AN AIRCRAFT OBSERVED THERMAL INTERNAL BOUNDARY LAYER ALONG THE CAPE SOUTH COAST

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ABSTRACT:
Aircraft observations offer a unique meteorological perspective of coastal internal boundary layers along the Cape south coast. One case study near the Gourits River mouth on 22 June 1989 is analysed using aircraft-derived wind, temperature and turbulence data collected every 800 m over a 25 km cross section. A weak coastal low pressure cell imposed a shallow easterly flow and weather conditions were stable and humid. The speed of surface easterly winds halved from the coast to the river under the infuence of surface friction. Surface temperatures, measured by an infrared sensor, increased from 17°C at the sea to 25°C over the river valley. Upward sensible heat fluxes caused a westward tilted thermal internal boundary layer in the first 100 m. Convergence and river channelling forced the thermal internal boundary layer to become vertically aligned above 100 m. Vertical velocity fluctuations were more vigourous in the internal boundary layer. Implications for the dispersion of air pollutants from proposed petroleum refineries and nuclear power stations are discussed.

INTRODUCTION

Small scale meteorological structure is inherent in coastal zones where adjacent sea temperatures are cool and the terrain is steep and undulating (Comrie, 1988; Jury, 1988). Winds may be channelled or obstructed and air temperatures may vary sharply in the horizontal and vertical. Because the coastal zone is often utilised for urban and industrial development, and because the subsequent atmospheric dispersion of urban and industrial pollutants is dependent on the structure of winds and temperatures, an improved understanding of internal dispersion regimes within the coastal boundary layer is necessary (Jury, 1989). On the Cape south coast near the Gourits River mouth urban development is presently sparse, however a new oil refinery in support of offshore drilling is being built and proposals for nuclear power stations to the east and west have been put forward. Just west of the Gourits River mouth the AEC have a proposed nuclear site. Hence this region (shown in Figure 1) is suitable for field studies aimed at determining coastal atmospheric dispersion regimes.

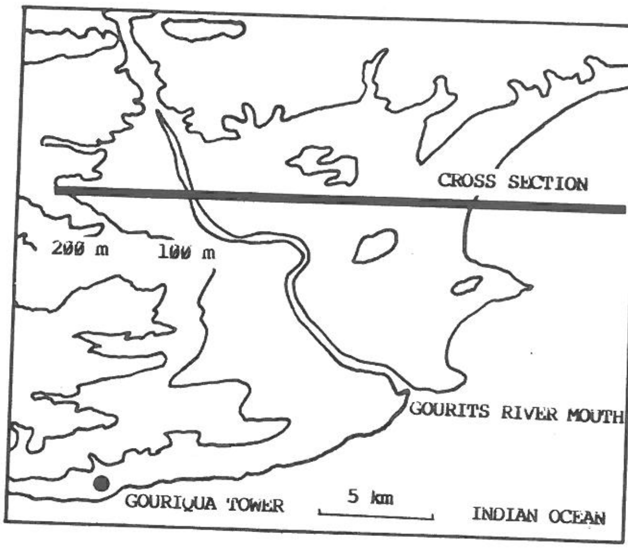

Figure 1 - Topographic map of the case study area showing the aircraft cross section line, Gourits River valley and Goriqua tower location.

During June 1989 an instrumented aircraft was based at the George airport so that a sequence of research flights could be made over the edge of the Agulhas Current. The main purpose of the aircraft observational programme was the quantification of air-sea interactions and changes in weather over the warmer offshore waters (Jury and Courtney, 1990). Following the Agulhas surveys, on days with fair weather and seabreezes, the aircraft performed cross sections over limited areas of the coastal zone to determine whether any internal boundary layers had formed. Changes in winds, temperatures and turbulent intensity were monitored. A number of cross sections were analysed and the results of 22 June 1989 are selected for presentation here.

DATA

A Cessna 310 aircraft was instrumented with a Tracor wind-navigation system which makes use of Omega and VLF transmissions to provide position fixes. Air speed and flight heading information combined with the position data gave wind vectors every 10 seconds. The aircraft altimeter was used as a height reference and sections were made at 100 and 300 m above sea level. Sea and land surface temperatures were remotely sensed using a Barnes PRT-5 infrared radiometer. Measurements of air temperature and dewpoint temperature were made using a Rosemont 102 thermistor and an EG & G hygrometer. A high response pressure sensor constructed by Prof J Bell at UCT provided vertical velocity fluctuations. All sensors were read by a Hewlett-Packard data logger at 10 second intervals. The flight speed was about 80 ms^{-1} so the distance between data points was 800 m. The two leg 25 km long E-W cross section took less than 15 minutes of aircraft flight time. Analogue strip chart recordings were made of the high response pressure sensor to determine turbulent scales and intensities. Time, position and height readings were made concurrent with the meteorological data, enabling subsequent mapping and analysis. Further details of the data processing scheme are available in Courtney (1989).

