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Ozone observations and research in New Zealand – A historical perspective

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Introduction

This paper is a summary of the ozone work carried out in New Zealand, mainly within the New Zealand Meteorological Service, during the last seven decades. Its main aim has been to link local research activities to the progression of many new ideas and discoveries reported internationally in atmospheric physics, chemistry and dynamics, particularly in the last four decades. Results of analysis of up-to-date series of total and Umkehr ozone observations made in New Zealand are also discussed.

Early ozone projects in New Zealand, 1929–1960

Total ozone observations in 1929

The earliest total ozone observations were carried out in New Zealand at Christchurch (43.5° S, 172.5° E) during August to November 1929 with a Fery spectrograph, as part of the first global ozone-monitoring network organized by Dobson from Oxford. The instrument was on loan for the duration of the experiment, and the photographic plates were evaluated at Oxford. Since in those days it was practically impossible to obtain copies of weather charts from distant places on a regular basis, Dobson had invited local meteorologists to contribute short discussions on the relationship of daily ozone variations with meteorological conditions in their own regions, to be included in the final publication of the network results. Kidson of the New Zealand Meteorological Service did so for the New Zealand observations[1], laying the foundations of interest in ozone research within the Meteorological Service.

Acquisition of Dobson spectrophotometer No. 17

After a satisfactory commercial production of three prototypes of Dobson's 'new' photo-electric ozone spectrophotometer in the early thirties, building of a larger batch of 20 instruments was planned for 1936 at a reduced cost of £156 each, and all interested organizations, among them the N. Z. Meteorological Office, were invited to place an order at this time to avoid higher individual costs later. However, for financial reasons, the final order from New Zealand could only be made in 1937 for one Dobson instrument, which was expected to arrive in 1938. Due to calibration difficulties, and then the outbreak of the war, dispatch of the No. 17 instrument to New Zealand was delayed. Moreover, permission to retain the instrument in England for the duration of the war for purposes of 'urgent defence investigations' had been received and granted. This request was based on the contemporary belief, that correlations between daily ozone variations and synoptic events could be used in forecasting, particularly where upper air observations were scarce[2]. After the war, further modernizations of the No. 17 instrument at Oxford were carried out, which again delayed its arrival to New Zealand until 1950. More or less regular weekday observations of total ozone were started in 1951 at Wellington (41.3° S, 174.8° E), carried out by the staff of the newly formed Research Section of the Meteorological Service. Prior to this time, interest in the significance of ozone observations was maintained by following and summarizing up-to-date information on research overseas[3].

Analysis of Wellington total ozone data, 1951–1960

The Wellington total ozone data for the 1951–1960 period were derived from observations on the single 'C' wavelength pair, as the then recently recommended use of the double 'AD' wavelength pair commenced only in 1960, a short time before a major break-down occurred in the optical wedge of the No. 17 Dobson instrument.

The distribution of total ozone with seasons and latitude, and its variations with shorter scale synoptic events was reasonably well known by the fifties, mainly from Northern Hemisphere observations. The frequent gaps in the daily series, caused by missing observations on the weekends and during bad weather, made the Wellington data[4] unsuitable for analysis of short-term variations. It could be shown, however, that the annual variations were characteristic for a mid-latitude station, that biennial variations were present in the spring ozone maxima, and that the apparent decreasing linear trend for the 1952–60 period was not statistically significant[5].

Work in the sixties and seventies

The extended network of observations during the IGY (1957/59) and IQSY (1963/64), as well as the introduction of new observing techniques such as rocket soundings and satellites, gave more detailed knowledge of the wind and temperature structure of the stratosphere. Balloon-borne instruments for the direct measurement of the vertical distribution of ozone became available for routine use, and Umkehr measurements were standardized. Studies were made of the spread of radioactivity originating from several nuclear tests in the fifties[6], which, together with the use of ozone and water vapour as quasi-conservative tracers, also helped towards understanding the transport mechanisms operating in the stratosphere, and between stratosphere and troposphere[7]. In addition to advances in atmospheric dynamics, the classical photochemical theory has been extended by inclusion of hydrogen and nitrogen cycles into the reaction schemes previously containing oxygen only[8,9]. Thus newer general circulation models were advanced[10,11], but many questions still remained to be answered about the nature of the distributing mechanisms, the possible reasons for the observed year-to-year variations, particularly in the Southern Hemisphere, and hemispheric differences of the observed ozone distributions[12,13].

