FORECASTERS' FORUM

Real Front or Baroclinic Trough?

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In a recent study, Sanders and Hoffman (2002, hereafter SH) found that only about half of the cold-front segments appearing on surface maps of the National Centers for Environmental Prediction (NCEP) from December 1999 through February 2000 were associated, even loosely, with a moderately strong surface baroclinic zone. In an earlier study (Sanders and Kessler 1999), some extreme examples had been identified in which an abrupt nocturnal temperature rise was analyzed as the passage of a cold front. These features are clearly not the type of structure described by Bjerknes (1918).

To enlarge the sample of comparisons between analyzed fronts and baroclinic zones reported by SH, a comparison was made for the period between 7 February and 29 March 2002. The fronts were again taken from analyses prepared by the Hydrometeorological Prediction Center (HPC) of NCEP. The maps of surface potential temperature were prepared at the Department of Atmospheric Science, The University of Arizona, and were manually analyzed without knowledge of the concurrent frontal analysis. As in SH, the times were 0000 and 1200 UTC and the area of analysis was the same. The analysis consisted of isotherms at intervals of 8°C. Areas of moderate or intense gradient, representing an 8°C contrast of potential temperate over distances of no more than 220 or 110 km, respectively, were marked. These distances represent values of the gradient close to those used by SH.

Edges of frontal segments occurred where the analyzed notation changed, generally at centers of low pressure, or where indicated in the analyses, or at the edge of the analyzed area. Warm fronts, cold fronts, and stationary fronts were separately considered. A small number of occluded segments occurred but were considered as extended portions of cold or warm fronts, depending on whether the air following the frontal wind shift was colder or warmer than the air ahead.

Whereas SH considered each segment as associated or not associated with a baroclinic zone, in this study the total length of each segment was measured, as was the length associated with a baroclinic zone. Association was considered to occur if the analyzed front lay within 220 km of the warm edge of a zone, or was within it. Where the orientations of the front and of the zone differed by nearly 90°, the two were considered associated if the air on the cold side of the front was significantly colder than the air on the warm side, but not otherwise. The length and proportions of frontal segments associated with baroclinic zones are presented in Table 1.

In the table the fractional length of segments associated with baroclinic zones was around one-half for both times and for all frontal types. Cold frontal segments were not less associated, as in the study by SH (seen in their Table 3). The lengths of stationary and cold fronts is understated because in many instances the segment was terminated when it reached the limits of the area of analysis of potential temperature, usually over the ocean. If the temperature analysis had extended over the oceanic regions, the association would have likely been weaker because of the lack of prominent contrasts in these regions. Warm fronts were fewer and shorter than other types, representing in many cases stubs ahead of an analyzed cold front with less than compelling indications. In the earlier study a decision was made whether the segment as a whole was or was not associated with a baroclinic zone. The present study may be less subjective. In an attempt to mimic the procedure used in the earlier study, we determined whether each individual frontal segment was or was not associated with a baroclinic zone over at least 50% of its length. The proportions of each frontal type meeting this criterion were 0.53, 0.43, and 0.45 for stationary, cold, and warm segments, respectively. In both studies it is apparent that many analyzed fronts are not asso-

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TABLE 1. Mean length of analyzed frontal segments and mean fraction associated with a moderate or intense baroclinic zone, 7 Feb–29 Mar 2002.

	0000 UTC			1200 UTC		
Frontal type	N	Mean length (km)	Fraction	N	Mean length (km)	Fraction
Stationary	73	1659	0.50	102	1309	0.51
Cold	89	1488	0.47	107	1431	0.43
Warm	41	824	0.43	39	738	0.41

ciated with marked temperature gradients. This result is not acceptable!

The question arises whether Bjerknes intended that a significant temperature contrast accompany a front. Reference to the original paper in which the frontal concept was introduced (Bjerknes 1918) shows in a sentence near the start that prominent convergent wind shifts are "distinguished by characteristic thermal properties." The steering line and squall line (later termed the warm front and cold front, respectively) enclosed the "warm sector" of the cyclone. The "discontinuous" character of the change of temperature on passage of these lines was said to be apparent. There can be little doubt that Bjerknes intended that the wind shift be accompanied by a significant gradient of temperature. The lack of this gradient in about half the cases examined indicates that these wind shifts do not represent "real" fronts in the sense described above.

