QUARTERLY JOURNAL
OF THE
ROYAL METEOROLOGICAL SOCIETY

Vol. 111 OCTOBER 1985 No. 470

Quart. J. R. Met. Soc. (1985), **111**, pp. 877–946 551.509.3:551.511.2:551.511.32

On the use and significance of isentropic potential vorticity maps

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(Received 12 February 1985; revised 2 July 1985)

SUMMARY

The two main principles underlying the use of isentropic maps of potential vorticity to represent dynamical processes in the atmosphere are reviewed, including the extension of those principles to take the lower boundary condition into account. The first is the familiar Lagrangian conservation principle, for potential vorticity (PV) and potential temperature, which holds approximately when advective processes dominate frictional and diabatic ones. The second is the principle of 'invertibility' of the PV distribution, which holds whether or not diabatic and frictional processes are important. The invertibility principle states that if the total mass under each isentropic surface is specified, then a knowledge of the global distribution of PV on each isentropic surface and of potential temperature at the lower boundary (which within certain limitations can be considered to be part of the PV distribution) is sufficient to deduce, diagnostically, all the other dynamical fields, such as winds, temperatures, geopotential heights, static stabilities, and vertical velocities, under a suitable balance condition. The statement that vertical velocities can be deduced is related to the well-known omega equation principle, and depends on having sufficient information about diabatic and frictional processes. Quasi-geostrophic, semi-geostrophic, and 'nonlinear normal mode initialization' realizations of the balance condition are discussed. An important constraint on the mass-weighted integral of PV over a material volume and on its possible diabatic and frictional change is noted.

Some basic examples are given, both from operational weather analyses and from idealized theoretical models, to illustrate the insights that can be gained from this approach and to indicate its relation to classical synoptic and air-mass concepts. Included are discussions of (a) the structure, origin and persistence of cutoff cyclones and blocking anticyclones, (b) the physical mechanisms of Rossby wave propagation, baroclinic instability, and barotropic instability, and (c) the spatially and temporally nonuniform way in which such waves and instabilities may become strongly nonlinear, as in an occluding cyclone or in the formation of an upper air shear line. Connections with principles derived from synoptic experience are indicated, such as the 'PVA rule' concerning positive vorticity advection on upper air charts, and the role of disturbances of upper air origin, in combination with low-level warm advection, in triggering latent heat release to produce explosive cyclonic development. In all cases it is found that time sequences of isentropic potential vorticity and surface potential temperature charts—which succinctly summarize the combined effects of vorticity advection, thermal advection, and vertical motion without requiring explicit knowledge of the vertical motion field—lead to a very clear and complete picture of the dynamics. This picture is remarkably simple in many cases of real meteorological interest. It involves, in principle, no sacrifices in quantitative accuracy beyond what is inherent in the *concept* of balance, as used for instance in the initialization of numerical weather forecasts.

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