The thermodynamic structure of the atmosphere over South Africa: Implications for water vapour transport

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Abstract

Frequent, persistent and the spatially-continuous occurrence of absolutely stable layers of air are confined to the features of the Southern African atmospheric environment. The elevated layers occur preferentially at ~850 hPa (over the coastal regions only), ~700 hPa, ~500 hPa and ~300 hPa throughout the troposphere. They are highly effective in acting as upper air boundaries that control the free diffusion of aerosols and trace gases (including water vapour) in the vertical and may have repercussions on scales ranging from local to synoptic. The seasonal stability characteristics and temporal and spatial continuity of the elevated absolutely stable layers are examined over the eastern half of South Africa and related to a previous case study of moisture transport patterns on rain and no-rain days.

Introduction

The vertical component of dispersion in the atmosphere is a function of the buoyancy present, being greatest under unstable conditions and least under stable conditions during which turbulence is suppressed (Diab, 1975; Mohan and Siddiqui, 1998). Earlier research on stability structure and inversions focused mostly on the boundary layer and the first elevated temperature inversion (Taljaard, 1955; Tyson, 1963; Hart, 1971; Diab, 1975, 1978; Tyson et al., 1976; Venter and Tyson, 1978; Snyman et al., 1990; Harrison, 1993). Temperature inversions will not be the focus of this paper. Instead, absolute stability, a less stringent measure of the degree of atmospheric stability than an inversion, yet one which is competent to determine the vertical mixing in the atmosphere, will be considered. An absolutely stable layer is defined as having a lapse rate which is less than the saturated adiabatic lapse rate. Under such conditions, free upward motion is inhibited. The formation of absolutely stable layers may be attributable to either radiative cooling from the earth's surface, horizontal advection of warmer air over a cooler surface and *vice versa*, or adiabatic warming from upper air subsidence under anticyclonic conditions (Taljaard, 1955; Oke, 1987; Preston-Whyte and Tyson, 1989; Ahrens, 1993). The stable layers often represent the level at which elevated decoupling occurs between circulations of the lower middle and middle upper troposphere.

The degree of persistent elevated absolutely stable layers was noticed first throughout the troposphere over Pretoria during the 1992 South African Fire-Atmosphere Research Initiative (SAFARI-92) period of late winter and early spring (Garstang et al., 1996). Tyson et al. (1996a), subsequently pointed out that multiple absolutely stable layers frequently occur in the atmosphere over the whole of Southern Africa. In their examination of the structures of the elevated absolutely stable layers during various synoptic circulation types over the subcontinent, Cosijn and Tyson (1996) observed that the layers were both temporally persistent and spatially continuous over the subcontinent on non-rain days, and that they influence air transport significantly.

The consequences of the layering of the atmosphere for the accumulation of anthropogenic and biogenic products throughout the troposphere are considerable. Whereas both surface and elevated absolutely stable layers may lead to local high concentrations of air pollution in the troposphere, it is the elevated layers which play an important role in controlling medium- to long-range transport and recirculation of aerosols and trace gases (Preston-Whyte and Tyson, 1989; Garstang et al., 1996; Tyson et al., 1996b). The multiple, persistent absolutely stable layers trap aerosols and trace gases (including water vapour) below their bases by inhibiting turbulent mixing in the vertical. Such situations have obvious implications for local and regional transport of water vapour and other constituents of the atmosphere. Should these penetrate through one layer, accumulation will occur below the next and so on. Once accumulation beneath a discontinuity has occurred, horizontal transport occurs preferentially at that height and tends to be capped by the layer above (Tyson et al., 1997). The effects of accumulation are evident to the naked eye at the 700 hPa and 500 hPa levels over the interior of South Africa, particularly in winter. On days when the stable layers are observed, dense dust and haze belts are likewise present at these two levels as a major discontinuity between the hazy, polluted lower tropospheric air and clear air aloft (Tyson et al., 1996a).

Fine-weather conditions over South Africa occur around 80% of days in the year (Schulze, 1965; Harrison, 1984) and encourages the development of absolutely stable layers in the atmosphere. The predominantly stable troposphere promotes the trapping of material between the layers and only abates with deep convection and the occurrence of unstable barotropic easterly disturbances or with the passage of intense baroclinic westerly disturbances.

The persistence and strength of the discontinuities have implications for rainfall, with the lower layers in particular acting as vertical boundaries constraining turbulent mixing and hindering the development of convective precipitation (Ching et al., 1984; Lyons and Calby, 1986). The ~700 hPa level appears to most frequently control the level of maximum flux divergence of water vapour over the summer rainfall region of the South African plateau (D'Abreton and Lindesay, 1993; D'Abreton and Tyson, 1995; 1996). The role of the ~700 hPa stable layer in governing

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