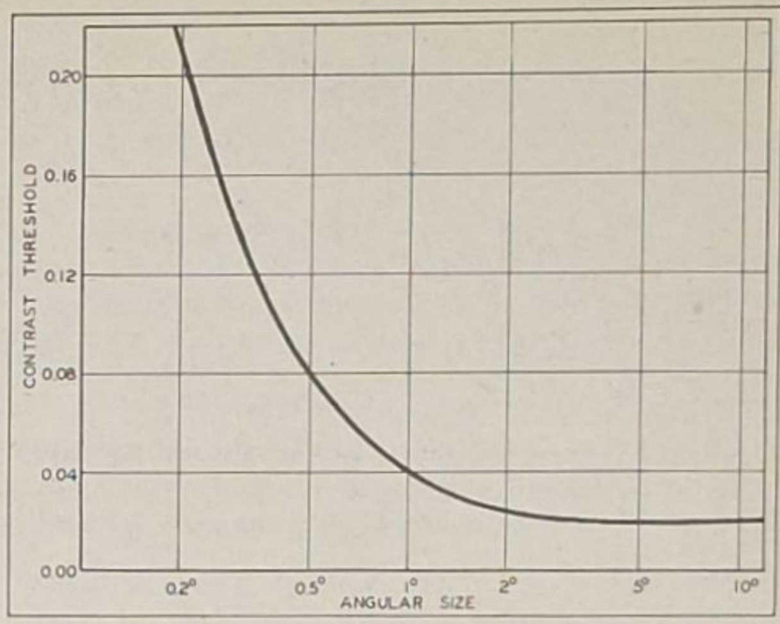


Figure 1: Visibility markers' least diameter must subtend more than 0.5° at the observer's eye or the contrast threshold will be too great.

There is another circumstance which will adversely affect the observer's contrast threshold. This is the presence in the field of vision of a bright light or strong glare, such as sunlight reflecting from water or from an automobile windshield. The effectiveness of such a "dazzle source" increases rapidly as it comes closer to the line of sight. In practice, a sighting tube or even a clinometer may be advantageously used to shield the eye from glare (figures 3 & 4).

It is important that visibility markers stand prominently against the horizon sky, or at least against a long, free line of sight.

The suitability of visibility objectives is more important than to have many of them, although markers at the critical distances of 1 and 3 miles (and any specific ranges used locally for air traffic control) are very desirable. It is better to interpolate between good markers than to try to use markers at more frequent intervals which are not appropriate in size, shade, or background. An example of

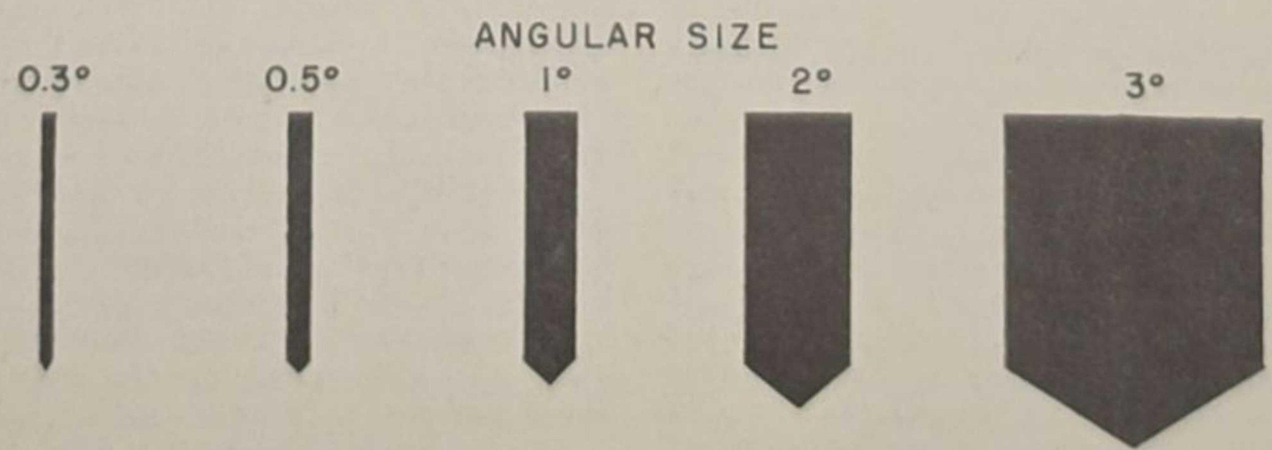


Figure 2: The least diameter (width) of each black polygon subtends the angle indicated for it when this page is held exactly one foot from the eye.

a suitable series of markers is: a dark bush at a distance of 100 yards, a small building 500 yards away, a clump of trees a mile away, and a wooded hill three miles distant.

Use of the visibility markers chosen and interpolation between them should be systematic on the part of every observer. Except for noting variations in the visibility in directions which have no suitable markers, attention should be directed exclusively at the appearance of the designated objectives. Their identification and their distances should be memorized. To aid in interpolation, the appearance of each marker should be noted when the next marker beyond is just at the limit of its visual range.

PHYSICAL REASONING

The following section will demonstrate a scientific basis for the conventions just set forth. A set of severely standard conditions will be stated, from which an equation can be derived to express the resulting visibility. Then deviations from these conditions which are large enough to meet field exigiencies and yet small enough for satisfactory accuracy can be computed. It will be seen that the final results coincide with the recommendations already given.

Let us call a standardized visibility the *standard visual range*, and for our ideal conditions let us agree that:

(1) The object will be black; that is, it will absorb all light which falls upon it.

(2) The object will be large enough so that variations in apparent brightness near its edges will not affect the clarity with which it may be seen.

(3) The background will be the sky at the level horizon.

(4) The illumination will be daylight on a clear day.

(5) The object will be considered to be at its standard visual range when it is just barely discernible, so that the least increase in its distance would render the objective completely invisible.

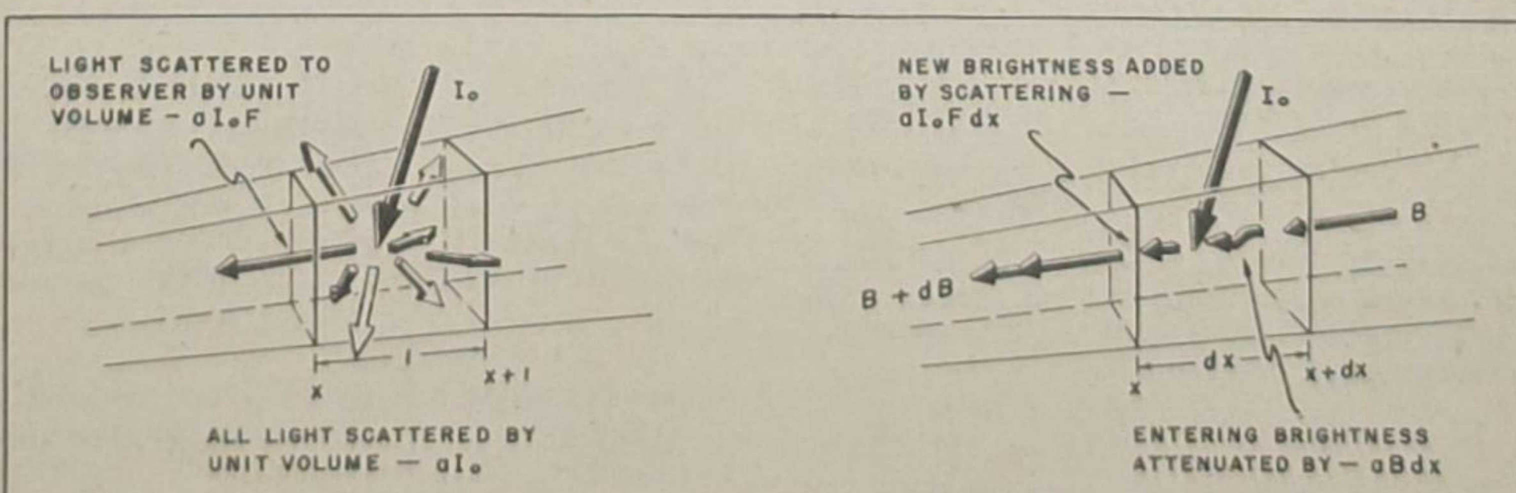
(6) When the object is just barely discernible to one observer, it will be just barely discernible to any observer.

(7) The atmosphere along the line of sight from the observer to the object and beyond will be homogeneous and evenly illuminated.

In daytime observations, visibility markers are gradually obscured at increasing distance and finally disappear because a phenomenon called "air light" gives the dark objective a certain apparent brightness, reducing the contrast. Sunbeams enter the pencil of atmosphere between observer and object, only to have much of that light scattered in all directions by the molecules and foreign particles in the air mass. Some of this illumination is scattered toward the observer, and this air light is that which seems to brighten the marker toward the brightness of the horizon behind it.

When the apparent brightness of the black object is just barely distinguishable from that of the horizon sky behind, the standard visual range is defined. This distance is obviously a measurement of the turbidity or "scattering power" of the air mass at the surface, a quantity which has both forecasting and operational significance.

