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THE PROBLEM OF SEA LEVEL PRESSURE REDUCTION

James L. Wiesmueller
National Weather Service Forecast Office
Denver, Colorado

The following paper illustrates a recurring problem in analysis and numerical weather prediction (NWP) relating to the technique of sea level pressure reduction. It is known that the procedure of reducing barometric readings of elevated land stations to some standard reference level such as sea level or 1000 mb may give rise to intolerable errors in the field representing the horizontal pressure force (Sangster, 1960). Discrepancies in sea level pressure for neighboring high elevation stations can be on the order of 10 mb in some situations (Saucier, 1955).

The problem which frequently arises in this technique are inherent in the method by which station pressure is reduced to sea level. The basis for extrapolation of pressure from some measured level to sea level is found in the hypsometric equation, an integrated form of the hydrostatic relation. This fundamental principle simply states that in absence of accelerated atmospheric motion, the pressure at any point is exactly balanced by the gravity force, and is equal to the weight of the air column above that point. Therefore, this expression is an indication of the variation of pressure with height. Furthermore, since pressure is directly related to temperature and density (from the equation of state), the thickness of an air column is proportional to the mean temperature in the layer, or in other words, the pressure difference between any two surfaces is proportional to the mean virtual temperature through that layer. This is the basis for reducing pressure to a standard level, but also leads to problems because of assumed properties through a fictitious air column extending below elevated stations.

In the pressure reduction technique it is assumed that a fictitious air column extends below the station of interest, with properties of that column presumed to be similar to the actual air column if the plateau or mountain were not present. This leads to a number of assumptions of the local lapse rate based on the 12 hour mean station temperature, station elevation, and climatology. The deviation of the local lapse rate from a standard lapse rate is taken into account in a "correction for plateau effect and local lapse rate anomaly." This correction is employed for stations above 1000 feet in elevation and is computed by using station temperature, annual normal temperature, and elevation. The purpose of this correction is to minimize seasonal variations of sea level pressure due strictly to mean annual temperature variations at elevated stations. This assures that the amplitude of the annual variation of pressure reduced to sea level is no more than about 5 mb for each station in North America regardless of elevation (Manual of Barometry, 1963).

As previously mentioned, the pressure reduction method is derived from the hydrostatic principle. Stated qualitatively:

$$\text{hydrostatic eqn} \xrightarrow{\text{integrating}} \text{hypsometric eqn} \xrightarrow{\text{simplifying}} \text{reduction eqn}$$

$$\boxed{P_o = P\,r}$$ pressure reduction equation

where: P_o = sea level pressure
P = station pressure
r = reduction ration, where $r = 10^{(KH/\bar{T}_v)}$.

This is the equation commonly employed in standard reduction techniques. Here K is the hypsometric constant and H is the elevation of the station. The r in the equation is defined as the reduction ratio and is simply the ratio of sea level pressure to station pressure for each degree of temperature at a particular station. The r value is computed for individual stations and incorporates various assumed quantities such as humidity correction_and the correction for plateau effect and local lapse rate anomaly, to get T_v. The observer merely needs to know the 12 hour mean temperature and station pressure to compute sea level pressure. From the above relationship it is obvious that large r values result in correspondingly large sea level pressures, and that large r values arise from low temperatures. It follows then that low temperatures lead to artificially high sea level pressures, while high temperatures lead to artificially low sea level pressures. Moreover, since sea level pressure tendency is also greatly affected by reduction errors the 3-hourly reported pressure tendency is the only reliable measure of surface pressure tendency in mountain and plateau regions (Saucier, 1955). Therefore, a major consequence of this technique is the large errors in horizontal pressure fields especially in regions of large temperature gradient. The practice of using a mean 12 hour temperature also tends to mask important diurnal variations in the surface geostrophic winds (Sangster, 1967).

The case of February 19-20, 1986 is an example of the problems typically arising out of the sea level reduction technique. This case is typical of those occurring during the cool season on the High Plains in conjunction with Arctic outbreaks and shallow anticyclonic upslope precipitation events. Fig. 1 is the station plots for 18Z February 19 showing the extreme thermal contrast between single digit temperatures in Arctic air dropping south out of the Dakotas, and much warmer 60 degree temperatures immediately to the lee of the Rockies. Applying pressure reduction techniques to this situation results in very high pressure being generated over the Central and Northern Plains relative to those in the warm air just to the west. This in turn results in very large, but fictitious, horizontal pressure gradients between, say Denver and North Platte, NE as depicted in the 24 hour NGM sea level pressure prognosis (Fig. 2). These gradients are suggestive of surface geostrophic winds on the order of 130 knots. This, of course, does not agree with the observed surface winds more in the range of 10-20 knots. Such a forecast would also imply much stronger orographic uplift than in reality with significant upslope clouds and precipitation on the High Plains. Problems of this sort with the NGM will be lessened with the change to enhanced vertical mixing of potential temperature made on April 23. This should result in weaker horizontal temperature gradients in the low levels with fronts, hence less reduction error.

