WEATHER OBSERVATIONS ON MOUNT WASHINGTON

PROBLEMS AND SOLUTIONS

We have had several inquiries from Bulletin readers concerning the methods we use to measure snowfall and snow depth on Mount Washington. In this article I will try to answer these questions and will also take the opportunity to discuss most of the other problems of weather observations on the Mountain and the solutions which have been developed for these problems.

The two aspects of the weather which cause our problems are of course high winds and icing. "Icing" is the term we use to describe the deposition of rime ice from clouds at sub freezing temperatures or of clear ice from freezing rain and drizzle. The development of instruments to measure these two phenomena has occupied quite a bit of our time since the founding of the Observatory and the results of this work have been of value not only to the Observatory but to many other groups as well. But the problems are not all solved; for some of them we foresee solutions, or at least improvements. For one of them no complete solution seems possible and for another a solution is possible but not practical. We will begin by discussing these two hard cases.

PRECIPITATION AND SNOWFALL

The problem here is caused by wind and is three-fold:

- ✓ The airflow in the vicinity of the open top of a precipitation gage will generally reduce the catch. Solution - shielding of the gage by means of an inverted, double angled, conical shield which maintains an approximately parallel flow across the gage mouth.
- ✓ The many buildings on the Summit prevent the location of the gage in an undisturbed location. This compounds problem number three, discussed below. To avoid the influence of buildings would require that the gage be too far from the Observatory to be practical. (It is now approximately midway between our front steps and the Summit House. Even this short trip becomes impossible in winds much over 110 mph, when one is carrying an eight-inch diameter, three foot tall gage.) Furthermore, the location must be in a nearly level area near the summit in order to avoid slope effects. Studies during the early years of the Observatory demonstrated this fact.
- ✓ No gage, no matter how well shielded, can tell the difference between old, blowing snow and newly fallen snow. Sometimes on a day of clear blue sky, but with strong winds and the air full of blowing snow to a height of at lest 30 feet above the ground, we will find that the gage has collected a foot or two of the stuff in a few hours. When it is snowing and the wind is over 50 mph or so (normal conditions for a Mount Washington storm), it is impossible to be sure how much of the catch is real. In fact it is often impossible to be absolutely sure whether it is snowing or not. Under these conditions we try to make a rough correlation of the snowfall and melted precipitation figures and our reported amounts are estimates.

SNOW DEPTH

Here the problem is the size and variability of the drifts on the Summit. Normally most of the ground area is bare. A few places have large drifts every winter, the size of which depends very little on the amount of snowfall. For instance, the drift in the angle of the Yankee Building always seem to reach a sort of equilibrium midway up the second floor windows. Other drifts come and go at the whim of the wind. No set of fixed stakes could be relied on to give a representative average under all conditions, unless we used a very large number of stakes. So our reported snow depths are also estimated - "Guesstimates" would be a better word.

WIND SPEED

Wind speed is the most spectacular and interesting of our measurements and also one of the most important for some of our research projects and for our public functions. Probably more time and effort have been expended in an attempt to improve and maintain the Observatory's anemometers than for all our other weather instruments combined. The early work with heated rotating anemometers has been extensively described by others. We still use standard Weather Bureau three-cup anemometers during periods when the Summit is not experiencing icing, but these instruments are of course useless under icing conditions unless the accumulation rate is very low.

It was recognized quite early in the Observatory's history that wind speed could be measured in the same way that an aircraft measures its airspeed - with a pitot static tube. This is a device which senses the difference between the air pressure on a forward facing surface and a surface parallel to the airflow ("total pressure" and "static pressure"). Many problems had to be overcome before a workable system was developed. An adequate vaning

system was designed with heaters to prevent icing, a method was devised to prevent ice formation in the pressure lines and a suitable recorder was installed. This work was done largely by the late Adam J. (Bud) Eckert of the Eighth Weather Squadron Detachment at Mount Washington, with valuable assistance and encouragement from Vincent Schaefer, then at the General Electric Company. The system we use today is basically the same as the one developed in 1945 and put into official use on April 1, 1946.

The instrument in use today was designed for the Observatory by John Conover. It consists of a one piece cast magnesium hub and tail with an integral skirt extending about four inches down outside the top of the mast which is a section of two inch pipe.

