UP ISN'T ALWAYS THE WAY OUT

BY JAMES METCALF
AOPA 631468

A particularly frustrating aspect of aviation meteorology is the quest for simple "rules of thumb" prescribing flight procedures for given weather situations. It is frustrating both for the meteorologist, who knows that the complexity of the atmosphere prevents his adequately describing its effects on aviation by a few simple rules, and for the pilot, who must accept with every rule of thumb a list of exceptions or a range of uncertainty.

A case in point is icing encountered in the vicinity of warm fronts and the question of whether icing conditions can be avoided by climbing into warmer air above the warm front. We will first examine the origin of the principle of climbing to avoid ice, second consider the conditions under which it may or may not be valid, and third discuss ways of identifying these conditions in a particular situation.

A warm front is formed as a warm and usually moist air mass flows over a colder air mass. This typically occurs on the east side of low pressure centers, where southerly flow (in the northern hemisphere) brings tropical or subtropical air into contact with polar air. As the warm air is lifted over the cold air near the surface, its pressure decreases and it cools. Clouds form as its moisture condenses.

It is important to understand that, while the temperature of the warm air mass at a given altitude will be higher than the temperature of the cold air mass at the same altitude, the temperature of the warm air may or may not be higher than the temperature of the cold air directly below. Typically, the air above the warm front, which slopes upward over the cold air mass, is warmer than that below the front, so that the warm front is characterized by a temperature inversion.

Viewing the front in cross-section (Fig. 1), you can see that the isotherms must have an "S" shape to depict the

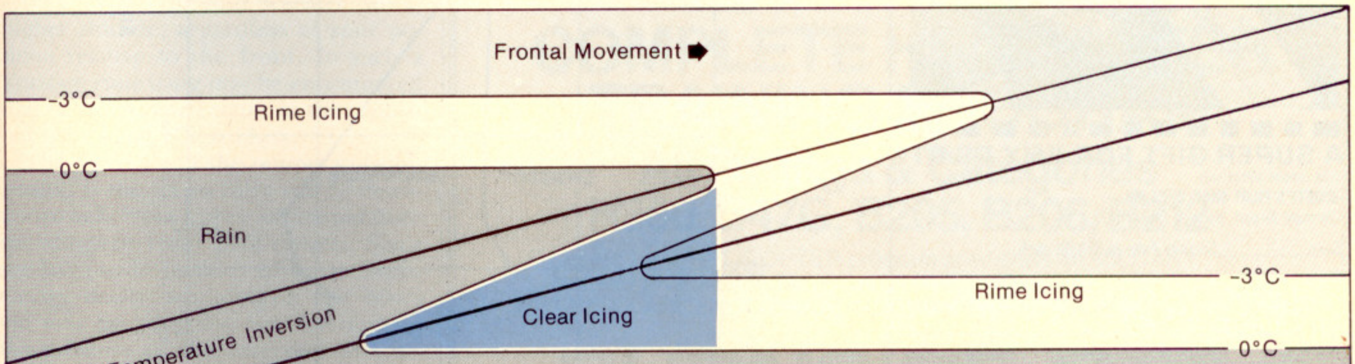

Fig. 1. In this cross-section of a warm front, the isotherms are S-shaped to depict the inversion where the warmer air slopes upward over the cold air mass. Theoretically, a pilot caught in the clear icing "pocket" could climb into the above-freezing zone where rain can get rid of his ice, but real-life conditions seldom approximate the textbook depiction and he could easily find himself trapped.

inversion. If the air on the warm side of the front is above freezing temperature at the surface, then there *must* be some region of the front in which air at above-freezing temperature overlies air at below-freezing temperature. Frozen precipitation falling into this region from above will be melted in the above-freezing air.