The next step is to determine the apparent brightness of the object under fixed conditions, and then to find out how slight a contrast in brightness the eye can distinguish. If a beam of light with intensity I passes through a thin layer of an opalescent medium with thickness Δx, its intensity will be diminished by a certain amount which we will call ΔI. This



Figures 3 & 4: Much of a sunbeam's light is scattered by a unit volume of air in all directions. This scattered sunlight adds to the apparent brightness of an object, reducing the contrast of a black visibility marker with its background and shortening its visual range.

diminution will depend also on the "darkness" of the medium, or what we will call its coefficient of extinction, a. One might say, $-dI = I\,a\,dx$
the minus sign representing the fact that intensity is lost. Rewritten as

$$\frac{dI}{I} = -a\,dx$$

the equation can be integrated to give

$$\ln I_x - \ln I_o = -ax$$

which transforms to

$$I_x = I_o\,e^{-ax}$$

where e is the natural logarithmic base.

The result may be understood in unmathematical terms: if the intensity of a beam of light is reduced to one-half by passing through three miles of atmosphere, it will be reduced to one-fourth after six miles, one-eighth after nine miles, and so on. A beam of intensity I_o will be reduced to 1/e of its initial value after passing through 1/a miles of atmosphere.

But more light than that in a direct beam reaches the observer: the air light does also. This additional amount will depend on a number of compilicated relationships: the angle between the sunbeam and the observer's line of sight, the amount of the sunbeam reflected back into the line of sight by the earth, and even the size and nature of the motes in the atmosphere. Fortunately however, all these will have the same influence on each of the two lines of sight being compared (one to the object and one to the horizon). All these variables can then be lumped into some quantity which we will call F, which will cancel out of the expression for contrast.

We can say that F connects the strength of the sunbeam with the apparent brightness, B, of a unit length in the pencil of atmosphere which is in the line of sight (see figure 2). The contribution of brightness from Δx will be the apparent brightness of that portion less what it extracts from the pencil's brightness by its own absorbtivity. That is, as shown in figure 3, $dB = aI_oF\,dx - aB\,dx$

$$\frac{dB}{I_oF - B} = a\,dx$$

Integrating, $\ln(I_oF - B) - \ln K = -ax$.
To determine the constant of integration, we note that if the pencil is of zero length its brightness will be zero:

$$\ln(I_oF - 0) - \ln K = 0$$

or, $K = I_oF$.

so $$\ln(I_oF - B) - \ln I_oF = -ax$$

$$\ln \frac{I_oF - B}{I_oF} = -ax$$

then $$B = I_oF\,(1 - e^{-ax}) \qquad (2)$$

This value of B gives us the apparent brightness of a black object at the distance x. To get the brightness of the horizon sky, all we need do is let x become very large so that e^{-ax} approaches zero. Then, if B_h is the brightness of the horizon sky,

$$B_h = I_oF$$

We are now ready to set up an expression for the contrast between the brightness of the object and that of the sky behind it. The easiest way to express this contrast is to write the difference in actual brightnesses as a proportion of the horizon brightness. If we call the contrast C, then

$$-C = \frac{B - B_h}{B_h}$$

where the minus value of C indicates that the object appears darker than the horizon. Substituting the values already derived above for the brightnesses,

$$-C = \frac{I_oF\,(1-e^{-ax}) - I_oF}{I_oF} = -e^{-ax}$$

If the extinction coefficient is such that contrast dimishes to one-half in three miles, it will diminish to one-fourth in six miles and to one-eighth in nine miles.

The condition set up earlier, that the object be at the limit of its standard visual range when just barely discernible against the horizon sky, corresponds to the least value of contrast C which can be detected by the eye. Let us call the least discernible contrast the *contrast threshold*, designated by small c.

Another condition imposed was that c would have the same value for all observers. This is approximately true in practice, the value of c being nearly 0.02 for normal conditions of illumination. This value will be used for computing the standard visual range. If d is the standard visual range, we can write

$$C = e^{-ad}$$

Solving this equation for the standard visual range, d,

$$\ln c = -ad$$

$$d = \frac{1}{a} \ln \frac{1}{c} \qquad (3)$$

This is our final expression for the standard visual range in terms of the extinction coefficient of the atmosphere and the contrast threshold of the observer. For the value c = 0.02, this becomes

$$d = \frac{3.91}{a} \qquad (4)$$

Interestingly enough, d is not dependent upon the azimuth of the object with respect to the sun.

DEVIATIONS

Let us consider first that the object is not black, but that it is a vertical gray screen which reflects a proportion R of the light which falls upon it. The fraction R is called the *albedo* (whiteness) of the object. Let us consider also that the sky is overcast, so that the illumination from it is perfectly diffuse.

A perfectly white vertical screen would "look" equally at the white clouds and the dark earth, so the illumination on it is half the sky brightness. The brightness of the gray screen therefore, is

$$Bg_o = \frac{RB_h}{2}$$

The brightness of the gray screen when seen from a distance will be the sum of this brightness, attenuated by the scattering through the air column between it and the observer, and the "air light" scattered into this column from the general illumination. Taking these from equations (1) and (2),

$$Bg = Bg_o e^{-ax} + B_h \ (1-e^{-ax})$$

Substituting the value just derived for Bg_o

$$B_g = B_h \ (1-\frac{2-R}{2}e^{-ax})$$

Using the same expression as previously for the contrast, C,

$$-C = \frac{B_h - B_h}{B_h}$$

From the equation second above,

$$\frac{B_g}{B_h} = 1 - \frac{2-R}{2} e^{-ax}$$

$$\frac{B_g}{B_h} = 1 = \frac{B_g - B_h}{B_h} = -\frac{2-R e^{-ax}}{2} = -C$$

Taking c as the contrast threshold again, and d_g as the visual range of the gray screen, we have

$$c = \frac{2-R}{2} e^{-ad_g}$$

Solving this as before for d_g, we obtain

$$d_g = \frac{1}{a} \ln \frac{1}{c} \ (1 - \frac{R}{2})$$

This is our final expression for the visual range of a vertical gray screen on a cloudy day.

If the screen is white, then its albedo, R, is 1 and its visual range, d_w, can easily be obtained from the equation above since it reduces to

$$d_w = \frac{1}{a} \ln \frac{1}{2c} \qquad (5)$$

For the value $C = 0.02$,

$$d_w = \frac{3.22}{a} \qquad (6)$$

Comparing this with the standard visual range, equation 4, it is seen that a black object may be seen 1.23 times as far as a white one, or an increase of about 25% in visual range.

If the standard of accuracy in making the observation is such that a ten percent error is the maximum allowable, we can compute the greatest albedo which an object might have and still be a suitable visibility mark. This albedo turns out to be 0.65, a rather high value. Therefore, under conditions of diffuse illumination (a cloudy sky), the darkness of the marker is less important than when the sky is clear and the sun is shining.

When the line of sight is largely shaded (as by a large cloud) while the air beyond is in sunlight, the visual range will be somewhat increased because of the reduced amount of air light between the observer and the object. On the other hand, any factor which increases the illumination in the line of sight (a white snow surface, or smooth water when the sun is low and the reflection great) will decrease the visual range somewhat.

The definition of visual range made earlier requires that the observation be taken at the contrast threshold. Let us determine the effect of variations in c on the measurement of the visual range.

Suppose one observer has a contrast threshold of 0.02, while another has one of 0.04, the difference being a physiological one. The range as determined by each will be

$$d_1 = \frac{3.91}{a} \qquad d_2 = \frac{3.22}{a}$$

which yields the result, when compared with the visual ranges of black objects and white ones, that the keener-eyed observer will see a white object just as far as the other sees a black one.

If a deviation of ten percent from the standard visual range is again permitted, it is found that the value of c may be permitted to vary from 0.0136 to 0.0294. This is quite a wide range, and is sufficient to take care of minor physiolocical variations in the observers, changes in the general level of the illumination, etc.

If the contrast threshold were raised to 0.10 instead of 0.02 by a belief that the object should be seen "clearly," the corresponding values of visual range for black and white objects would be

$$d_b = \frac{2.30}{a} \qquad d_w = \frac{1.61}{a}$$

The highest permissible albedo of the object for a ten percent error would then be 0.42, a considerably lower value than with the normal contrast threshold. The conclusion which can be drawn is that the lower the value of c for a given observation, the less will be the error due to the non-blackness of the object.

Progress in Meteorology

by Dr. David Brunt

(from a presidential address delivered before the Royal Meteorological Society).

Meteorology is at once the youngest and the oldest of sciences, and the application of physical principles to explain atmospheric processes is relatively recent.

Let us consider the present state of meteorology and what remains to be done:

ATMOSPHERIC PHYSICS

The monatomic and diatomic molecules in the atmosphere do not radiate or absorb at ordinary atmospheric temperatures; except for monatomic oxygen, which at levels above 100km. absorbs ultraviolet radiation in the range from .13 to .175 microns. Nearly all the absorption and radiation within the atmosphere is due to the triatomic molecules of water vapor, carbon dioxide, and ozone. Whether other polyatomic molecules are effective in absorbing and radiating is as yet undecided. The detailed structure of the spectra of water vapor, carbon dioxide, and ozone is known with too little certainty to enable us to compute the nature and rapidity of the changes of temperature at different levels.