All of this casting is covered with electric heaters built up from glass cloth, Nichrome ribbon and polyester resin. The top of the pipe mast holds a ball bearing and the shaft which turns in the bearing is hollow to accommodate heater leads and the copper tubing for the total and static pressure lines. The pitot static tube, of a standard electrically heated aircraft type, is mounted on the hub tilted a few degrees below the horizontal so as to be parallel, on the average, to the airflow which has an upward component in the vicinity of our tower.

The mast extends about seven feet above the top of the tower. The electrical leads and the pressure tubing (which changes to rubber tubing a couple of feet below the hub) hang freely inside the mast. There are no slip rings or rotating pressure connections to cause trouble; twisting of the lines is seldom a problem, because the wind rarely shifts 360 degrees in one direction and, if it does, we simply turn the instrument back around one turn to untwist the lines. There is some restriction to the vaning at low wind speeds due to the lines. This effect becomes noticeable at about 30 mph and below 20 mph vaning is almost completely curtailed, but the accuracy of the system is low at these speeds for other reasons.

Some of the moisture entering the total pressure opening of the pitot static tube, which points directly into the wind, will eventually find its way into the connecting tubing where it may freeze and disable the instrument. Several methods have been used to combat this problem. At first a heated trap was installed in the line within the hub.

This method was abandoned in favor of a more active technique where dry air was continuously pumped into the total pressure line from within the building. This, of course, affected the calibration of the wind and pressure instruments; and it was not completely successful, perhaps because the pumped air was not completely dry. In 1966 the pumping system was eliminated and heater cable wrapped around the pressure lines. Ice plugs still occasionally form in the tubing sections in very severe weather, especially in the short unheated areas in joints in the pressure line. However, this happens only three or four times per winter and can usually be cured without bringing the instrument and lines indoors, which can be a major project in bad weather.

Our most frequent problem with the present system is riming of the hub and skirt. Power for the skirt and tail heaters is controlled by Variacs. If the power settings are high enough to prevent any rime formation, there is a danger of burning out the heaters. Therefore, except under very light icing conditions, rime does tend to form on the skirt and must be removed by hand or by jarring the mast. This may have to be done once an hour or more under severe conditions, otherwise the rime rapidly builds up sufficiently to block the static ports or to cause the pitot static tube to point out of the wind. Thus the heaters' main function is to facilitate de-icing.

The total and static pressure lines from the pitot static tube descend into the Observatory weather room, where they are connected in "parallel" to three instruments:

1) A Hays Draft Recorder, a circular 24 hour chart calibrated 0 to 10 inches of water differential pressure, which provides our primary official wind speed record, both for hourly average speeds and peak gusts.
2) Another identical Hays recorder with a constriction in the total pressure tubing which provides a damped record useful under extremely gusty conditions and which also acts as a backup to the primary recorder.
3) A U-Tube manometer, 0 to 15 inches of water, used for checking the recorder calibrations and for measuring differential pressures above the recorder range.

The 10 inch scale range of the recorders covers winds up to about 160 mph. The manometer range is not sufficient to measure a record breaking wind. If we get a big blow we will have to improvise; but we plan to correct this situation. Such high winds are extremely rare; we have had no recorded gusts of 160 mph or over since 1950.

Because differential pressure is proportional to the square of wind speeds, it is impossible to read wind speeds of less than 30 mph with any accuracy on either the recorders or the manometer. (One inch of water corresponds to about 50 mph; four inches to about 100 mph.) This fact, plus the sluggish vaning of the pitot static tube at low speeds, means that we must rely on the three cup anemometer at low speeds even under icing conditions.

Our present wind speed measuring system is reasonably satisfactory, both for reliability and for accuracy. We plan to improve it as time and funds permit.

BAROMETRIC PRESSURE

The barometric pressure which is observed by a weather station is ideally the static pressure of the atmosphere, static pressure being what is sensed by a barometer which is at rest with respect to the surrounding atmosphere. If there is any wind, the pressure inside a building will normally not be identical to the static pressure; but the difference cannot be accurately predicted, because it depends on the shape of the building, the location and size of the openings and the wind speed and direction. For normal valley style winds the error is small, but on Mount Washington it can be several tenths of an inch of mercury. This is problem number one.