Bjerknes (1918) stated that the ascending vertical motion associated with the cyclone occurred exclusively in association with the frontal surfaces. He added that "the warm and cold masses of air in its (sic) entirely have no ascending motion of importance." Since the slope of the warm-front surface was small, the ascent (and cloud and precipitation) extended over a broad region in advance of the front at the surface. In contrast the ascent and precipitation at the cold front occurred in a narrow band immediately to the rear of the surface wind shift. In the warm sector, and in the cold air mass to the rear of the front, there was little if any cloud. This was subsequently seen to be an overstatement, since widespread cloud and precipitation were observed to occur in the presence of modest temperature gradients with no front near. Further, the development of quasi-geostrophic theory showed how ascent and descent were attributable to the failure of geostrophic transports of heat and momentum generally to maintain a baroclinic atmosphere in geostrophic balance, with no requirement for temperature discontinuity. The accelerations and ageostrophic winds resulting from this imbalance were responsible for vertical motions that could be explained without resorting to discontinuities.

The lack of many analyzed fronts to show significant thermal contrasts might be due to a lack of consideration of routine surface temperature analysis even when it is done. It is ironic that the surface, where there is an order of magnitude more observational temperature information than at upper levels, is the only standard level for which temperature analysis is not routinely displayed. A reason often stated for this lack is representativeness of the observations. Alternatively one could point out that the extremely small scales on which surface temperatures sometimes vary cannot be dealt with in current analysis and forecasting. There is no problem in obtaining a reasonable analysis of surface potential temperature [used in an attempt to account for the effects of variable elevation, as is done routinely at the University at Albany, State University of New York (SUNYA; information online at www.atmos.albany.edu), at 3-h intervals]. There is a discrepancy of as much as 3°–4°C between the plotted temperature values and those read from the isotherms. This is attributable to the use of all observations and a Barnes-type (1964) smoothing in deriving the analyzed isotherms, whereas the number of plotted observations on the map is constrained by the size of the plot.

It might be argued that the values of gradient determining moderate or intense baroclinic zones are arbitrary. So they are. But it is difficult to imagine how to show regions of relatively strong gradient without some boundary values. Use of smaller magnitudes would result in a larger proportion of analyzed fronts being associated with significant gradients, but it would also mean an increased number of nonfrontal baroclinic zones, determined by the same magnitude of gradient. In the limit the entire map area would be shaded, indicating significant gradient. So far as analyzed fronts are concerned, it is easy to find examples in which air on the warm side of the front is colder than air on the cold side.

An example of the analysis of a situation containing a real front is shown in Fig. 1. Intense baroclinic zones were observed along the eastern slopes of the Rocky Mountains while the surface frontal analysis from 1 to 3 January 2004 extended nearly to the east coast of the United States with at most a moderate baroclinic zone (not shown). On 4 and 5 January the front was associated with an intense baroclinic zone over a substantial portion of the central United States. A detailed analysis for this period appears in Fig. 2. The abruptness of the wind shift and the strength of the frontal temperature contrast is apparent. The precipitation at this time was confined to a shield in the colder air, corresponding to the Bjerknes model. After this time the analyzed front moved rapidly southeastward and quickly lost temperature contrast. Despite the changes in the character of