Analysis of vertical ozone distributions, 1965–66

Total ozone observations resumed at Wellington again in 1965, after renewal of the optical wedge, some modernization of the electronics, and recalibration of the No. 17 Dobson instrument have been carried out at Aspendale (37.9° S, 144.7° E). Soon after, a series of Brewer–Mast electro-chemical ozone-sonde ascents were made at Christchurch. The results were compared to the vertical ozone distributions and their seasonal variations observed at Aspendale and estimates were made of the horizontal transport of ozone by transient eddies, of the annual average vertically integrated ozone flux, and the ozone budget for the 38–43.5° S latitude, surface to 70 mb region[14].

Analysis of Antarctic ozone and temperature distributions

There were early indications of significant differences between the subpolar regions of the two hemispheres of the seasonal latitudinal ozone distributions[15]. Using the stratospheric temperature and ozone data available since the IGY, studies were made of the springtime 'sudden' warmings over the Antarctic region, together with their correlations with ozone variations, and with the features of the changes in high latitude and polar vortex circulations in the lower stratosphere[16,17]. It was found that dynamically active warm regions of the stratospheric south polar vortex were coupled with high ozone content and inner cold regions with low ozone content during the winter and spring. Correlations between the short period ozone and stratospheric temperature fluctuations were high during the sudden warming periods, and year-to-year changes of the spatial correlations of ozone and temperatures between Antarctic stations corresponded to the yearly differences in the large scale spring circulation of the polar stratosphere. A relationship between the times of onset and the magnitudes of the spring ozone maxima over high latitudes was indicated, i.e. late occurrences of the final warming resulted in lower seasonal ozone maxima and vice versa, whereas no such relationship was found for mid-latitude ozone data.

Quasibiennial oscillations

Since the discovery of the quasibiennial wind oscillation in the equatorial stratosphere[18], biennial variations were noted in ozone data at many locations, including New Zealand[5] and Antarctica[17]. A much later analysis of the New Zealand total ozone data up to 1984 numerically determined the quasibiennial component, which was found to have a mean period of 28 months, and accounted for ≈ 12% of the total variance[19].

Correlations with the solar cycle

Much interest was also shown in possible correlations of ozone variations with the 11-year sunspot cycle, but due to the lack of sufficiently long periods of reliable data series, particularly at high stratospheric levels, the published statistical results were controversial[20]. In New Zealand, Umkehr observations started in 1971, after the ozone observing project was transferred from Wellington to Invercargill (46.4°S, 168.3°E). Although the variations of the ozone content of the highest Umkehr layer for the period 1971 to 1980 showed a relative maximum near the period of the sunspot minimum in 1976 (ref. 21), this observation period barely covered one and a half solar cycles, and repetition of a similar relationship during the next cycle was not observed.

Long-term trends and atmospheric scattering

Even before the theories of ozone depletion by fluorocarbons were put forward in the mid seventies, ozone data were searched for possible long term linear trends. Linear trends of up to 10% total ozone increases were found at various places in the world[22], and up to 6% at some Australian stations[23] for the 1960–69 period. Kulkarni suggested that these trends could reflect a worldwide change in the haziness of the atmosphere due to air pollution. This would influence the characteristics of atmospheric scattering and the calculation of total ozone. He estimated that about 53% of the observed trend at Brisbane during the sixties was possibly due to this cause. His method of obtaining the scattering terms from the total ozone observations was criticized and a new graphical method was proposed by Basher[24]. The New Zealand ozone data for the 1965 to 1976 period were analysed, separating long term variations of ozone and scattering by using the Basher method, and by making use of the zenith blue sky C'C" wavelength pair observations[25]. Since it was found later that use of second order terms in the graphical method artificially inflated the 'true' ozone variations due to propagation of errors[26], the magnitudes of the long term ozone oscillations found in the latter analysis became doubtful. For the purpose of estimating the long term variability of turbidity in New Zealand, a new analysis was made with a revised method and data updated to 1980[27]. While the presence of long term oscillations in the scattering terms was confirmed by the results, these did not appear to be simply related to the possible transient effects of volcanic eruptions as suggested earlier, and power spectrum analysis showed that short term variations of six months and less were the most significant.

Development of the 'Canterbury' filter photometer

The New Zealand Meteorological Service has promoted and taken active interest in the development of an interference filter ozone photometer at Canterbury University, which started as a Ph D project in 1967. Only limited comparisons were made of the first experimental model with the No. 17 Dobson instrument[28]. The filter photometer was further remodeled[29] and comparisons were carried out routinely at Invercargill during 1975–76 (ref. 30). While some of the problems with the new filter photometer have been overcome[31], and a few commercially produced instruments were in operation at some ozone stations at a later stage, the project folded by the eighties.