Problem number two is the fact that the true static pressure on Mount Washington is lower than the pressure measured in the free air at the same altitude. This is due to the Bernoulli Effect. The Presidential Range acts as one side of a huge Venturi tube and the wind is "squeezed" between the mountains and the stable stratification of the upper atmosphere. The increase in wind speed requires a decrease in static pressure in the vicinity of the mountain tops.

Ray Falconer, then at the Observatory, studied this problem by comparing uncorrected pressure data with values for the same altitude and times obtained by interpolation from weather maps. One result of his study was a graph from which, knowing the wind speed, one could find the correction to be added to the observed pressure to obtain a value which would agree quite closely with the weather map. This manual correction method was used beginning in March, 1945.

The corrections obtained from Falconer's empirical curve are proportional to the square of the wind speed. This suggested the possibility of using the total pressure sensed by the vaned pitot static tube, being developed at that time for wind speed measurement, as the source of pressure for the barometer and barograph. When this was tried, the resulting automatically corrected data fitted the weather maps with a mean discrepancy of approximately one millibar. This may not be fortuitous for the case of Mt. Washington; for it can be understood why it should be true, since air coming to rest at the tube entrance should no longer have a Bernoulli pressure drop. It certainly affords us a simple way to correct our station pressure measurements.

The method we use now was officially adopted on April 1, 1946. The total pressure from the pitot static tube is led to the sealed cistern of a Bowen barometer and also to a sealed case containing a microbarograph. A constriction in the pressure line reduces "pumping" of the instruments during gusty winds and also helps keep moisture out of the total pressure line by minimizing the "in and out" flow of air which would be induced by the large volume of the barograph case.

WIND DIRECTION

The Observatory has never had an entirely satisfactory system for recording wind direction. Various instruments have been used from time to time and some have lasted several years before breaking down. Wear and tear on the vane itself is easy to fix, but the electrical transmitters have all proved susceptible to corrosion or mechanical failure.

Icing of the vane is of course a problem, but to my knowledge we have never had a heated wind vane. The major stumbling block is how do you provide electrical connections to a vane heater while maintaining sensitive vaning in light winds?

Currently we are using a standard Weather Bureau vane with electrical dial indicator. This instrument is surprisingly rugged and has lasted through one winter without any catastrophic problems, but it is not readily adaptable to operation with a recorder.

Another problem with wind vanes is that of excessive motion (whipping) in gusty winds, particularly when turbulence is caused by nearby buildings. This is also a serious problem with the vaned pitot static tube, where it may result in recorded wind speed values which are too low. We are considering the possibility of applying some sort of mechanical or electrical damping to the vane shaft which will reduce the whipping without restricting normal vaning at low speeds.

TEMPERATURE

This is the least of our problems, although the accurate measurement of temperature in any location is never as easy as it may seem. Our standard Weather Bureau instrument shelter must get along without a door which would be either frozen shut or torn off by the wind. The shelter contains a maximum and a minimum thermometer and the bulb of our Foxboro thermograph. The minimum thermometer is unreliable during high winds, because the index tends to be vibrated down into the bulb. During winter storms the shelter becomes liberally coated inside and out with rime and snow, so that when the weather clears, the thermometers register the wet bulb temperature until the shelter is

cleared off. This is not a serious problem because, when we are not in the fog, the official three hourly temperatures are taken with a sling psychrometer and the thermograph record is corrected from these readings. During icing conditions, the psychrometer reading will be too high due to the liberation of the heat of fusion when ice forms on the bulbs; and therefore the minimum thermometer in the shelter is used for current temperature readings at these times.

CONCLUSIONS

The problems encountered by those hardy pioneers of 1932 are still with us. Automation reaches the point of diminishing returns faster on Mount Washington than in the valley, but still a few of our weather observation tasks have been made easier and the results more accurate since the early days.

We still hope to make improvements, notably in the wind velocity instrumentation. Here the problem, as usual, is that when we have the money we don't have the time, and when we have the time we don't have the money (or, often, the talent).