Problems associated with adiabatic changes, with stability or instability, and with subsidence of dry or saturated air have been reasonably well clarified, though the precise conditions in which subsidence occurs on a large scale are still unknown. There are also some uncertainties with regard to the nature of the nuclei on which condensation in liquid and solid form can occur in the atmosphere.

ATMOSPHERIC DYNAMICS

By far the most difficult aspect of meteorology is the dynamical aspect. The general equations of motion contain far too many terms to allow of simple handling. We can readily arrive at a first approximation to the wind, the geostrophic wind, but in a system of geostrophic winds there can be no change of pressure and no weather. It has not yet been possible to lay down the precise conditions in which the different types of pressure inequalities came into existence.

There remains a wide field of unsolved problems with regard to turbulence. The extension of G.I. Taylor's statistical theory of turbulence has yielded a theory of evaporation which gives absolute values of the evaporation in any meteorological condition, but which leaves the problem of evaporation from large areas of water unsolved.

The depression, anticyclone, and tropical cyclone, though long recognized on the synoptic chart, are still far from being clearly understood. We have acquired a picture of the association of the weather in a depression with the air masses and fronts, but have not yet been able to explain the dynamical and thermodynamical causes of the development of the depression. Far less attention has been devoted to the anticyclone, partly through a mistaken idea as to its persistence and good behavior.

We still have no complete theory of the general circulation of the atmosphere. With the accumuluation of observations has come a recognition of the complexity of the general circulation, and a general tendency to avoid attempting to find a complete theoretical explanation of so complicated a system.

INSTRUMENTS AND OBSERVATIONS

Surface observations of pressure, temperature, and wind are now made with a degree of precision which appears to meet all practical needs, but the measurement of humidity is still subject to uncertainty. In the free air, the development of radiosonde (electronic) methods has facilitated the measurement of temperature and wind, but accurate measurement of humidity has yet to be attained by instruments of a standard type.

STATISTICS AND REPRESENTATION

Until recently, little effort was made to represent upper air data synoptically, except for the use of charts of pressure distribution at constant levels. In recent years, charts representing conditions on isentropic surfaces have been rather widely used. It was sometimes wrongly assumed that an isentropic surface must be a surface of flow of air. Strictly speaking, a surface of flow is not isentropic, or isobaric, nor a level surface. Isobaric surfaces would be easier to use, and would give all the results which can be derived from isentropic surfaces. Much remains to be done with regard to the interpretation of these synoptic charts, whether drawn on isobaric or other surfaces; and until we have learned to interpret these charts, it will still remain true that the accumulation of upper air data has led to little progress in meteorology. Indeed, the relatively slight use hitherto made of upper air data has been one of the greatest disappointments of the last 25 years.

The evaluation of coefficients of correlation between observations made at different stations, and at different times, has, in the hands of Sir Gilbert Walker, led to some interesting and valuable results in regard to "world weather," and has made it possible to formulate seasonal forecasts for some regions of the world. The uncertainty which appertains to such methods of weather forecasting is that of the persistence of the high correlations which may subsist for the period used in the statistical analysis.

The value of harmonic analysis of meteorological observations has probably been over-estimated. Meteorological phenomena show a remarkable tendency to display, or at least to simulate, periodicity. The lengths of the periods found in temperature, pressure and rainfall records are unquestionably curious, and cannot be related to any known physical phenomena. Examples of such periods are 61 months, 42 months, 37 months, and 26 months; none of these can be explained by relating them to a dynamical or physical process of the same period, and until we have some understanding of the origin of such periods it is difficult to accept them without question.

The solution of the problem of forecasting the weather over extended periods of time, even for one week ahead, has so far eluded us in this country, and, in view of its economic importance, this problem merits serious investigation.

BIO-METEOROLOGY

Almost all forms of life---whether human, animal, insect or vegetable---are affected by climate and weather, but in few cases can it be said that the effects are clearly understood. A considerable volume of literature deals with the incidence of, and prevention of damage by, spring frosts; but many of the other aspects of the effects of weather on different forms of life have never been seriously investigated. There is, for example, an urgent need for the investigation of the repercussions of weather on the distribution and number of insects.

Even the effects of weather on man have not been worked out in detail... A bold and inspiring effort to relate man's activity to his environmental conditions has been made by Major S.F. Markham in *Climate and the Energy of Nations.* It would appear that there are parts of the world in which white men cannot settle without serious degeneration of energy setting in at the third generation. In the Report of the Carnegie Commission, *The Poor White Problem in South Africa.* there occurs the sentence: "It should be the aim of education to help people to control their environment." I should like to amend this to read: "It should be the aim of education to help people to control their environment, where this is possible, and it should be the business of the State to ensure that the citizen does not choose an environment which is beyond effective control."

This suggests that the State owes its citizens a duty which it has not hereto recognized. I would go farther and say that this is an *urgent* duty, if we are to avoid the risk of the upheavals produced by the present war leading to large scale migrations of people into regions which are not suitable for permanent occupation by white men. Markham quotes the Prime Minister of Rhodesia as pleading that the Colonial Office should immediately make a survey of the whole of the British Empire, to determine in which parts white people are to be allowed to live, and propagate their species, and settle. If such a survey is ever undertaken, and it obviously should be undertaken at the earliest possible time, the meteorologist should take part in the work along with the medical man and the economist.

FUTURE PROBLEMS

The preceding remarks will suffice to show that while there has been real progress in meteorology during the last 62 years, there yet remain wide fields of investigation for the future. To name a few of these, there remain the problems of devising suitable instruments for measuring and recording humidity at all heights; the detailed structure of the spectra of water vapour, carbon dioxide and ozone; the nature of condensation nuclei in the atmosphere; the formation of rain; the relative importance of radiation and turbulence in the vertical transference of heat; the dynamics of pressure changes; the general circulation of the atmosphere; the best mode of representation and interpretation of upper air observations; forecasting over intervals of more than one or two days; and a vast field of applications of meteorology in the biological sciences. These are but a few of the concrete problems which call for fundamental scientific research. Solutions of many of these problems would have considerable value in our private and national life.

Sir George Airy once said that "the observing is out of all proportion to the thinking in meteorology," and the remark is still pertinent, though perhaps not so painfully true as in Airy's day. Symons, in commenting on Airy's remark, added, "At present, of all hopeless courses which a young man who requires to earn his livelihood could choose, few are so bad as that of a meteorologist." This is perhaps no longer true, but not many years ago it could still have passed as fair comment.

What we have to decide at this stage is how to provide for a serious attack on some of the outstanding problems in our science. Little consideration is required to show that many of these problems are of great complexity, and are not likely to be solved except by men of the highest ability, with adequate initial training. At the present moment the outstanding need in this country is for adequate provision of facilities for teaching and research, which should be the business of the universities.

UNIVERSITY TRAINING AND RESEARCH

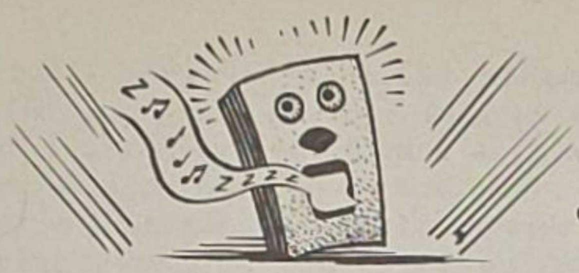
The problems of meteorology may be instrumental, physical, dynamical, statistical or biological. Leaving aside the biological aspect, we conclude that the previous training of the entrant into meteorology should include a wide training in physics, a considerable familiarity with instruments, and a good knowledge of mathematics, with some knowledge of statistical methods. So much knowledge is required before the learner can appreciate the complexity of atmospheric processes, that it is obvious that, so far as university training is concerned, meteorology must be treated as a post-graduate subject, to be studied after a first degree in science has been obtained. My own view is that the ideal course for a first degree, as a preliminary to a special training in meteorology, is an Honours course in physics, with mathematics as a subsidiary subject. This is the preliminary training which experience has proved to be the best, so far as the University of London is concerned. So much of meteorology is concerned with physical concepts that any lack of a thorough knowledge of physics is a very serious handicap. Moreover, the practical training in a physical laboratory gives the student that familiarity with instruments which is desirable in any research worker.

Men with what I have called the ideal initial qualifications can, in a one-year course at the university, learn the basic theory of the physics and dynamics of the atmosphere sufficiently well to fit them for work in a meteorological service. But a still more desirable plan is to have the student spend two years from the time of his first degree in the study of meteorology at the university, devoting most of his second year to research under some supervision.

I attach much importance to the development of ability to do research, for a number of reasons. Firstly, the man who can do original research is likely to be the most efficient type of meteorologist, since he is able to seize upon salient new facts and find their explanation, so adding to our sum of knowledge. Secondly, he obtains some kudos among his fellows when he makes some appreciable contribution to his subject. And thirdly, and perhaps the most important of all, he gets far more fun out of life, since doing successful research is among the most satisfying things in the world.

Emphasis has been laid upon the desirability of giving the really able man the opportunity to do research at an early stage of his career. Energy, originality, and the ability to work rapidly, all tend to diminish with increasing age, and the greatest good to our subject can only be achieved by making the greatest use of the qualities of youth. I do not wish to give the impression that many men now working at meteorology, who never received any formal training in the subject, are not doing work of a high order; but I am confident that most of these who have ever devoted time to research in meteorology in this country would agree with me that a systematic training in the subject would have saved them much labour, and much uncertainty as to what had been done and what remained to be done.