International cooperative projects

Some ozone soundings and total ozone observations were carried out in New Zealand at the time of the passage of an instrumented aircraft of the NASA CV-990 latitudinal survey mission in November 1976 (ref. 32).

Total ozone observations, additional to the daily routine, were introduced at Invercargill from March 1977, to coincide with the passage of a US satellite carrying a multichannel filter radiometer, from which global ozone data were derived at the Satellite Ozone Analysis Center at the University of California. Invercargill was one of the global network of Dobson stations to provide 'ground truth' to be compared with the satellite observations[33]. This project continued until the end of 1984.

Surface ozone measurements

Increasing attention had been given in the seventies to variations of ozone in the troposphere, to the origin of 'natural' ozone and the effect of increased levels of industrial pollution on ozone distributions at low levels[34,35]. From 1973, shorter and longer period observations of surface ozone variations have been carried out in several urban and rural locations in New Zealand. It was found that generally more ozone was observed at semi-rural than at urban locations, indicating that local pollution primarily acted as an ozone sink in the surface layers[36]. As an example, a comparison of the monthly mean surface ozone values observed at Invercargill and at the Cape Grim (Tasmania) baseline station during 1983 is shown in Figure 1. The observations were carried out with Dasibi UV absorption instruments both at Cape Grim[37] and at Invercargill, and data refer to all conditions. It is seen that mean surface ozone values were lower at Invercargill in all seasons, particularly during autumn and winter. At all New Zealand locations, yearly maxima occurred in the late winter–early spring, and minima in late summer–early autumn. Diurnal variations showed afternoon maxima and morning minima which were strongly correlated with variations of boundary layer mixing conditions during the day. No significant incidence of photochemically induced smog episodes was found in the cities, and on a few occasions when local ozone production occurred, these remained below the US. Federal Air Quality Oxidant Standard, then considered[38] to be 8 pphmv/h.

Surface ozone measurements were also made at Scott Base, Antarctica, during two summer seasons, which indicated that maritime airmasses contained more ozone than polar continental airmasses passing over the Base[21].