Since rain drops do not immediately freeze at temperatures of −5° to −10° C, supercooled liquid water drops will

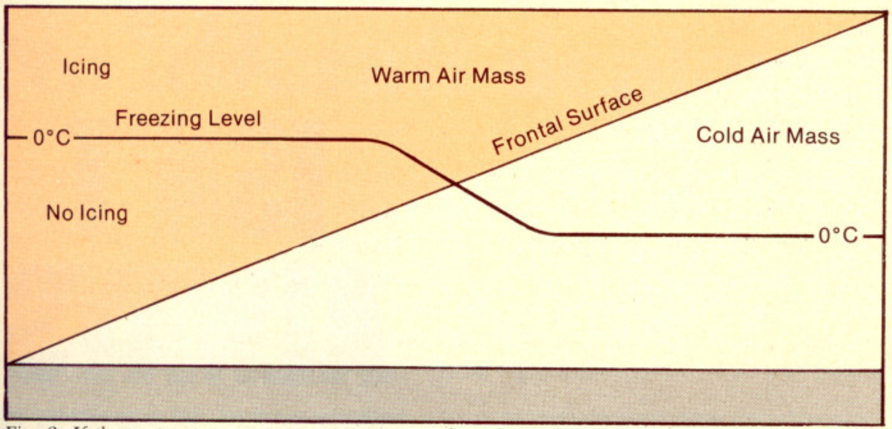

Fig. 2. If the temperature contrast across a warm front is not large, or if relative air mass motion is slow, there will be no inversion, and less chance to climb out of icing.

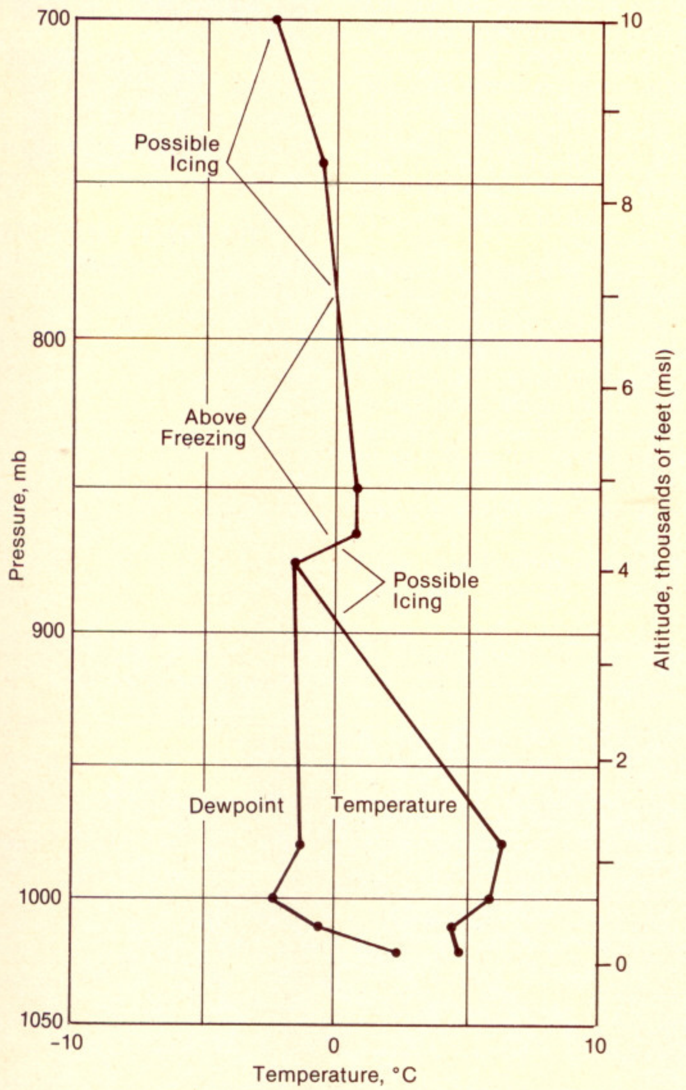

Fig. 3. Upper air soundings show whether a warm front has an inversion that can be used to escape icing. This one shows an above-freezing layer between 4,300 and 6,800 feet into which a plane caught beneath in clear icing conditions could climb for relief.

be present in the air below the frontal temperature inversion. These will be encountered as clear icing. From the cold air below the front, one can (in principle) climb to air above freezing temperature to avoid ice or to melt ice already accumulated.