When faced with this dilemma it may profit forecasters to turn to analyses and prognoses based on constant pressure surfaces such as the 850 mb and surface geostrophic wind charts, and the boundary layer wind forecasts. These products are not derived from reduction to sea level techniques and are therefore a more realistic representation of the pressure and wind fields near the ground. The 24 hour 850 mb prognosis (Fig. 3) clearly shows this. The extreme thermal gradient is still evident but the height gradient has almost entirely disappeared. The boundary layer wind forecast (Fig. 4) is also more realistic and does not reflect the surface gradient forecast. A useful diagnostic tool in this situation is also the surface geostrophic wind chart (Fig. 5). These are produced from altimeter settings thereby incorporating surface topography and important diurnal variations in the geostrophic wind (Sangster, 1967). It must be cautioned, however, that the boundary layer winds and surface geostrophic winds may be a very poor representation of the actual observed surface winds in areas of complex mountainous terrain. Even on flat terrain the actual winds are most often much less than geostrophic because of surface friction.

What has been presented here is not intended as any profound revelation, but rather illustrates that the well known problem of sea level reduction is still with us and must be recognized and dealt with accordingly in operational forecasts.

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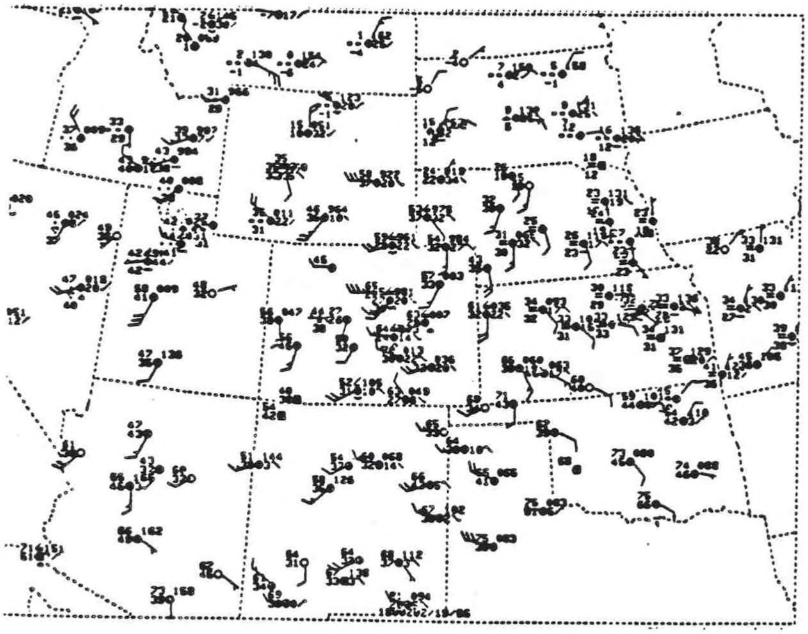

Fig. 1. 18Z, 19 February 1986 Surface Analysis.

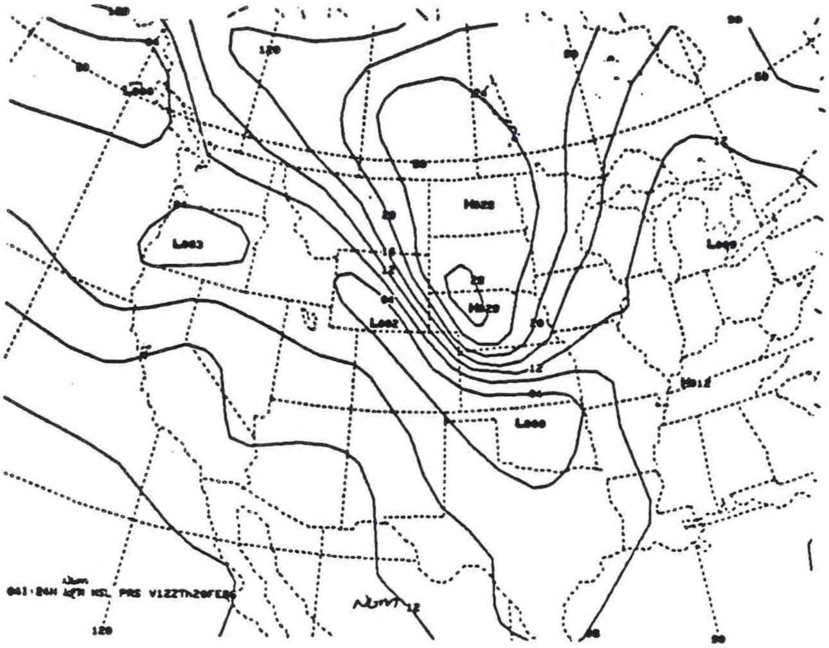

Fig. 2. 24 Hr NGM Surface Prognosis 12Z, 20 February 1986.