At first sight it might appear that the future of meteorology lies entirely with the professional, or technical expert. There is no reason to suppose that this will be more so in the future than at the present time; and recent numbers of the *Journal* have shown that it is still possible for the amateur to make useful and highly interesting contributions to our knowledge. We must aim at encouraging such work, by giving such help and guidance as may be necessary to any amateur who desires to carry on an investigation in his spare time.



SINGING SONDE

You might be surprised if your radiosonde receiver were to stop short in the middle of an ascent and begin to chant,

"Off we go, into the wild blue yonder..."

But men who received their radiosonde training at Chanute Field any time after November 1943 would not only be nonchalant, they would know who was responsible

As soon as radiosonde classes began at Grand Rapids and Chanute, it became apparent that the effectiveness of instruction was limited by a monotony in actual radiosonde flight-records receivable during a short training period. A well trained radiosonde operator should be familiar with the soundings characteristic of different air masses in every season of the year; and he should be able to work with soundings when they are complicated by such problems as icing, turbulence, and radio interference. Obviously, it was impossible to keep students at school until all of these conditions had been encountered during the course of training. What was needed was a device which could reproduce the transmitter signals for any desired sounding at any time that the sounding was needed for instruction: a method of simulating radiosonde observations.

Sgt. Sergei M. Fomenko is the man who developed simulated radiosonde observations for the Chanute training program. A professional inventor in civilian life, he shrugs aside his work at Chanute as something of little importance---too obvious to deserve mention. But when the story is written of how the Weather Service expanded, there should be a place included for men like Fomenko, who, with plenty of ingenuity and only $2.95 for materials, improvised an important training aid.

The system is simple and ingenious. A standard radiosonde transmitter is utilized, with the baroswitch and the temperature and humidity element resistances replaced by a single variable resistance network. By controlling the values of the resistance in this network it is possible to reproduce the desired temperature, relative humidity, and reference signals; as well as to switch from one signal to another in proper order. Accuracy of reproduction requires that audio-frequencies be controllable to within 1/20 of an ordinate, and consequently an extremely fine adjustment of the variable resistance is necessary. This adjustment is made possible by a network of 14 fixed resistors with magnitudes varying from 62.5 ohms to 512,000 ohms. These 14 resistors are so arranged that any resistance may be obtained which is a multiple of 62.5 and lies in the range from zero to 1,023,937.5 ohms. This spread is sufficient to reproduce accurately the range of audio-frequencies from 15 to 100 ordinates. Hence, given a point on a sounding plotted on the recorder record, it is possible to adjust the resistance network so that the transmitter will send the signal which corresponds to the given point. By this means a complete radiosonde observation can be simulated.

The most ingenious part of the system is the method by which a whole radiosonde record can be sent automatically by the variable resistance network. This automatic control is accomplished by the use of standard teletype transmitters. Marking contacts of the transmitters are used to operate the 14 switches in the resistance network, with a different combination of marking contacts corresponding to each possible combination of network switches. Three teletype transmitters are necessary to control all 14 switches at the same time, because each transmitter is capable of operating simultaneously only the five marking contacts which correspond to the five perforated holes in the teletype tape.

It follows that the three teletype transmitters operating together on tape transmission will be able to reproduce automatically, in succession, any predetermined combinations of the 14 marking contacts, thus simulating any series of audio-frequencies in the desired range. Audio-frequencies corresponding to every tenth of an ordinate from 15 to 100 are translated into a code of three teletype characters, one for each transmitter. A synchronous motor is adjusted to advance the tape at a constant rate of 16 steps per minute. At this speed of transmission the ordinate values need to be encoded only for every 0.025 inch of the original record in order to produce a properly-spaced, simulated record.

Given an actual recorder record, or an idealized record prepared from an adiabatic chart, it is easy enough to prepare the simulated radiosonde observation. Ordinates are measured at proper intervals and values encoded into groups of three teletype characters, one character in each group for each transmitter. Tapes are then cut for the automatic transmission of the three series of characters. Just start the transmitters and an accurately-simulated observation will appear on the recorder.

"In fact," says Sgt. Fomenko, "almost anything that can be plotted on a recorder record can be simulated by this method, including pictures and musical scales." Since there is a wide range of audio-frequencies between 15 to 100 ordinates, it is easy enough to determine the teletype characters corresponding to the notes of a scale and to encode a simple tune for transmission.

"Off we go, into the wild sky yonder..."

GLIDER OBITUARY

Chalk up a forecast error resulting in an aircraft accident during August; this one ahead of a NW-SE occlusion lying across Minnesota, South Dakota, Nebraska, and the flight path.

A Horsa glider on a ferry mission was to be towed by C-47 from Alliance, Nebraska, to a Missouri terminal. Contact Flight Rules were to prevail: the tow was not equipped with automatic pilot or position indicating instruments which would assist the glider pilot to maintain the proper towing attitude if he should ever lose sight of the tug ahead.

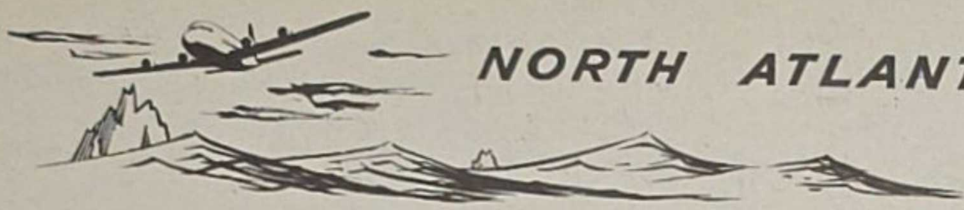
The forecast predicted quite adequate weather for the trip: although scattered thundershowers were indicated, general conditions of 2,000 foot ceilings and 6 mile visibilities were expected.

But listen to the man who was on the spot: "I was the pilot of the tug. My proposed course was blocked (when the frontal zone was reached) by a solid bank of clouds which kept the ceiling below 1,000 feet. I flew off course for about 100 miles without finding an opening." The concurrently-reported weather bore out this statement, because the teletype carried accounts of ceilings variable between 600 and 1,000 feet, as well as visibilities from 3/4 to 6 miles in rain and fog.

If the pilot had returned to his base at this point, the total cost could have been measured in gas and time. However, the pilot obdurately ignored regulations. According to his own statement: "I advised the glider pilot on the interphone that we would descend and fly under, (although) the ceilings were ragged and as low as 200 feet at times. Heavy scattered showers forced us to fly with visibility reduced almost to zero for short periods. It was in a shower that my C-47 lurched a little and I felt the glider cut loose."

Operations at the crash scene reported, "Tow rope caught under the glider's nose wheel when the glider pilot lost sight of his tug in bad weather, necessitating release from tow and a forced landing. Ceilings were estimated at 1,000 feet, above scud as low as 100 feet. Heavy rain was in progress, with visibility from zero to one-half mile."

No injuries were suffered, but the glider was damaged severely.



NORTH ATLANTIC ICING

by LT. JOHN B. BLAKE

With D-Day already set for the spring of 1944, a continuing and uninterrupted flow of men and supplies to England throughout the winter months of 1943 and early 1944 was a prime necessity. Surface convoys could not transport the entire load alone, so the North Atlantic Wing of the Air Transport Command faced the responsibility of cargo and ferry operations across one of the world's more dangerous air routes in winter weather, long recognized as severe and treacherous. If the AAF and RAF were to conclude the "softening-up" operations against the Nazi-held continent in time to permit invasion on schedule, the ATC has to keep the air route open, weather conditions notwithstanding.

To promote safe operation, extensive weather reports were indispensable. Gaps between reporting stations on the North American mainland, on Greenland, Iceland, and on the British Isles had to be filled in by radio reports from weather reconnaissance aircraft which could investigate pertinent areas and levels. C-54 cargo planes were assigned to this duty, and teams of forecasters from the 8th Weather Squadron made the extensive observations required, including statistical analyses of the occurrence and duration of all meteorological phenomena. (See "C-54 Weather Obs", *Weather Service Bulletin*, August 1944)

Not the least of the dangers encountered by planes shuttling between Newfoundland and northern England during the winter months is aircraft icing, long recognized as a major operational hazard to safe flying. To obtain a more complete understanding of icing occurrence and its dangers along the North Atlantic Route, careful observations were made and records were kept of all icing conditions encountered by the weather ships.

CLASSIFICATION OF ICING

Observed icing was classified into the two general types encountered in flight: rime and glaze. Intensity of each condition was determined in accordance with the definitions set forth in Weather Bureau Circular N: *light*, indicating that the condition can be safely handled for an indefinite period by the de-icing equipment; *moderate*, calling for an alteration in the flight plan although the icing can be handled safely, and *heavy*, too severe a condition to be handled by de-icing equipment and requiring either a change in flight altitude or a return to base.