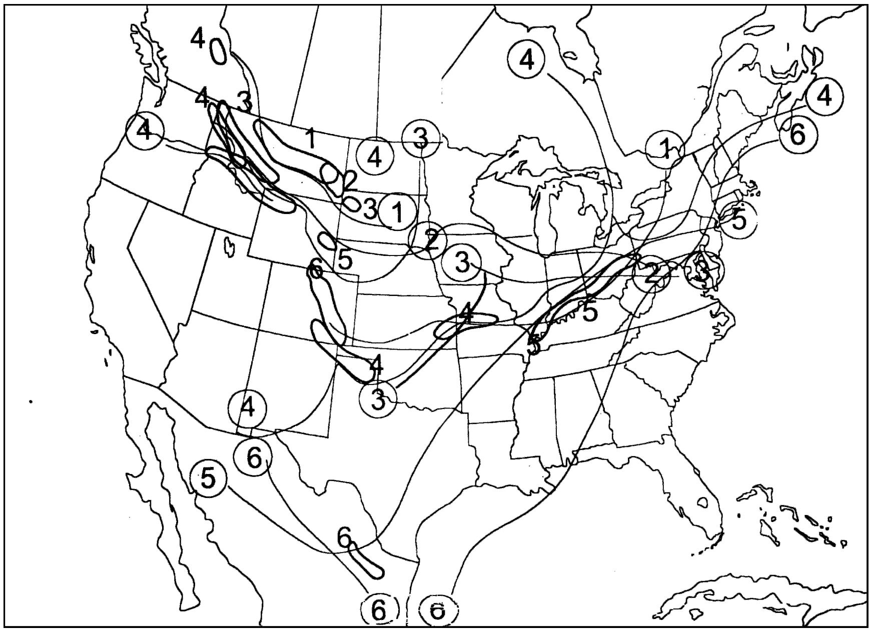

FIG. 1. Analyzed fronts (thin lines) and borders of intense baroclinic zones (heavy lines) at 0000 UTC 1–6 Jan 2004. The dates of zones and fronts are indicated by the numerals, circled in the case of the fronts.

the analyzed front over this period, the same frontal symbols were used throughout. This situation, which is common in routine analysis, seems unsatisfactory

A contrasting example appears in Fig. 3, for a situation in which the analyzed front extending southward from a low center in southern Canada lacks a significant contrast of temperature.

The question is then what to do about these analyzed fronts lacking appropriate temperature contrast. They might be simply ignored and omitted from the analysis.

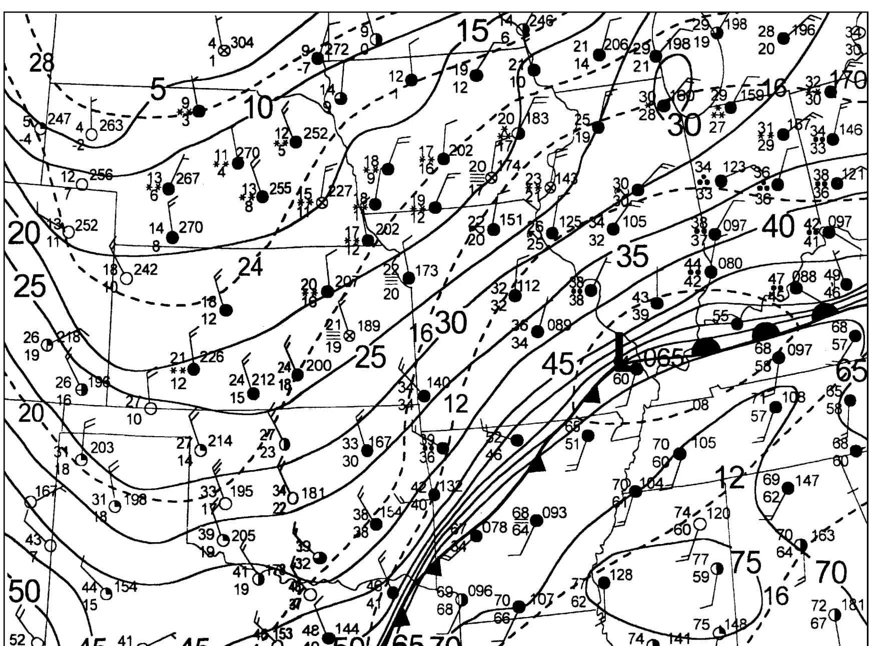

FIG. 2. Surface analysis of isotherms (solid, at intervals of 5°F) and sea level isobars (dashed, at intervals of 4 mb) at 0000 UTC 5 Jan 2004, over the north-central United States. The front is indicated by the heavy line, with conventional symbols. Plotting models at stations are conventional.