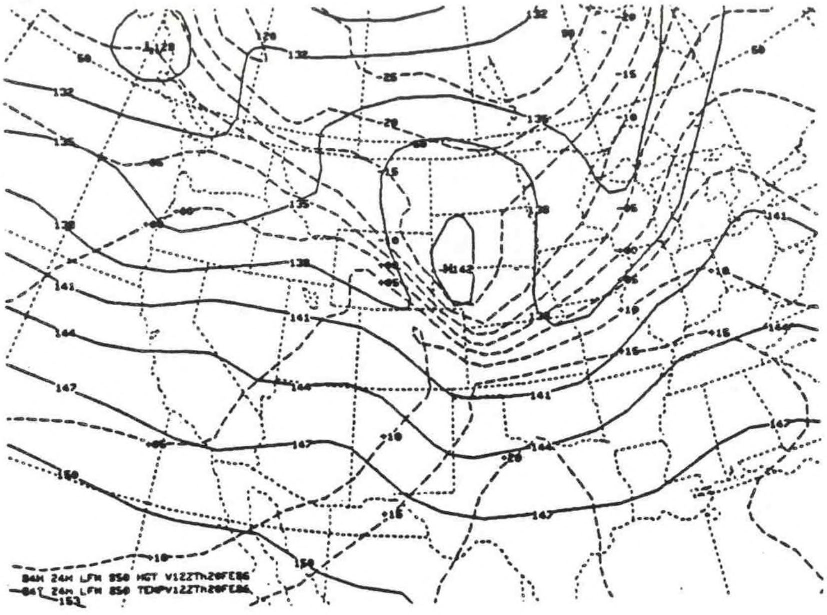

Fig. 3. 24 Hr NGM 850 mb 12Z, 20 February 1986.

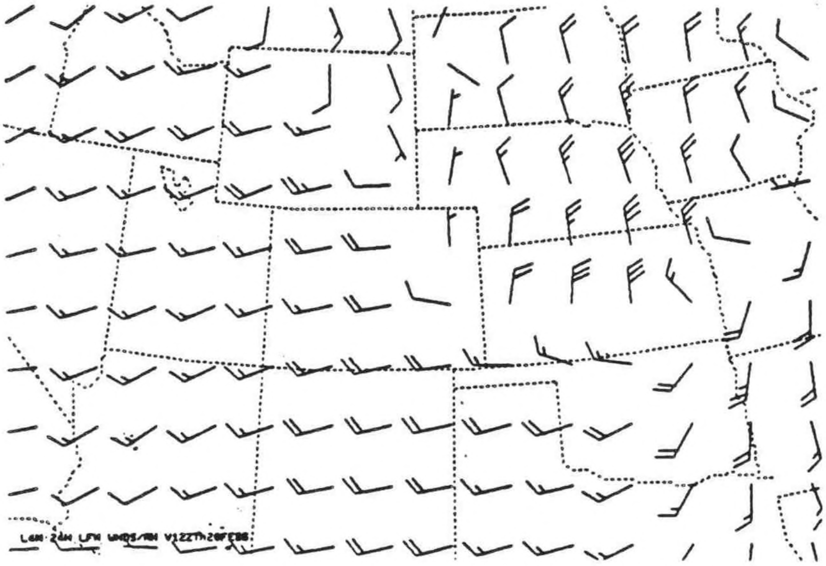

Fig. 4. 24 Hr Boundary Layer Winds, 12Z, 20 February 1986.

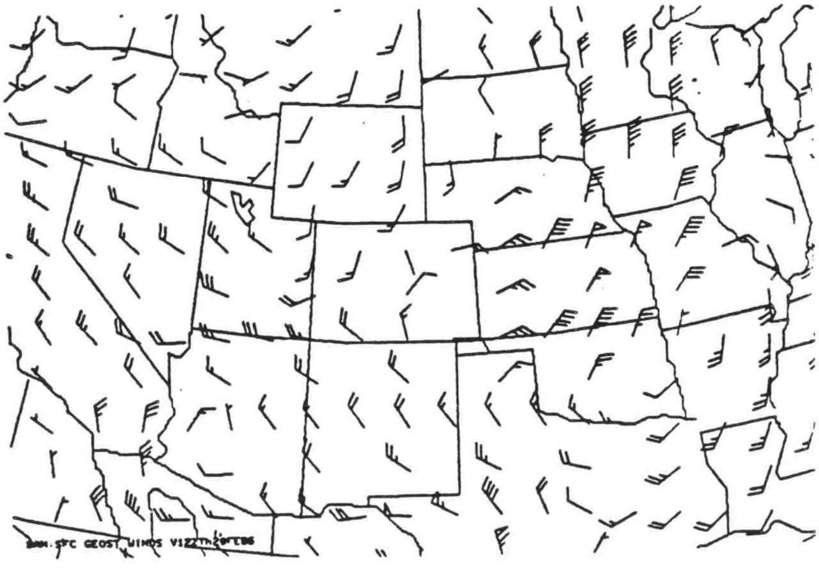

Fig. 5. Surface Geostrophic Winds, 12Z, 20 February 1986.