It should be noted here that both classification and the determination of intensity are necessarily subject to individual interpretation. Rime and clear ice often occur together, and the ultimate classification by type depends then upon the judgment and experience of both the pilot and the observer. Intensity likewise is governed by the type and speed of the aircraft and the experience of the pilot or observer. C-54 ships are equipped with de-icing equipment as complete as that on any plane, and are flown by experienced pilots who know how to handle the aircraft in all icing conditions. Smaller and less completely equipped planes might well have considerable difficulty with icing which presented no problem whatever to the C-54s. In one instance the pilot reported "light rime" but remarked that he would consider the condition extremely serious for a plane not equipped with de-icing equipment.

From January through May 1944, in the course of the weather reconnaissance flights, a total of 258 cases of icing were reported. These were distributed according to type and intensity as follows:

Light rime	173
Light glaze (a*)	51
Moderate rime (b*)	20
Moderate glaze (c*)	10
Moderate to severe rime	1
Moderate to severe glaze	1
Moderate to severe rime and glaze mixed	1
Severe rime and glaze mixed	1

a*--Includes 19 light rime and glaze mixed.
b*--Includes 8 cases light to moderate rime.
c*--Includes 1 case light to moderate glaze, and 7 cases moderate rime and glaze mixed.

From these figures it is apparent that the largest incidence of icing encountered (86.8%) was light in intensity and offered little difficulty to the C-54 ships. In nearly every case of icing observed, the de-icing equipment was sufficient to remove the bulk of the ice, and in the majority of cases, there was no effect on plane operation. In the few cases when icing did interfere with operation a reduction in air speed or a change of altitude was sufficient to eliminate the danger.

SYNOPTIC SITUATION

The largest number of icing cases were encountered in connection with frontal structures. Cloud formations along frontal zones are usually more extensive and developed to greater heights than in an air mass. Consequently they extend to ordinary flight levels, and because of their greater horizontal extent, icing conditions encountered in such clouds are likely to be of longer duration.

In all, there were 173 cases of frontal icing and 80 cases of non-frontal icing reported. These were distributed as follows:

FRONTAL ICING		NON-FRONTAL ICING	
Cold Fronts	27%	Cumulus clouds	55%
Warm Fronts	12%	Stratocumulus	25%
Occlusions	24%	Other types	20%
Uncertain	37%		

Of all 258 icing conditions encountered, 34 were classified as moderate or severe. 35% of these cases occurred in connection with occluded fronts, 21% in connection with warm fronts, 15% in connection with cold fronts, 24% in connection with non-frontal cumulus, and 5% in connection with other cloud formations, non-frontal in character.

In general, the following relationships between the synoptic situation and icing conditions were noted:

a. The majority of icing cases encountered in connection with non-frontal conditions and with cold fronts occurred in cumuliform clouds.

b. The majority of cases of frontal icing occurred in connection with occlusions. (It is believed that most of the icing conditions encountered in fronts uncertain as to type were probably associated with occluded fronts).

c. Most cases of moderate to severe icing occurred in connection with warm and occluded fronts (56% of all cases). This may be attributed to the more extensive cloud formations encountered and the longer duration of icing conditions in them. Since cold frontal clouds are less extensive, they may frequently be avoided or passed through at the tops of the cumulus where only light rime is general.

d. 54% of all cases of moderate to severe icing occurred in connection with cumuliform clouds.

e. Oceanic stratocumulus, formed in a southerly flow of air, is an important cloud formation for icing conditions. 25% of non-frontal icing conditions were encountered in this type of cloud. Such clouds often are carried inland far enough to cover some of the commonly used terminals on the North Atlantic route.

TEMPERATURE

Figure 1 demonstrates the percentage occurrence of icing at various temperatures as observed. *From the graph it is quite apparent that there is no definite lower limit to the temperature at which icing can occur.*

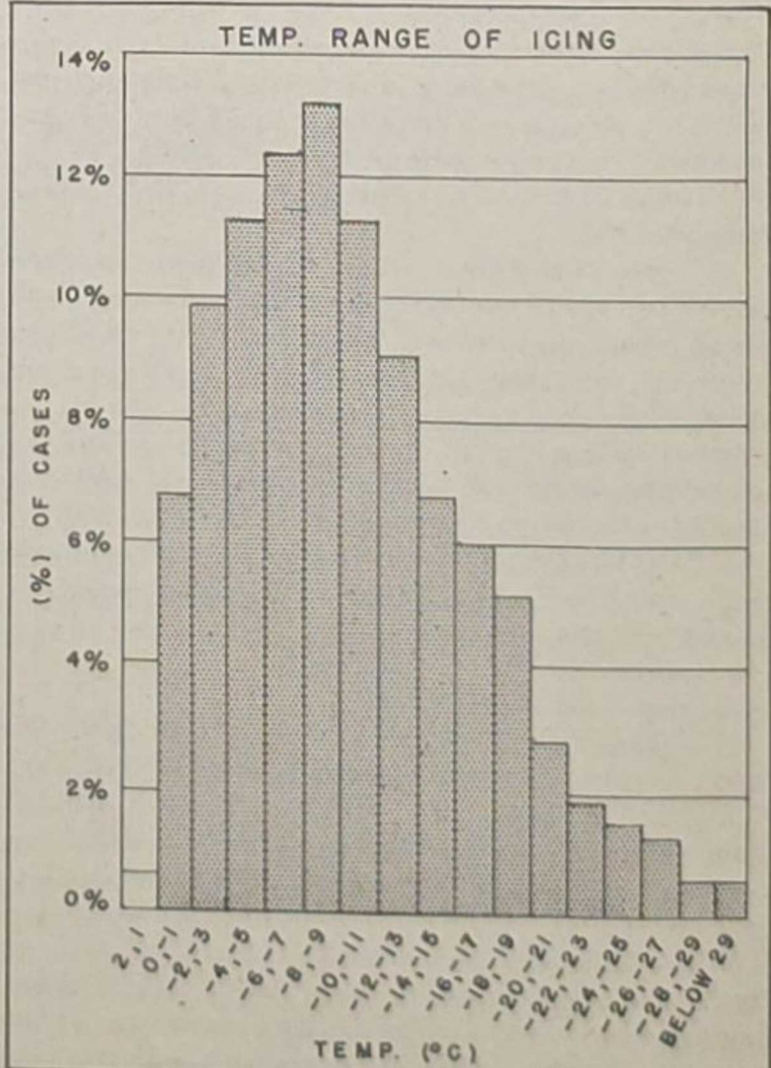
Temperature observations for these flights were made with an ESL psychrometer, specially constructed for accurate in-flight readings. Indicated temperatures were corrected for the dynamic heating effect, and it is believed that the dry bulb thermometer indicated quite accurate readings in clear air. In precipitation or in clouds, however, water collected on the bulb producing a "wet-bulb" effect so that indicated readings were somewhat lower than the true temperature. If the water collected and froze, the released heat of fusion acted to raise the temperature.

For some time the $-18^{\circ}C$ isotherm has been considered a temperature below which most icing conditions would be light in intensity and probably rime in character. But four out of the 34 cases of moderate or severe icing were encountered when the temperature was below $-18^{\circ}C$. These were:

1. Light-to-moderate clear ice in cumulonimbus at -23° to $-28^{\circ}C$.

2. Moderate rime in cumulonimbus tops at $-26^{\circ}C$.

3. Moderate rime in cumulonimbus tops



at - 21°C.

4. Moderate rime and clear ice in an occluded system at -23°C.

One of the great icing dangers in cumulonimbus clouds results from the co-existence of snow particles, ice particles, and water droplets as a result of the extreme turbulence. A plane flying through these condtions accumulates a rough variety of moderate rime and clear ice because the freezing water droplets on the plane entrap some snow and ice particles. Probably there is sufficient moisture in liquid form to cause light icing only, but with the additional snow and ice the deposit may build up at a fairly rapid rate. This process can take place easily at temperatures below -18°C. 11% of all the icing cases were encountered at temperatures below -18°C; one at -41°C (light rime at 13,000 feet in a cumulonimbus top).

A generalization can be made that moderate icing at very low temperatures is confined ordinarily to cumulus activity and is quite rare under stable conditions. But in-flight observations make it quite clear that the -18°C isotherm cannot be taken as the lower limit for even moderate or severe icing.

RELATIVE HUMIDITY

Since icing conditions are found in cloud formations where the relative humidity is necessarily high, it was suggested that the humidity trace from the aerograph might be valuable to the pilot as a forewarning of icing conditions. Extensive tests of this problem were made by comparing the humidity readings at the time icing conditions were first met with the humidity readings 20 minutes previous. No significant results were obtained.

In those instances when the relative humidity twenty minutes prior to icing was 50% or below (41% of all cases) one quarter of the cases showed a marked increase in humidity, and slightly over one half showed a significant increase (20% or more). In other words, approximately one-half of the cases showed insufficient increase in relative humidity to serve as an effective warning of icing conditions.

In the 13% of cases where the relative humidity twenty minutes prior to icing was 55 to 65%, slightly less than one-half showed an increase of 20% or more in relative humidity. When original humidity readings were 70 to 75%, less than one sixth of the cases showed an increase of 20% or more. In the remianing cases where relative humidities were 80% or above twenty minutes prior to icing, the initial humidity values were too high for any change to be of value.