Apart from instrumentation improvement, there are two areas which might repay further study. One of these is the investigation of the effect of wind on snow accumulation and its measurement (possibly tied in with spring runoff studies). The other is the study of the Mountain's effect on atmospheric pressure and wind flow.

CLOUD FORMATION

Clouds, nature's fingerprint of the water cycle--thenever ending cycle of water evaporation, condensationand precipitation. Water at the earth's surface getsheated and evaporates into the atmosphere in the formof water vapor. Warm moist air gets lifted over amountain. A large area of surface air gets lifteddue to a converging airmass. A front pushes in fromthe west and lifts the warm air up into the atmosphere.All of these mechanisms have a common thread of risingexpanding air. The air cools as it rises into theatmosphere. Air can hold less moisture at coolertemperatures. Condensation occurs, changing water vapor towater droplets. Microscopic droplets of condensed waterattach themselves to tiny dust particles in the air.If the temperature is cold enough tiny ice particleswill form. These tiny water droplets or ice particlesthat have formed around dust particles become visibleto us in the form of clouds. Clouds are visible waterdroplets or ice particles in the air.The types of clouds that you see when looking up in thesky depends on the weather conditions that you areexperiencing. Sometimes, clouds are beautiful to lookat. On a sunny day you may see clouds that resembleanimals and other forms found in nature. Clouds can alsolook frightening. A dark ominous sky might cause you toturn on your radio or The Weather Channel to find out ifsevere weather is approaching.Meteorologists, Farmers, Mariners, and other outdoorsensitive workers rely on reading the clouds to determineconditions in the atmosphere. Some clouds form only infair weather, while others produce showers or thunderstormswhen warm warm, humid air becomes saturated. Still othertypes of clouds appear as a storm approaches. In the nextsections we can take a look at the many forms of cloudsthat exist, and the types of weather with which they areassociated.

WORST EVER?

Between the hours of 0600 and 0900 on the morning of January 7th there was a sudden shift in the wind from the south to the northwest. During this period light snow was falling, limiting visibility to somewhat less than an eighth of a mile. The temperature had been rising slowly throughout the day reaching a maximum of 4 degrees at 0845. Between 0700 and 0900 the wind averaged 13 miles per hour. The barometer during this period continued to fall steadily as it had since 1730 on the 6th. At approximately 0900 the wind began picking up, continuing to do so until shortly after 1400 at which time it was averaging 75 miles per hour. It remained relatively constant until 2200 when it began increasing once again. This trend continued until just after 1700 on the eighth at which time it was averaging 112 miles per hour gusting to 134. The wind had been quite gusty up until this time with an average difference of 15 miles per hour between lulls and peaks. Shortly after 1700, however, the gustiness augmented tremendously with the velocity increasing as much as 115 miles an hour in two or three seconds! This marked the beginning of a gradual decline in average wind speed which continued through the ninth when at midnight it had dropped to 28 miles per hour. Prevailing wind direction remained north west until between 1600 and 1700 on the 7th during which it backed to the west. It held from this direction until 1645 on the 8th when it once again returned to the northwest.

Corresponding with the increase in wind velocity at 0900 was a steady fall in temperature which continued until shortly before 0900 on the 8th at which time a minimum of minus 46.2 was reached. The barometer continued its downward trend until 1300 on the 7th, when it leveled off, remaining relatively steady until approximately 0500 on the 8th.

The light snow which began late in the day on the 6th ended at around 1240 on the 7th, shortly after the sudden change in wind velocity and temperature. The 6.8 inches of snow accumulated during the storm was picked up by the wind at about 1015 on the 7th and continued to reduce visibility to near zero until 1950 on the following day.

The average wind velocity for January 8th was 92.2 mph with a peak gust of 134 which occurred at 1710. The temperature averaged 37.5 below zero with the minimum for the day recorded between 0900 and 1115 when the temperature held steady at minus 46.2. The maximum for the day was registered between 2300 and 0000 when the temperature reached 22 below. The worst combination of wind and cold occurred between 1000 and 1100 when the wind averaged 99 miles per hour with gusts to 117 and the temperature down to minus 46.2. The still air equivalent of such a combination is approximately 150 degrees below zero! It might be added that with perhaps the exception of a few mountain ranges on the perimeter of the Antarctic and of Mt. McKinley in Alaska, there is no spot on the face of the earth capable of dishing up such an extreme combination of wind and cold. Although there have been many days in the Summit's history when higher wind velocities have been recorded and days on which the temperature has been as low or lower, after a detailed study of the Summit's past weather history, we concluded that, at least as far back as 1935, there has never been a day on which such a severe combination of low temperatures and high winds persisted over such an extended period. The windiest period of the day was between 1600 and 1700 when the wind averaged 107 miles per hour with a peak gust of 134.