It is important to note that the region of above-freezing air has a limited horizontal extent in the direction perpendicular to the front. It typically has a greater horizontal extent along the front, but its structure is determined by several factors. These include the temperatures of the two air masses, the temperature difference across the front, and the speed of the airflow up the frontal surface, any of which may vary along the front. The occurrence of icing is determined by the moisture content of the warm air, the rate at which water vapor is condensing and forming precipitation, and the altitudes at which precipitation is formed.

Warm frontal precipitation typically originates as ice crystals, which grow by accretion of small supercooled water drops and by aggregation with other ice crystals. Thus you should not usually encounter clear icing above the highest position of the zero-degree isotherm, although rime icing may occur due to the presence of supercooled cloud water drops, which are too small to precipitate. The occurrence of clear icing, due to supercooled precipitation-sized water drops, indicates the presence of air above freezing temperature *directly* above the region in which clear icing occurs. Whether the region of above-freezing air can be reached by climbing *on course* depends on the horizontal extent of that region.

If the temperature contrast across the front is not large or if the relative motion of the air masses is not great, then one may find the type of structure depicted (Fig. 2). Since no temperature inversion is formed in this case, you cannot expect to find warmer air at higher altitude, regardless of your position relative to the front. In such a situation rime icing may be encountered due to supercooled water in the clouds, but clear icing is less likely.

The presence of the temperature inversion at the warm front can be determined only from upper air temperature soundings or from pilot reports. Since the large-scale features of warm fronts change slowly, soundings a few hours old may be adequate for determining the presence of the inversion and, allowing for movement of the front, for determining its position and horizontal extent. Pireps can serve to verify one's analysis.

The time for which a given set of soundings may be used in this way can be determined from examination of a sequence of surface weather analyses showing frontal movement. Major changes in frontal position or in surface weather since the time of the upper air soundings would indicate that the soundings can no longer be viewed as representing "current" conditions. Wind data near the front must also be examined closely, since significant changes of wind with height (wind shear) can occur near temperature inversions.

The accompanying sounding (Fig. 3) was made at Chatham, Mass., on Cape Cod at 1900 EST, 2 April 1977, in advance of a warm front which was associated with a surface low pressure center over Lake Huron. The front at the surface was at least 150 nautical miles from the station, its exact position being hard to define because of limited data over the ocean. The temperature inversion below 1,000 feet was probably due to cooling over the ocean. The frontal temperature inversion was just above 4,000 feet, where the temperature increased from −1.8°C to +0.8°C.

Above the front the temperature was above freezing for a depth of more than 2,000 feet. The air was saturated up to about 18,000 feet and continuous light rain was occurring at the surface at the time. The precipitation must have originated in the moist air above the frontal inversion and would probably have existed as supercooled liquid water between 3,500 and 4,300 feet. Clear icing encountered in this region could therefore be avoided by climbing to an altitude between 4,300 and about 6,800 feet.

The horizontal extent of this temperature structure can be determined in part by examination of soundings from New York City and Albany (not shown). The frontal temperature inversion at Albany was based at 2,600 feet (920 mb) and extended to 5,700 feet (819 mb) with a temperature increase of 4.3°C. The air was saturated between 2,600 and 8,100 feet, and light rain showers were observed at the surface. However, because the temperature at the base of the inversion was +0.6°C and the freezing level was at 9,700 feet, well above the inversion, no clear icing due to supercooled rain would have been expected.