Before arriving at any conclusions fromthese figures it must be remembered that the cases of icing which occurred without significant increase in initially low relative humidities were experienced in towering cumulus clouds. This is understandable when we remember that the air surrounding these clouds is likely to be dried out because of the compensating down-drafts associated with the convective activity of the clouds. Similarly, in those cases where significant increases in relative humidity preceded icing conditions, the pilot also received warnings of impending ice from the increase in frontal altocumulus and altostratus decks.

There were many cases of significant increases in relative humidity which did not presage icing conditions. Also, even when increasing humidities foretold icing conditions correctly, there was no way of determining what change in flight level should be effected in order to avoid icing.

It would appear then that the humidity trace in its present stage of development is not a sufficiently precise or reliable indicator to be of much value to the pilot as an icing indicator. What value it may have is undoubtedly enhanced at night when it is more difficult to see clouds ahead in the path of the aircraft. It may prove, however, to have considerably more value as an indicator, not of icing, but of general cloudiness in a region, even before the clouds are visible to the pilot.

TURBULENCE

After a consideration of the reports on turbulence in connection with all icing conditions reported by the C-54 observers, it would appear that there is some connection between turbulence and moderate to severe icing. While moderate or severe icing occurred in only 13% of all icing cases, 25% of the 32 cases when concurrent icing and moderate or severe turbulence were reported has at least moderate icing. Conversely, out of 34 cases of moderate or severe icing, 24% occurred in conjunction with moderate or severe turbulence, although out of a total of 258 cases of all types of icing, only 12% were in conjunction with moderate or severe turbulence.

On two flights in particular, although the aircraft were flown in icing conditions for 1½ to 2 hours, neither picked up any ice except during intermittent periods of short duration when the ships experienced some light to moderate turbulence.

(continued on page 21)

Fortune *Smiles*

by LT. CUSHMAN REYNOLDS

Weathermen from Charleston to Chabua, and from Jacksonville to Julienhaab, have every right to be proud of the achievements of their own service. Every gallon of gasoline that is carried over the Hump to General Chennault, every bomber that crosses the Atlantic or the Pacific, and every bomb that explodes in Berlin or the Kuriles is, in a sense, delivered by the weathermen. Yet the big headlines and the newsreels never tell of the weathermen; they tell of fighter pilots, bomber pilots, Marines, paratroopers, PT crews, submariners, Rangers, infantrymen, swing-shift Sadies, college girls harvesting beans, and Boy Scouts collecting old pots and pans. Weathermen are pretty thoroughly unsung, except for occasional brief mention in the back pages. No city editor can be expected to find much news value in a sudden cyclonic shift at 10,000 feet or a prediction voiced in Newfoundland that Prestwick might be socked in tight all day tomorrow.

There is no need, of course, for any AAF weatherman to be distressed by the fact that his brother who flies P-38's in Italy and his cousin with the tanks in France receive a greater share than he of public glory. He knows that one reason his brother lands his P-38 is a crack weather service and he knows that his cousin hit the Normandy coast when the weathermen said the weather would permit the operation. Moreover, nobody---fighter pilot, tanker or weatherman---is fighting a war for personal glory.

However, weathermen are only human, and the consolations of philosophy possess their limitations. Weathermen, therefore, will be pleased to learn that the nature and excellence of their work has been sufficiently impressive to engage the attention of the editors of *Fortune* magazine. In its November issue, *Fortune* carries an article entitled "Thunder over the North Atlantic," which is an extensive report of the magnificent achievement of Eighth Weather in insuring the flight of cargo and tactical aircraft across the North Atlantic. However, although Fortune's reporter, Mrs. Jean Ford Brennan whose husband is a Captain of Marines, bases her story on an 8,000-mile flight in a B-17 through Eighth Weather, she introduces her subject with an overall review of the strategic and tactical importance of a weather service throughout the world.

The Eighth was selected by *Fortune* for special treatment because, with the war in what can be called---with obvious qualifications---its later stages, the Eighth seemed to possess the most portentous material from which to anticipate postwar transport problems. The most thickly travelled inter-continental aerial trade routes will be across the North Atlantic. Before the war the North Atlantic was flown only during the summer months, but the Air Transport Command is demonstrating that planes can be routed around the winter storms of the North Atlantic as successfully as around the summer storms. Last winter, three C-54's flew the North Atlantic on schedule and this winter many more will be on the same run. Without a first rate weather service assisted by an equally first rate communications system, such winter flights would be inconceivable. Obviously, now that such flights have been proven practicable at all times of the year, several nations and many airlines will wish to make regular runs in peacetime. Flying the North Atlantic under peacetime conditions will raise questions regarding weather service, communications, and other operational functions which must be settled by somewhat different standards than are admissible under wartime conditions. And the North Atlantic routes will be the prototypes of aerial routes across the Pacific and other comparable areas around the world.

However, to raise the diplomatic questions of tomorrow, *Fortune* first tells the story of what weathermen have accomplished since April 1941 when Eighth Weather was set up at Gander, Newfoundland. At that time, the British were losing close to fifteen per cent of the four-motored planes ferried across the Atlantic and most of the fifteen per cent were being lost to weather. With our entry into the war in December, ferrying operations were rapidly expanded and part of the expansion was the growth of Eighth Weather. From fifteen per cent the loss rate plunged downward despite the fact that we began to ferry medium bombers and even fighters. And while total losses are not available for publication, it is significant that in 1943 only six plane losses on the North Atlantic routes could be attributed to faulty forecasting.

Compass Error is the algebraic sum of variation and deviation:

[+ △] + VARIATION — TRUE

weather squadron whose RCO, Colonel Arthur F. Merewether, is believed to possess intimate knowledge of every square foot of his huge region. And a substantial part of the credit must go to the First Weather Reconnaissance Squadron which cooperates closely with the Eighth.

To achieve its record in routing planes across one of the stormiest areas in the world with the highest stakes in history on the table, Eighth Weather has established forty-six weather stations, including twenty forecasting stations, in New Hampshire and Maine, Newfoundland, Labrador, eastern Canada, Baffinland, Greenland, Iceland, Bermuda and the Azores. The men of the Eighth have withstood all lonely outposts everywhere. All the rigors of war are not to be found in combat theaters---and until not too long ago the North Atlantic was something of a combat theater itself.

In attempting a brief and essentially non-technical discussion of technical meteorological matters, *Fortune* commits itself to a few statements with which weathermen will find fault. However, *Fortune* has produced a report on Eighth Weather---and on the Weather Service in general---for laymen, not a textbook for meteorologists. Few weathermen possess the knowledge of the scope and historical implications of their work which the editors of *Fortune* have presented.

SWEET BLISS

In a recent thirty day period, the brand new RAWIN station at Fort Bliss, Texas (Radio Detection School, AAATC), maintained the highest average maximum altitude of all domestic RAWIN stations: 47,180 feet, compared with the next highest of 44,580 feet. The Fort Bliss station also transmitted the greatest number of regularly-scheduled observations during the period. 116 out of a scheduled 120.

NORTH ATLANTIC ICING

(concluded from page 19)

Although some effort was made to discover whether there might be some relation between icing and the time of day, no significant correlation between icing and time could be determined.

It was established that icing generally decreases with height. This is natural since clouds there are fewer, and most of those which do occur at higher elevations are ice crystals clouds. In aircraft operations, then, high level flight will generally give the least icing and weather. However, it will generally be found that a more practical way to avoid icing is to fly at varying altitudes rather than at excessively high levels because of the difficulties currently involved in use of oxygen equipment.

For combat crews and planes, icing was more of a hazard than for cargo operation. In fact, no re-routing or cancellation of a C-54 weather flight was caused by icing alone. Propeller and windshield anti-icers, pitot anc carburetor heat, and de-icing boots were used frequently. Thorough briefing, extensive experience, and advice of a forecaster in the crew enabled the C-54 pilots to choose suitable flight levels and operational procedures for avoiding dangerous icing conditions.

It's all very well to say, "Correct your True Course for the existing wind, flying the heading obtained from a Triangle of Velocities." But neophyte navigators will look in vain for an instrument which will indicate the plane's proper orientation directly. In practice it is necessary to interpret the data from a magnetic compass, first in light of operational conditions (which produce a *Compass Deviation*), and then with consideration for the plane's geographic location (which determines a *Compass Variation*).

DEVIATION

Modern aircraft are permanent magnets themselves, having been made of steel under influence of the earth's magnetic field. This polarity of a plane depends on its orientation during construction. An aircraft is also a temporary magnet, of a character determined by its flight attitude and location. Finally, electric apparatus sets up a magnetic field within the ship which fluctuates as one device is turned on, or another turned off. These factors determine the *Deviation*, which obviously will be different from one plane to another in a single formation.