RESULTS

Analogue traces from the high response pressure sensor indicate height variations along the flight track (caused by turbulence) for four section pairs taken on 20, 22, 27 and 28 June 1989 (Figure 2). The first and third pair of inverted pressure traces labelled with F are for a N-S section conducted just to the west of Cape St Francis, where Eskom have proposed the siting of a nuclear power station. The traces labeled G are for the Gouriqua site shown in Figure 1. The second pair of traces is for the case study analysed below. All traces contain a common tendency for reduced vertical velocity fluctuations (turbulence) over the sea. Crossing the coastline, air motions associated with embedded seabreezes induce upward fluctuations upon which turbulent eddies are super-imposed. In the case study, the transition from stable to unstable conditions is made up of a singular upward circulation cell of some 10 km extent reflected in both 100 and 300 m transects. In the last two examples stronger horizontal winds caused increased turbulence as shown by the growth in vertical eddy amplitudes inland. High frequency (probably transient) turbulent eddies of 1-2 km extent appear superimposed onto stationary circulation cells with length scales of about 10 km, presumably reflecting the seabreeze.

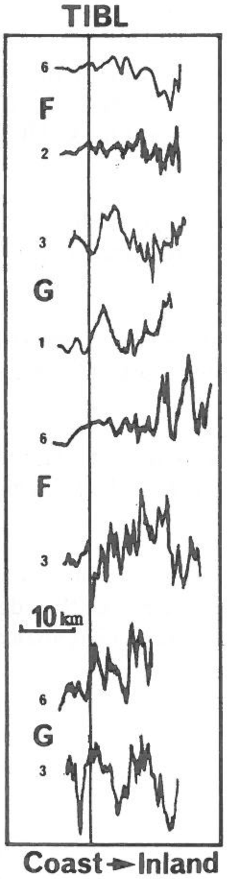

Figure 2 - Analogue traces of inverted pressure indicative of vertical velocity fluctuations, and turbulent scales and intensity. Pairs of traces are marked by F for Cape St Francis and G for Gouriqua. Small numbers refer to heights above sea level (X 100 m). Pairs are for (top to bottom) 20, 22, 27 and 28 June 1989.

Background weather information pertaining to the case study is shown in Figure 3. The synoptic weather chart shows a coastal low in the study area with high pressure dominant offshore. The Port Elizabeth radiosonde profile reflects the presence of high humidity and shallow surface easterly flow. Geostrophic winds were northerly and warm advection was indicated. A shallow isothermal layer was noted from the surface to about 300 m.

The meteorological structure of the Gouriqua cross section of 22 June 1989 is provided in Figure 4 for means (contours) and time derivatives (shading) of wind,

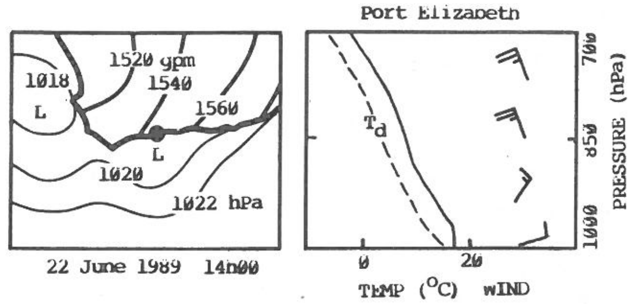

Figure 3 - Background weather conditions for the case study day: synoptic weather chart (left) for 22 June 1989 14h00 and Port Elizabeth radiosonde profile (right). The narrow spread of the temperature and dewpoint (dashed) profiles points to humid conditions on the case study day, despite northerly winds above the surface.

