PCGRIDDS-based isentropic analysis as a forecasting tool in the South African Weather Bureau

E de Coning

Weather Forecasting Research Programme, South African Weather Bureau, Private Bag X097, Pretoria 0001, South Africa

Abstract

The principles of isentropic analysis were introduced in the late 1930s, thus it is not a new concept. Although isentropic methods were used in the United States thereafter, they were abandoned due to several practical reasons that will be discussed in this paper. A revival of isentropic analysis took place in the 1970s due to certain corrections being made as well as the availability of computers to do the required conversion to isentropic co-ordinates in short periods of time. The main advantage of isentropic analysis is that it offers the ability to look at atmospheric motion in the way it actually happens - i.e., in three dimensions - due to the fact that isentropic surfaces follow the true motion of a parcel. This concept is especially important when moisture transport is evaluated since the "vertical" motion of the moisture is included in the graphical depiction on isentropic levels. Isentropic analysis of model output data is not meant as a substitute for isobaric analysis, but to complement it by offering a different and unique way to look at the data. In this paper the history and mathematical background of isentropic analysis are presented and then the common variables used in operational forecasting are defined together with their interpretation. A case study is presented where the conventional methods of forecasting missed the area where rain occurred, but isentropic analysis of the data clearly points towards the area where rain could have been anticipated. With the aid of PC-based software, the calculation of variables has become easy. Methods have also been developed to make the graphical depiction of isentropic variables easily accessible to an operational forecaster in South Africa. The operational use of isentropic analysis is recommended to supplement conventional methods used in forecasting offices around the country.

The history of isentropic analysis

Numerical weather prediction models usually provide a forecaster with output on pressure levels. Many a forecaster has, however, experienced difficulty describing moisture transport from one pressure level to the next due to the fact that atmospheric flow also has an adiabatic upward or downward component not depicted on the quasi-horizontal pressure levels. One way of overcoming this problem is through isentropic analysis where meteorological variables are depicted on levels of constant potential temperature, whose slope in many cases is identical to that of upward and downward trajectories followed by the air.

Potential temperature is defined as the temperature a parcel would have if it were transported without external energy gain or loss (i.e. adiabatically) to a pressure of 1 000 hPa. Hess (1959) showed that potential temperature is related to entropy (a measure of disorder expressed in $J \cdot kg^{-1}$) and by this relationship it followed that a parcel that ascends under dry adiabatic conditions conserves its potential temperature and also its entropy. Operationally meteorologists use the terminology 'isentropic' surface to refer to a level of constant potential temperature.

Isentropic analysis was first addressed by meteorologists such as Rossby et al. (1937) and Namias (1938). The former author argued that for synoptic time scales, parcels of air are thermodynamically bound to their isentropic surfaces in the absence of diabatic processes. Since the flow of air in the atmosphere is three-dimensional and not fragmentary (as depicted on isobaric surfaces), Rossby et al. (1937) were of the opinion that "*it can hardly be doubted that the isentropic charts represent the true motion of air more faithfully by far than synoptic charts for any fixed level in the free atmosphere*".

* To whom all correspondence should be addressed.
☎(012) 309-3081;fax (012) 323-4518 e-mail: estelle@cirrus.sawb.gov.za
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Analysis by means of isentropic co-ordinates was used by the United States' Weather Service in the late 1930s, but it was later discontinued due to the following reasons (Bleck, 1973 and Wilson, 1985):

- Standardisation took place during the 2nd World War and the aviation community required winds on constant pressure levels.
- Fast computers were not available at the time to perform the computations within operational time constraints.
- The Montgomery Stream function was initially calculated incorrectly; this was later rectified by Danielsen (1959).

The availability of computers in the 1970s together with Danielsen's correction created new opportunities for meteorologists to do analyses on isentropic levels, for research and operational forecasting.

Some recent studies done with isentropic analysis include work on:

- cut-off lows (Mills and Boa-Jun, 1995);
- elevated thunderstorms with heavy rainfall (Market and Moore, 1995);
- snow (Nolan and Moore, 1995);
- heavy rainfall over South Africa in 1996 (De Coning et al., 1998); and
- severe convection in South Africa (De Coning and Petersen, 1999).

Mathematical background to isentropic analysis

Following Hess (1959), potential temperature is defined as:

$$\theta = T\left(\frac{1000}{p}\right)^{\kappa}$$