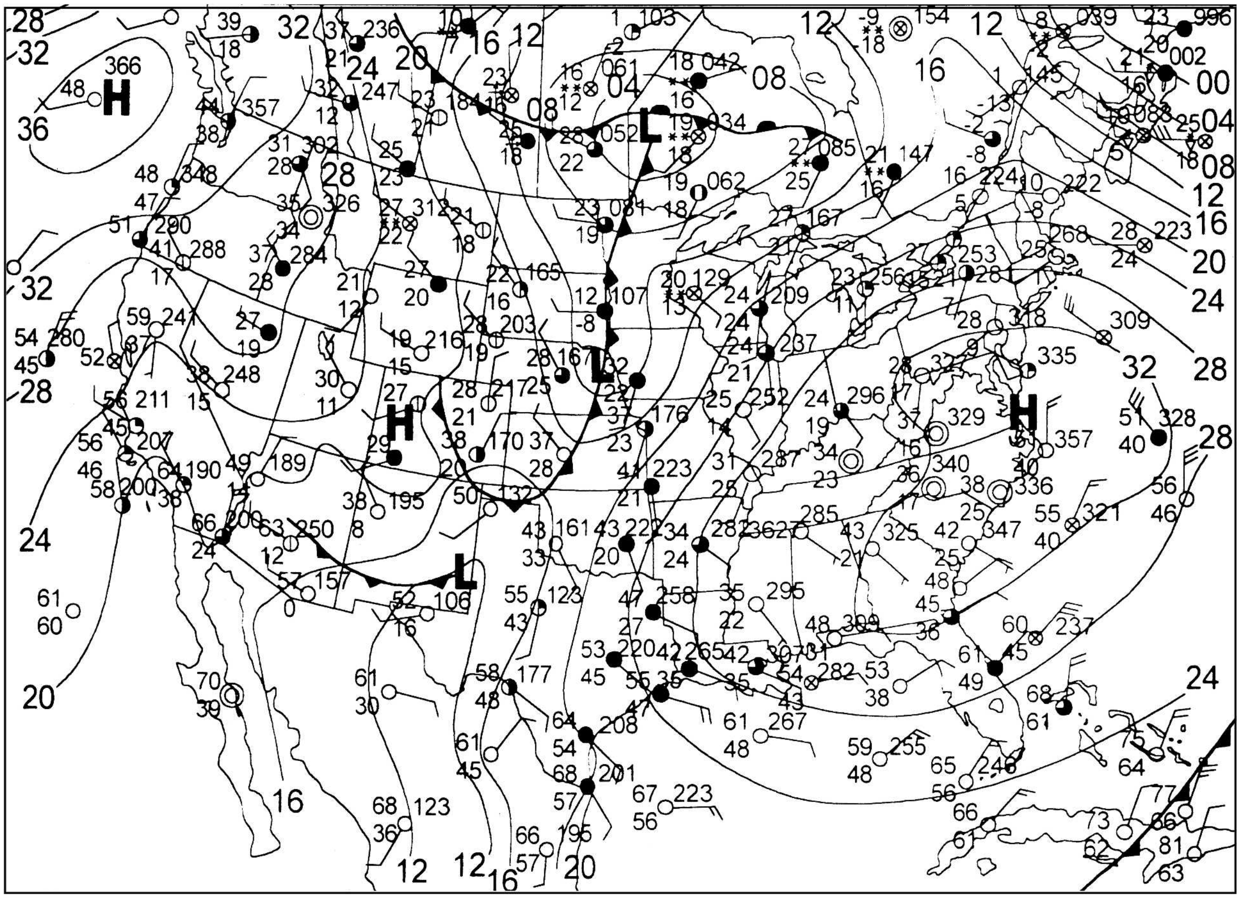

FIG. 3. NCEP surface analysis over the United States and adjacent portions of Canada at 0000 UTC 9 Feb 2004. Isobars are at intervals of 4 mb. Frontal notation and station plotting models are conventional.

This approach would have the merit of drawing attention to the real fronts with significant temperature gradients, which have an important effect on the weather. These other features, however, deserve attention because the wind shift can bring about a change in the character of the air, such as humidity or pollutant content, and because the wind shift generally portends an improvement in the weather, with an end to precipitation and extensive cloudiness. I suggest that this features be denoted a "trof" (or more accurately, a baroclinic trough when there is a temperature gradient along the line) because the wind shift is typically accompanied by a pressure minimum. Sanders (1999) has drawn the distinction between a front and a baroclinic trough. Troughs can also occur in air in which there is little temperature gradient. In such a barotropic case, there is little dynamical consequence in terms of vertical motion, cloud, or precipitation.

The trof is widely used in current surface analysis, yet there is no written definition of it, so far as I am aware, and continuity of its use in analyses is poor, perhaps for that reason.

A trof and a front share the following properties, which cannot therefore be used to distinguish them:

1) There is a cyclonic wind shift and a local pressure minimum.
2) There is a change in the source region of the surface air, as might be determined by a comparison of trajectories. It might be noted that a ridge of high pressure accompanied by an anticyclonic wind shift also has this character, yet there has never been a suggestion that a front should be placed along a ridge of high pressure;
3) There is a change of dewpoint or other element depending on humidity, such as wet-bulb temperature. The colder air is usually, but not always, drier than the warmer air. In any case, the humidity has little effect on density.
4) There is a substantial temperature change over a 24-h period, which may occur gradually and without any abrupt change in a short period.