If the synoptic weather maps for the dates of January 7th, 8th, and 9th are studied in detail the cause of the cold temperatures and high winds which plagued the Summit as well as the rest of New England during that period becomes readily apparent. On the morning of the 7th there were two well defined low pressure systems over the country. One of these was located over central Pennsylvania and western New York state and the other just off the coasts of Delaware and Virginia. Frontal systems from both of these storm centers trailed down into the Gulf of Mexico. Another storm which passed northeast of New England while moving along the St. Lawrence River Valley had dumped close to seven inches of snow here on the Summit before becoming stationary over Newfoundland. Extremely cold temperatures were associated with a strong high pressure cell located over western Missouri and eastern Kansas. Another high, also accompanied by very low temperatures, had moved down from northern Canada to the Hudson Bay area. At this time with the exception of northern Maine, temperatures were still above zero in New England.

On the morning of the 8th, however, the two lows which had previously been south of New England had combined and moved northeastward up the coast to western Newfoundland where they also became stationary. Under the influence of this tremendous vacuum the two high pressure cells began moving eastward, the one from Kansas and Missouri to central Indiana and the other expanding from Hudson Bay and dropping the 0 degree line south of Portland, Maine. A steep pressure gradient from the proximity of these weather systems to one another caused air to move very swiftly from areas of high pressure to the comparative vacuum of the low. The upper air currents circulating around the combined lows gained considerable momentum, resulting in the strong winds which swept across our area from the northwest.

Severe conditions persisted on the Summit throughout most of the day on the 7th. By midnight the wind was averaging 79 mph and the temperature had dropped to 35 below zero. I was on the night shift at the time and had just finished the daily summary when I noticed the trace on the wind chart falling off rapidly. The conditions outside indicated anything but a decrease in wind velocity and the barograph trace bore this out. Shortly after 0200 with the wind averaging close to 100 mph and the temperature down to minus 38, I bundled up as warmly as practical and made an assault on the tower. It occurred to me that the situation might necessitate a trip out onto the platform, a task about which I was anything but enthusiastic. Stopping on the second landing, I managed to separate the pitot lines with some difficulty at which time I discovered an ice block in the static tube. No amount of huffing and puffing would result in success and I had almost decided to risk a few minutes up on the platform when the lights suddenly dimmed. In a matter of seconds I was in total darkness. Power failure! The occurrence brought to mind a flood of thoughts none of which were pleasant. Wasting little time, I picked my way back to the weather room where I secured two flashlights and awakened Joel. I informed him of the situation and offered to go over to the television transmitter if he would take care of the cosmic ray monitor which would have to be reset.

I had just entered the transmitter building when the power was restored. Dick Cushman did not seem overly concerned with the status of things although he had not yet been able to ascertain exactly what had been the cause of the problem. All told, both buildings had been without electricity for about 4 minutes. I returned to the Observatory to check in on Cosmo while Dick roused Marty Engstrom. Joel felt confident that all was going well, so I returned once again to the tower. I encountered great difficulty in pulling myself up onto the platform and once there, wasn't exactly sure of how effective was going to be. It took a while to find a position that offered me some degree of confidence but the wind load on my extended arm made any calculated movement impossible. After several vain attempts at spinning the pitot head my eyelashes froze shut so I abandoned that phase of the project and returned to the second landing where success was finally realized with the alcohol gun.