The New York City sounding revealed a slight temperature inversion between 400 feet (1,000 mb) and 1,700 feet (955 mb) with a temperature increase of 0.8°C, and a freezing level at 10,000 feet (700 mb). The air was saturated from the surface to near 16,000 feet and continuous light rain was observed at the surface. At both these locations the air above and below the frontal inversion was warm enough to preclude structural icing at altitudes below 9,000 or 10,000 feet. It should be noted that in this area and southward rime icing would probably have occurred in the clouds above the altitude of the zero-degree isotherm.

The orientation of the region in which air above freezing temperature overlies air below freezing temperature can be estimated from the orientation of the isotherms in the upper air analysis. The zero-degree isotherm in the 850-mb analysis (Fig. 4), which is most useful in the present case, lies just north of Chatham, running northwesterly over upstate New York. In cross-section, the region of expected clear icing below the frontal inversion probably extends from just northeast of Albany, where the inversion base temperature is +0.6°C to somewhat southwest of Portland, Me., where the 850-mb temperature is −4°C.

The Portland sounding was not examined, but it is likely that the frontal inversion was above the 850-mb level and that the maximum temperature above the front was below freezing. Thus the region in which an airplane could climb to avoid clear icing was only about 125-nm wide. One can only guess at its length, as no soundings are taken in New Hampshire, Vermont or upstate New York. It may extend as far inland as Maniwaki, Quebec, where the temperature was −3°C at 850 mb and at 700 mb, and temperatures above freezing could have existed in the intervening layer.

The detailed analysis of temperature conditions near a warm front can be a rather lengthy exercise, even if the relevant data are at hand. Such data, however, are not generally provided in routine flight weather briefings. The pilot may have to call a National Weather Service office and talk directly to a weather forecaster to obtain the upper air temperature data in sufficient detail.

The complicated structure of weather conditions near a warm front demands detailed flight planning if extended flight through warm frontal clouds and precipitation is contemplated. In dealing with icing encountered near a warm front, the pilot can decide to climb or descend only on the basis of his knowledge of the particular weather system and the extent to which it approximates the "textbook" depictions. If the pilot has not analyzed the situation adequately, he may find himself with no good alternatives to an in-flight icing situation. □

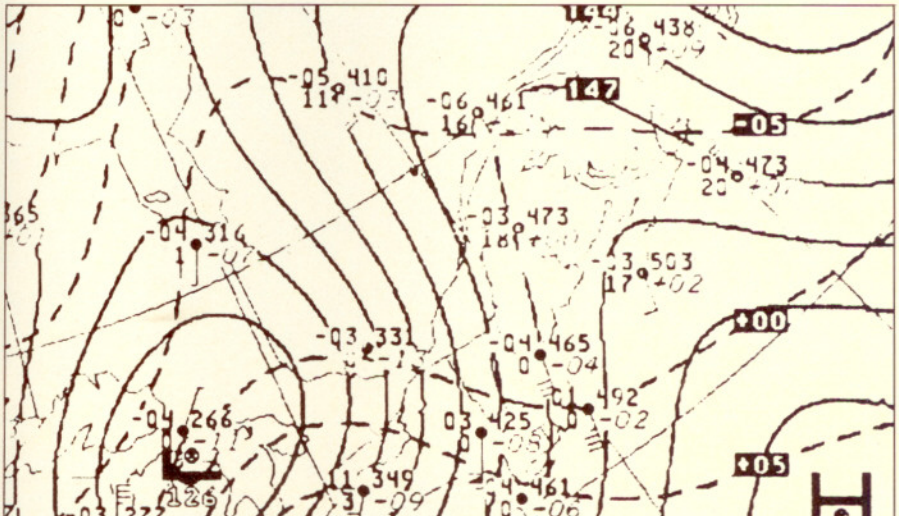

Fig. 4. A study of the isotherm orientation on the 850-mb upper air analysis can show where above-freezing air overlies freezing. This one indicates an area along the zero-degree isotherm that could experience clear icing below the frontal inversion.