Three-dimensional kinematic trajectory modelling of water vapour transport over Southern Africa

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Abstract

Back and forward kinematic trajectory modelling has been undertaken for rain and no-rain days over the central interior of South Africa in mid-summer. No-rain days (rain days) are shown to be characterised by dry (moist) south-westerly (northerly to north-easterly) flow originating over the South Atlantic (tropical Indian) Ocean. Air parcels for tropical-temperate troughs originate over the tropical Indian Ocean and trace south and south-eastwards across Southern Africa, corresponding closely to the position of the trough-associated cloud band. Trajectory modelling of a cut-off low pressure system reveals the presence and interaction of a cold, dry, descending conveyor from the south and a warm, moist, ascending conveyor from the north.

Introduction

Moisture content of the air plays *an* important role in determining the thermal stability of the atmosphere and is a crucial factor in the precipitation process. By virtue of its position within the subtropical belt of high pressure, South Africa is characterised by a semi-arid to arid climate. Among important factors affecting the moisture over the region, are the low levels of moisture available from the generally sparsely vegetated continental surface (Henning, 1989; Lindesay, 1992). Consequently, most of the moisture that contributes to precipitation over Southern Africa must be imported over the subcontinent from source regions elsewhere.

Despite the importance of water vapour transport for the production of rainfall over Southern Africa, few transport analyses have been undertaken for the region. Whereas studies of atmospheric moisture have been undertaken for West Africa (Adedokun, 1983; Anyadike, 1979), South America (Rathor et al., 1989), North America (Hastenrath, 1966) and Australasia (Hutchings, 1961), similar studies only recently have been conducted for Southern Africa (Jury and Lindesay, 1991; D' Abreton and Lindesay. 1993; D'Abreton and Tyson, 1995). During the often wet mid-summer month of January conditions are characterised by enhanced northerly meridional flow, in contrast to dry conditions when westerly zonal flow is the predominant circulation characteristic (D'Abreton and Lindesay, 1993). Analysis of divergent water vapour transport reveals that transport to the south-west from the tropical Indian Ocean is the most important source for water vapour in wet Januaries over South Africa (D'Abreton and Tyson, 1995). During dry Januaries, the vapour source regions appear to be located preferentially over the south-western Indian Ocean (D'Abreton and Tyson, 1995).

In this paper, water vapour transport *over* Southern Africa will be examined further using Lagrangian kinematic trajectory modelling. A trajectory climatology of January water vapour transport for rain days and no-rain days over the central interior of South Africa will be developed. In addition, vapour transport for various individual rain-producing systems will be examined. Finally, changes in air parcel water vapour content will be used to indicate, in general, major water vapour source and sink regions for South Africa.

Data and methodology

The European Centre for Medium Range Weather Forecasts (ECMWF) GRIB IIIb dataset, on a 2.5° grid, has been used for three January case studies, namely those of 1980, 1981 and 1991. The selection was done on the basis of one anomalously wet month (1981), one anomalously dry month (1980) and one month with average precipitation (1991). Daily rainfall statistics have been obtained from the South African Weather Bureau for the summer rainfall regions on the plateau of South Africa. Satellite imagery is from NOAA2 and N0AA5 polar-orbiting satellite (published by the Environmental Data Service of the United States *Oceanic* and Atmospheric Administration) and the geostationary Meteosat imagery {published by the European Space Agency/EUMETSAT).

The trajectory model is Lagrangian, with atmospheric motion being described in terms of individual air parcels moving with air streams resulting from changing synoptic circulation patterns (D'Abreton, 1996). The model uses the explicit method of integration defined by

$$x(t+dt) = x(t) + V[x(t)]dt \qquad (1)$$

where x(t+dt) is the *new* three-dimensional parcel position at t + dt, x(t) is the old position a and V(t) is the parcel velocity vector. The time-step (dt) used in the analysis is 15 min. A more complete description of the trajectory methodology is to be found in D'Abreton (1996). Forward and backward trajectories have been performed from designated points of interest as origin to give 20-d trajectories for each air parcel analysed.

Lagrangian methods have been applied extensively in the evaluation of synoptic-scale transport of anthropogenically-produced air pollutants and biogenicaerosols and trace gases (Eliassen, 1978; 1980; Eliassen and Saltbones, 1975; Krishnamurti et al., 1993; Tyson etal., 1996a; Garstanget al.. 1996). In this paper an attempt is made to apply the principles used in studies of the

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