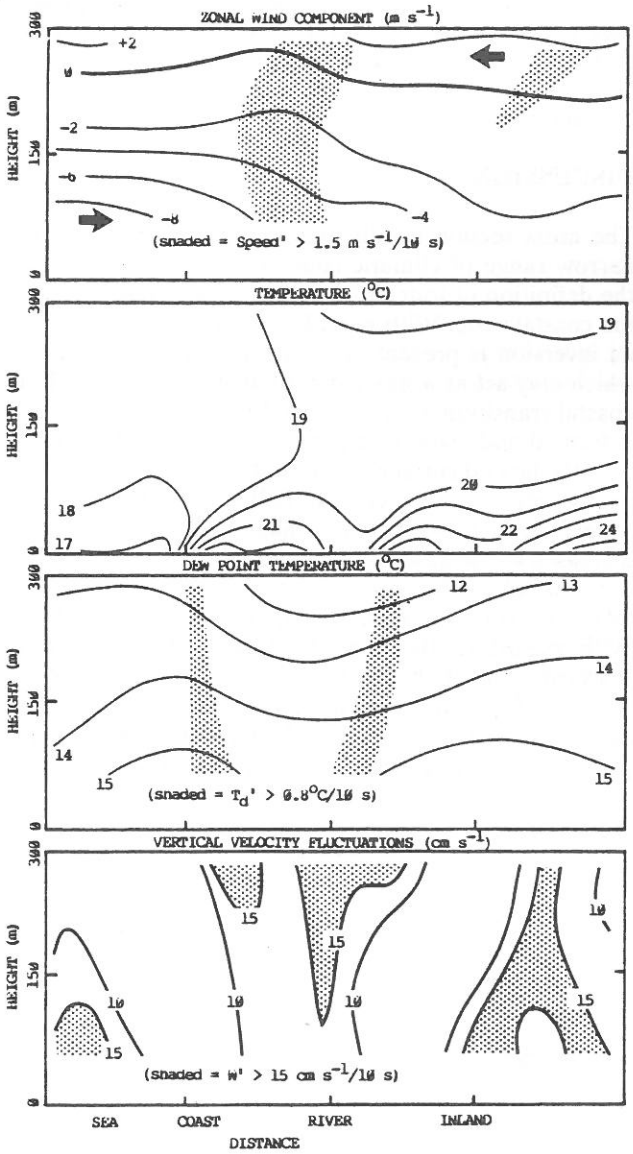

Figure 4 - Cross section meteorological analysis of (top to bottom) the zonal wind component, air and surface temperature, dewpoint temperature, and vertical velocity fluctuations. Time derivatives which emphasize turbulence are shaded.

temperatures and turbulence parameters. The Zonal wind component (top) verifies the presence of shallow easterlies capped above 250 m by northwesterly flow. Mid-way through the cross section a vertical band of turbulence is indicated by speed variances over 1.5 ms^{-1} (shaded). In the vertical band, zonal wind isolines lifted in the presence of an embedded seabreeze cell. Temperatures also increased in a vertical wall in the 200 - 300 m layer. Below 200 m a typical thermal internal boundary layer structure is noted and isotherms tilted westward with the wind. Over the river a depression in surface temperatures, hence reduced heat fluxes, was found. The thermal internal boundary layer structure (warm westward tilted surface layer) resumed further inland. In the moisture field, dewpoint isotherms sloped gradually upward to the west as horizontal winds followed a similar slope in the terrain. Some drier air was noted over the river at 300 m, between two moisture fluctuation bands (shaded). Vertical velocity fluctuations were coherent at the 100 and 300 m levels as represented by the vertical bands in the bottom panel of Figure 4. Departures of the vertical velocity pattern from that of temperature points to the channelling affect of the Gourits River valley which disrupted the thermal internal boundary layer.

DISCUSSION

The cross section results, while representative of only a narrow range of climatic conditions, nevertheless enable the definition of four distinct dispersion categories within the coastal zone. With regard to the temperature pattern, an inversion is present in the lowest 100 m over the sea which may act as a sink for recirculated pollutants. In the coastal transition zone a thermal internal boundary layer is formed and dispersion conditions improve dramatically over the heated surface of the coastal plain, where easterly winds would advect coastal pollutants. Over the river valley, surface winds are channelled and turbulence increases as the seabreeze and valley flow collide and the thermal internal boundary layer is disrupted. Further inland convective conditions obtain in the lowest 100 m. With regard to the wind field, it is thought that the seaward edge of the thermal internal boundary layer is where surface pollutants may be lifted into the return flow aloft. The reduction in speed of the surface easterlies provides the lifting mechanism through convergence.

The meteorological structure analysed in the case study serves to emphasize that dispersion prediction models based on data from tall towers located near the coast would not fully realise the trajectory and diffusion of atmospheric pollutants. The numerical models could, however, be improved by programming in repeatedly observed patterns as "background climatology" for data assimilation schemes. With the advantage of aircraft observations, atmospheric pollutants along the Cape south coast may be better managed in the next century.

ACKNOWLEDGEMENTS

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