Joel had made remarkable progress with Cosmo and all seemed back to near normal when Dick called. He and Marty had switched to No. 2 diesel and were reasonably sure that the engine block of No. 1 had frozen solid. Further investigation negated this theory, however, and it appeared that the radiator, rather than the block, had been responsible for the shut down. Not only had the radiator of No. 1 frozen but also that of No. 2. The temperature in the diesel room was seriously out of hand because of insufficient anti freeze. However, the seriousness of the situation did not become apparent until the water filter on No.2 exploded. From this point on things moved very quickly. Keeping one of the engines on the line was of primary importance and it was hoped that No. 3 would handle the task adequately while the louvers were closed in an effort to restore heat to the diesel room. Fortunately for all concerned it did. Having managed to get Cosmo squared away, Joel came over to offer his assistance. In addition to all the other problems, it was discovered that the heating system in the Yankee Network Building had ceased to function and that the water pipes were in danger of freezing. Joel volunteered to investigate the problem and so I took up a position by the instrument room window in order to make sure that his struggle across the Summit was successful. The wind at that time was averaging 92 mph with gusts frequently going over 100 and the temperature had dipped to minus 41. Needless to say, he made the trip in as little time as the wind would allow.

The third trip brought success, although only temporary, and we both returned to the transmitter where we were informed that the water pump had frozen. A portable electric heater was placed near the pump and the four of us concentrated our efforts on getting antifreeze into the radiators of the three diesels. I watched amazed as gallon after gallon disappeared into the tremendous cooling systems. At 0600 Joel returned to the Observatory to take the observation while I remained at T.V.. Joe Dodge was very interested in what was transpiring on the Summit as were the people at Pinkham and the Portland Weather Bureau. Having made the morning contacts, Joel and I began checking on things here. With the exception of a frozen water pump, all seemed in reasonable order. Joel fixed the pump while I kept a careful watch on the weather instruments which, to our utter astonishment, continued to function efficiently throughout the day. Numerous telephone calls inquiring about conditions on the summit were answered and volumes of weather data summaries covering past years on the mountain were brought down off the shelves and examined in an attempt to determine the status of the storm. At some time during this hectic period we both managed to grab a bite to eat, the last we would have until that evening. A 16 mm movie camera was set up in the doorway and with the wind averaging better than 100 mph and the temperature 45 below, Joel volunteered to make a trip out to the precipitation gauge, a trip about which he had some doubts before leaving the building and of the absurdity of which he was convinced by the time he had reached the bottom of the stairs. The round trip took less than two minutes despite the fact that the last several yards had to be negotiated on hands and knees.

It was at this time that the possibility of equaling the all time low temperature record on the mountain was realized and as a result of enthusiasm, frequent checks were made on the instrument shelter. At the 0930 contact with Portland we were assured of the likelihood of such a possibility and Joe Dodge, who was notified of the situation,

left his receiver on in order that we might keep him informed of subsequent developments. Despite all our optimism and elaborate pains which were taken, the temperature refused to go any lower than minus 46.2, a mere three tenths of a degree from the record.

The extreme cold and high winds made it increasingly difficult to maintain a comfortable environment within our living quarters and even with the furnace turning out its best and the burners, oven, and portable electric heaters going, the temperature at eye level remained between 40 and 50 degrees. On the floor it was nearer 17 degrees. Frost accumulated on the inside of all the windows and the water pipes had to be drained to prevent them from freezing. The temperature on the first floor was not much above zero and practically everything, including my developing solutions, froze solid. A chisel had to be employed to extract the frozen contents of a can of creamed corn before Joel and I could have dinner that evening. The only things on the first floor that didn't give us any trouble were the meat freezers. What little rime had built up on the western side of the building during the previous day had been removed had been removed by the wind and blowing snow and as a result the building shook quite violently, particularly toward the end of the day when the wind became very gusty. Everything that wasn't nailed down managed to move about and the roar outside was deafening. The interior of the building had become a natural vacuum and opening the front door never failed to trigger a rather elaborate sequence of events. A loud hissing noise would precede the opening of the cellar door, which would then bang violently into the clothes rack; all the clothes on the rack would extend themselves horizontally in the direction of the hallway; the trap door in the kitchen ceiling would rise a full foot above its opening and then come clattering back down into place; when the terrific suction would at last slam the front door shut, one's ears would pop. It was only with the greatest difficulty that the front door could be opened, and at one point I managed to put sufficient strain on it to shear off the pin which holds the knob in place.