Locally, a front is distinguished from a trof by the presence of a substantial temperature change at the time of the cyclonic wind shift. Spatially, a front is accompanied by a substantial temperature gradient, with the warm edge near the surface wind shift.

Perhaps of greatest importance for forecasting, clouds and precipitation occur on the colder side of the wind shift for a front and before the wind shift for a trof. Locally for a real front, this means on the colder side of the wind shift. For a trof, meridionally oriented and propagating eastward, adverse weather tends to occur ahead of the wind shift. This situation can be understood dynamically by quasigeostrophic reasoning, given a gradient of temperature along the trough line. Ascent is due to relatively strong geostrophic warm advection in the warmer air ahead of the wind shift, while cold advection and clearing favor descent after the wind shift. With a front the thermal advection by the nongeostrophic component of the wind is crucially important for the development of the strong temperature gradient near the ground and the narrow region of ascending air immediately adjacent to the wind shift and tilting with elevation over the cooler air, as explained by Hoskins and Bretherton (1972).

The difference between troughs and real fronts is shown schematically in Fig. 4. At a real front there is a packing of isotherms on the cold side of the wind shift. The shift is often abrupt, nearly 180°. Precipitation lies on the cold side of the wind shift, in a narrow zone in the case of a cold front and in a broader area in the case of a warm front. For a baroclinic trough there is a temperature gradient along the wind shift line, which tends to be accompanied by a local maximum of temperature. The wind shift is more gradual, in the cyclonic sense. There is warm advection ahead of the shift and cold advection to its rear.

In practice the line in the analysis, based mainly on the wind shift as it is now done, could be left without color and without the triangles and semicircles indicating the frontal character. These symbols could be added only when and where a significant temperature gradient accompanies the trough line, as suggested above. Adoption of this change in analysis procedure would have the merit of emphasizing the presence of real fronts, when they occur. The synoptic circumstances in which they occur has been little studied since the original description put forth by Bjerknes and Solberg (1922). The general category of trof includes the dryline (Schaefer 1974) and probably other features of the surface boundary layer that are important for forecasting but are little appreciated at present.

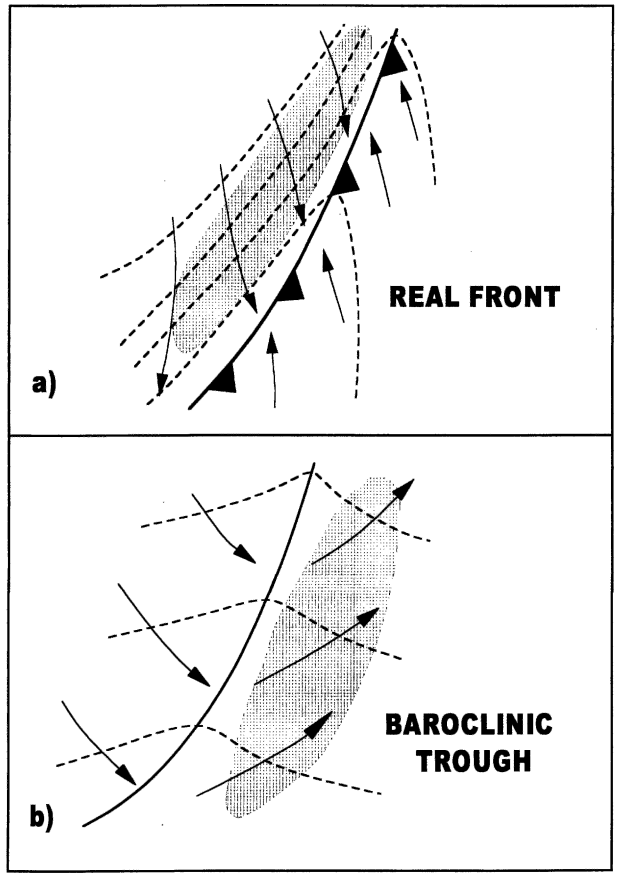

FIG. 4. Schematic sketches of (a) a real cold front and (b) a baroclinic trough. Heavy solid line shows the front or trough. Dashed lines are surface isotherms. Light solid lines are streamlines of surface wind. Stippled areas show regions of cloud and precipitation.

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