Rather than evaluate all the deviating influences one by one, a procedure known as "swinging the compass" is used to measure the total effect. Most usefully, a table of deviations is prepared by this method while the aircraft is in flight with all electromagnetic apparatus in operation. The information sought is the compass reading for a known magnetic heading:

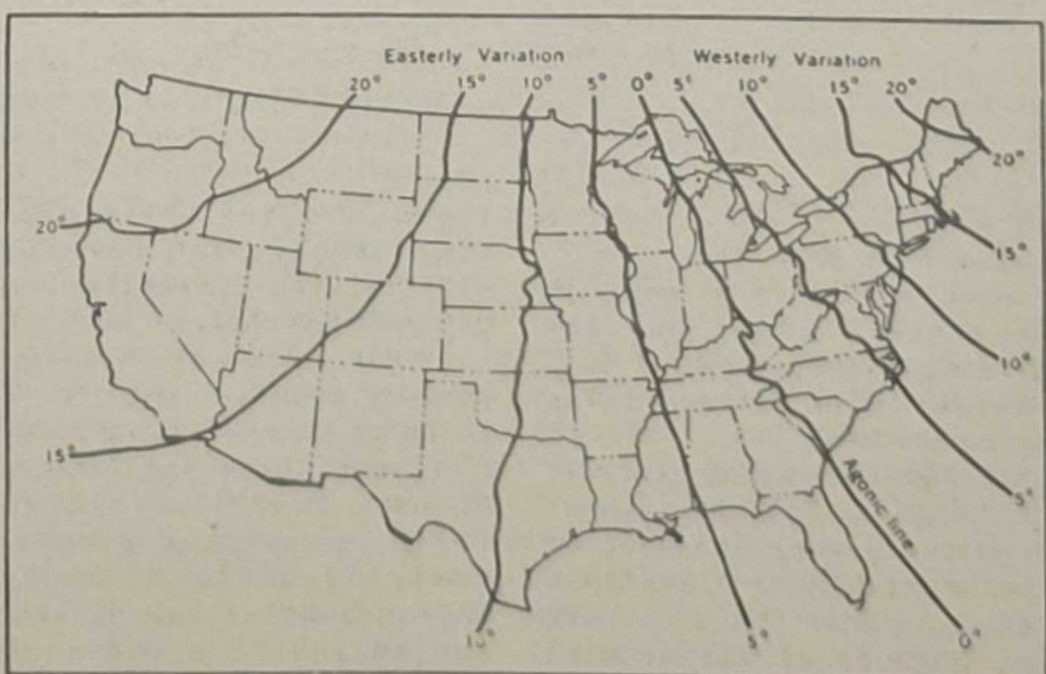
DEVIATION CARD

Magnetic	0	30	60	90	120	150
Compass	1	32	64	91	122	150
Magnetic	180	120	240	270	300	330
Compass	184	209	237	268	299	331

VARIATION

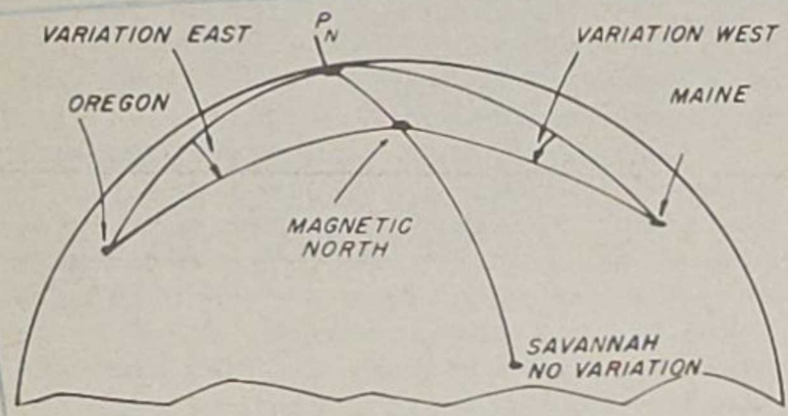
A compass needle will align itself parallel to a terrestrial line of magnetic force when *deviation* has been compensated, no matter what the heading. Then the angle between the needle and True North is *variation*, obviously caused by the displacement of Magnetic North from the geographic Pole.

Variation, then, is the same for every aircraft in a formation because it is a function of latitude and longitude only. Charts have been prepared which inform about the values at a given fix. These maps have isopleths of variation (isogonic lines) radiating from magnetic north.



In general, the undeviated compass points somewhat west or east of True North; to an extent indicated by the *isogonic* line which passes through the point in question. The *agonic* line has zero variation.

Compass Error is the algebraic sum of *variation* and *deviation:*



SIGN CONVENTION

When the Compass Error is east, the compass reads too low.

When the Compass Error is west, the compass reads too high.

For example,

given: 1) Variation is 10°W

2) Deviation is 12°E

3) True Heading desired is 152°

required: Compass heading to steer.

solution: The variation is west, so the compass must read too high. Therefore, 10° is *added* to the True Heading to obtain the Magnetic Heading, 162°.

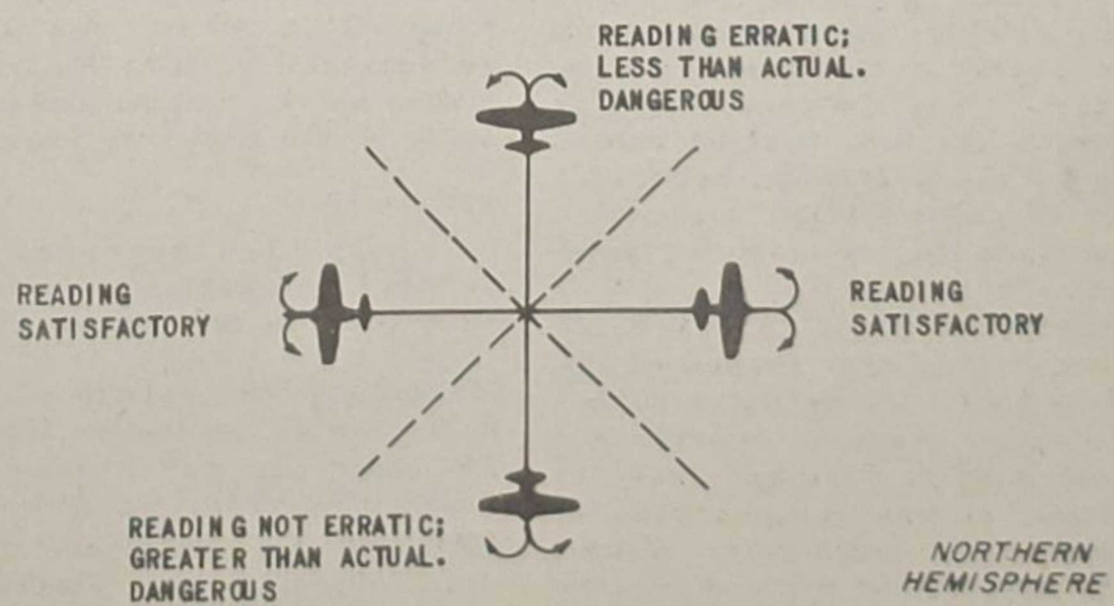
The deviation is given as east, so the compass has to read too low. Consequently, *subtract* 12° from the Magnetic Heading to obtain the Compass Heading, 150°.

DIP

There are really two components to the action of terrestrial magnetism on a compass needle: horizontal and vertical. The horizontal component produces *variation*, as discussed above. The vertical component causes *Dip*, which inclines the needle toward the compass card---a detriment to accurate readings. *Dip* becomes great at high magnetic latitudes, and makes a magnetic compass valueless there.

Dip sometimes can alter ordinary compass reading gravely at low magnetic latitudes: when the aircraft is turned or accelerated. As the figure below points out, this effect exists only on turns from North-South headings; hence the name, *"Northerly Turning Error."*

This hazardous phenomenon is avoided by reference to a gyrocompass, stabilized so well that Turning Error is overcome. Hence the advice (Part I) that Double Drift procedures be carried out with the aid of a gyrocompass. Otherwise, sole reference to a magnetic compass may cause the pilot to sharpen an attempted turn excessively. Such an effort to balance compass behavior might well result in a fatal spin.



NORTHERLY TURNING ERROR makes dangerous the use of a magnetic compass as the only guide in piloting turns. The vertical component of the earth's magnetism causes this phenomenon by augmenting the horizontal component, which is normally expected to act alone.

Headquarters Notes

HANDBOOK RESCINDED

T.O. 00-27, "Weather Station Handbook, Administration and Operation," long the "bible" of station weather officers and station chiefs, was rescinded 15 September 1944. The rescission was announced in T.O. 00-1, "Index of Technical Publications and Information," 1 October 1944.

No single publication is planned to replace the handbook. Weather Wing publications will be the medium for field distribution of directives concerning standardized operational and administrative procedures. Points not covered by Weather Wing publications will be determined by regional directives and memoranda, or left to the discretion of individual station weather officers.

STORM WARNINGS

The Severe Storm Warning Service, now operating in domestic weather regions, is built around 150 AAF weather stations as control centers of networks. Each center serves its own base and other installations of all kinds: general hospitals, ordance plants and depots, arsenals, remount areas, offices of the Engineer Corps, internment camps, relocation centers, civilian aircraft factories, and Service Command headquarters. Approximately 25 additional networks are proposed and should be in operation within a few weeks.

Purely local in character, these networks cover circular areas approximately 60 miles in diameter surrounding each control station. They are established in cooperation with the U.S. Weather Bureau and various civilian defense agencies. Local storms are spotted and tracked by volunteer observers who report by telephone to the control office.

The effectiveness of this warning service in protecting Army personnel and equipment from local storms which do not appear on teletype sequence reports and ordinarily can only be forecast from the synoptic situation was demonstrated at Laurinburg-Maxton AAF on 28 July. Volunteer spotters advised the station weather officer of the approach of a severe thunderstorm fully 30 minutes before it could be seen from the station and in time for him to warn all base activities to take precautions against high wind velocities. All operations on the field were halted at once, and tow planes and gliders secured with mooring ropes. When the storm hit approximately 45 minutes later, a peak gust of 71 mph was recorded.

Despite precautions, seven C-47s were damaged and over 100 gliders damaged or destroyed. However, it is reasonable to assume that injury to personnal and damage to equipment might have been served by a local Storm Warning network, for only 15 minutes elapsed between the time that the thunderstorm was first visible from the station and the time when wind velocities reached 70 mph---too short a time to take precautionary measures.

At Greenwood AAF, where a warning network had not then been established, a severe tornado struck the field on 27 July reducing some of the barracks to splinters, killing one soldier, and causing four or five BT-13s to burn. The movement of the storm up to and across the field was very rapid, and visual observations from the station alone could give no adequate warning of the storm since neither its speed, direction nor intensity could be estimated in time. Had there been a warning service in operation, it is possible that warnings could have been disseminated in time to prevent some of the damage.

The Severe Storm Warning Service has been given credit for preventing considerable damage to several other Army installations within the past few months. Official recognition of this contribution to the ground safety program appeared in a recent issue of the Army-Navy Journal.

HURRICANES

This headquarters has received several requests for references in the literature to the subject of hurricanes.

WEXLER, R., "The Filling of the New England Hurricane of September 1938, *Bulletin of the American Meteorological Society*, September 1939, pp 277-281.

BROOKS, C. F., "Hurricanes into New England," *Geographical Review*, January 1939, pp 119 to 127.

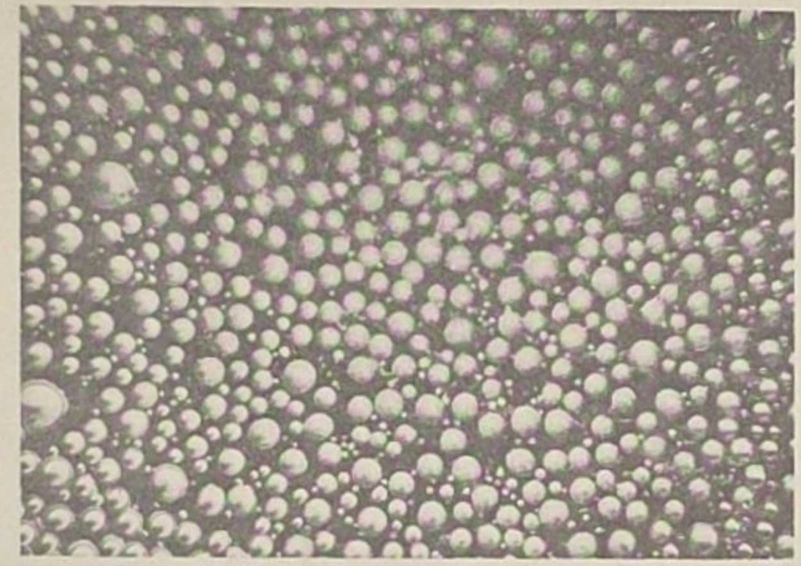
PIERCE, C.H., "The Meteorological History of the New England Hurricane of September 21, 1938," *Monthly weather Review*, 1939, pp 237-285.

COELUM AD PROELIUM ELIGE

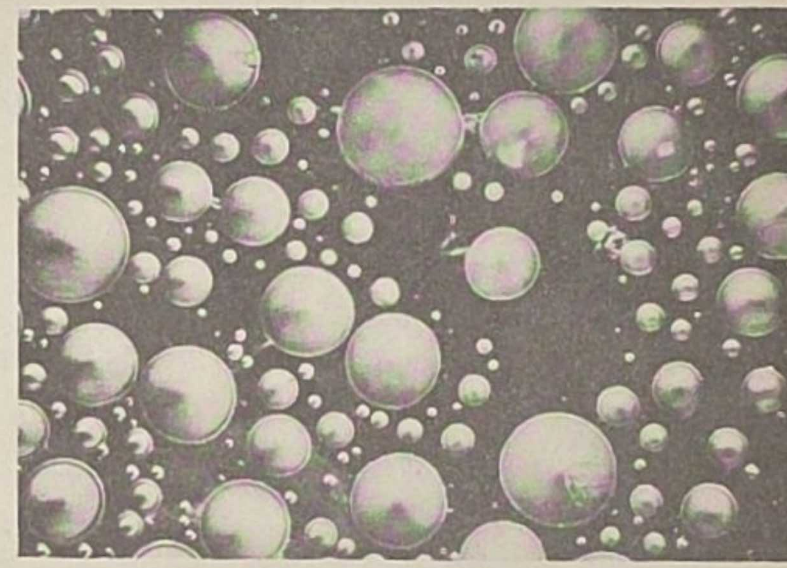
CONTENTS

(R) means Restricted

Rain, snow, and sleet fell during this shot, which was taken in a wind of 62 mph and at $-3°C$. Water content is 0.8 grams/cu. meter.



Except for magnification, this is the interior of a fog which has 0.8 grams of water in each cubic meter. $-5°C$ is the temperature.



At $-16°C$, light snow and fog is the WW here. Its 0.16 grams/cu. meter represents the smallest water content in this series.

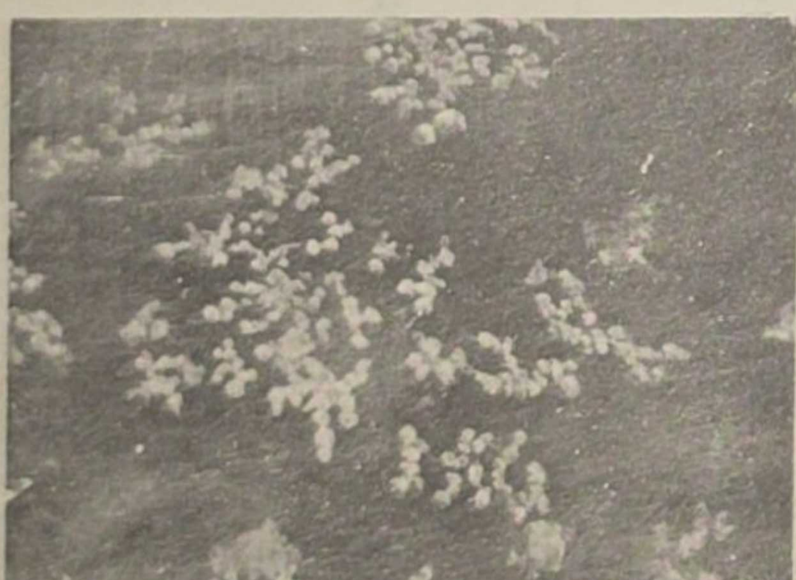
CLOUD MICROPHOTOS

0 500 1000

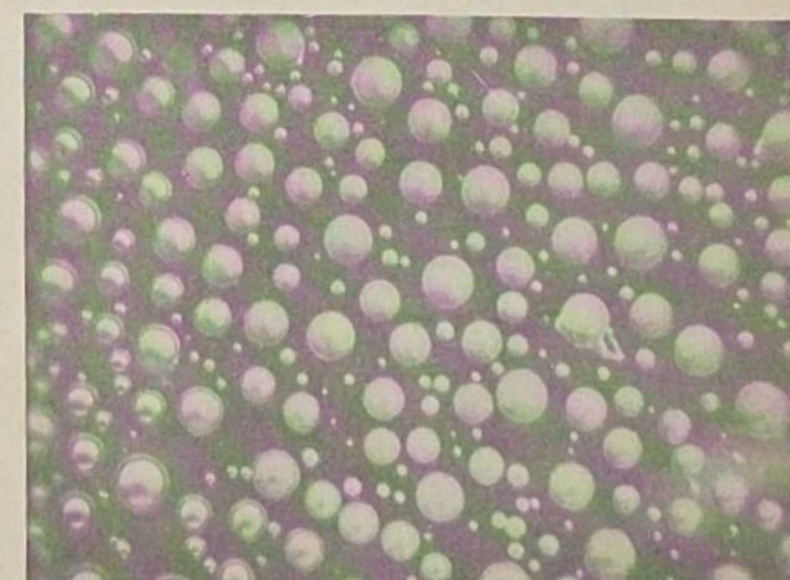
SCALE MICRONS

The observatory atop Mount Washington, New Hampshire, is strategically located to observe the interior of clouds, because many a cloud layer envelops this 6,000 foot peak. These microphotographs (65 diameter magnification) were taken there; the three above within 24 hours.

The importance of cloud droplet size in aircraft icing is modified by additional consideration of the amount of water per unit volume: high content favors glaze deposit while low content is associated with riming. Where the water per unit volume is constant, glaze is more likely in clouds of large droplets and rime when the water particles are small.



These small water droplets were photographed while rime icing was in progress. The liquid water content was only 0.2 grams per cubic meter, and the temperature, $-20°C$.



Large cloud droplets in this case were found at a higher temperature, $-5°C$, with a water content of as much as 1.2 grams / cu. meter. Glaze was forming at the time of exposure.