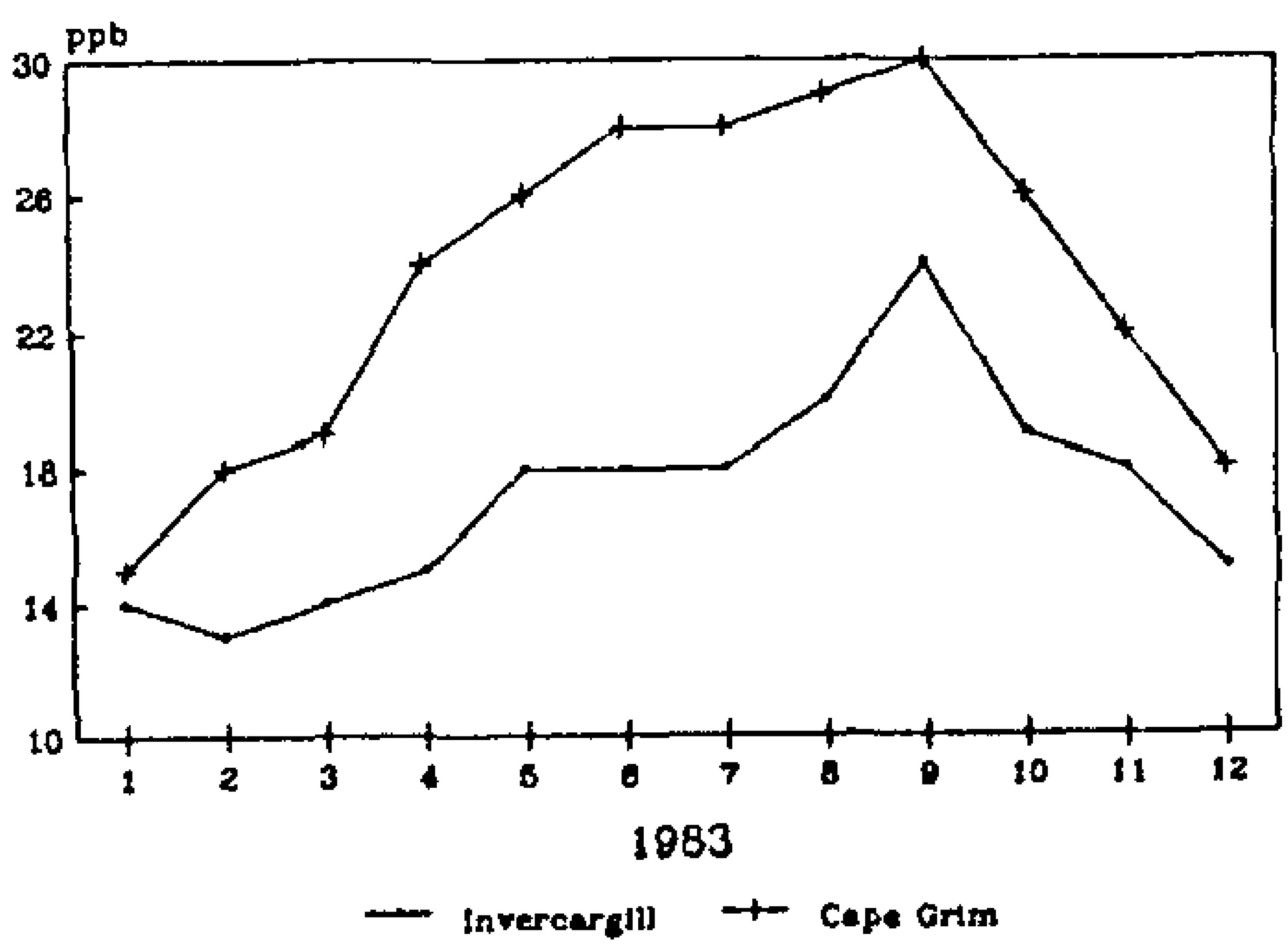

Figure 1. Variations of monthly mean surface ozone in 1983 at Invercargill, New Zealand, and at Cape Grim, Tasmania.

The eighties and nineties

Indirect observations of stratospheric ozone

Stratospheric ozone content was derived from spectral data in the 435–450 nm wavelength range observed by a ground-based long path absorption technique, which was developed at Lauder, New Zealand, mainly for observing NO_2 variations. Comparisons showed that the ozone amounts derived by this method were much less accurate than those measured by the Dobson instrument by about 20%. However, it was thought that because O_3 and NO_2 variations were obtained simultaneously, the observations may be used to provide comparisons with theoretical models of the coupling between these stratospheric constituents[39]. Similar observations were also carried out in Antarctica[40].

Measurement accuracy of the Dobson instrument

The search for long term trends in ozone data continued to gain importance, as theoretical predictions of ozone depletion by fluorocarbons, supported by increasingly elaborate computer models, became generally accepted. With the passage of time, longer period ozone data became available, which increased the reliability of statistical analysis. As the theoretically predicted total ozone depletion was relatively small, only a few per cent at most by the eighties, it was important to establish the magnitude of errors in ozone observations.

A review of the accuracy of the Dobson instrument and its measurements was made for the WMO by Basher[41].

Calibration history of Dobson instrument No. 17

As well known, long term stability of the calibration of the Dobson instrument is necessary to avoid false trends being introduced into the data. Standard calibration tests were devised at an early stage and summarized for the IGY[42], which were routinely carried out at many Dobson observation stations, including Wellington and Invercargill. The calibration history in New Zealand of the No. 17 Dobson instrument was reviewed recently, which has shown that measurements were carried out under a good standard of calibration throughout the observation period[43] of 1965 to 1987.

Ozone decreases during the eighties

The findings of the above review were important to establish the reality of long term variations found in the New Zealand ozone data, particularly of the consistently large negative anomalies of the monthly mean total ozone values which appeared relatively suddenly after 1984 (Figure 2). Deviations were taken from averages for the whole 1965–90 period, comprising total ozone data for Invercargill up to closure of the observations there in September 1987 and for Lauder from October 1987 to August 1990 (Ozone Data for the World). Relatively large and consistently negative total ozone deviations also occurred[19] at Melbourne during 1985–88.

Ozone content at high stratospheric levels, as shown by the Umkehr observations in Figure 3, also started to decline after 1980. Here again, data from Lauder have been used to extend the Umkehr series after September 1987. Note that deviations in these series are relative to long term means for the 1975–90 period. All long term linear trends, except in the 19–28 km layer, show significant decreases from 1975 to 1990. Interpretation of these trends is complicated by the uncertainties associated with the possible effects of the various volcanic eruptions which occurred in the early eighties[44]. The possible effects of large scale circulation changes associated with the unusually large El Nino Southern Oscillation circulation anomaly, which started at about the time of the El Chichon eruption in 1982, have also been considered[19]. However, no plausible causes have been found to date to explain the large decrease of ozone levels from 1984 to 1985, which amounted to about 6.7% of the 1965–84 average, and which could not be traced to a calibration discontinuity.

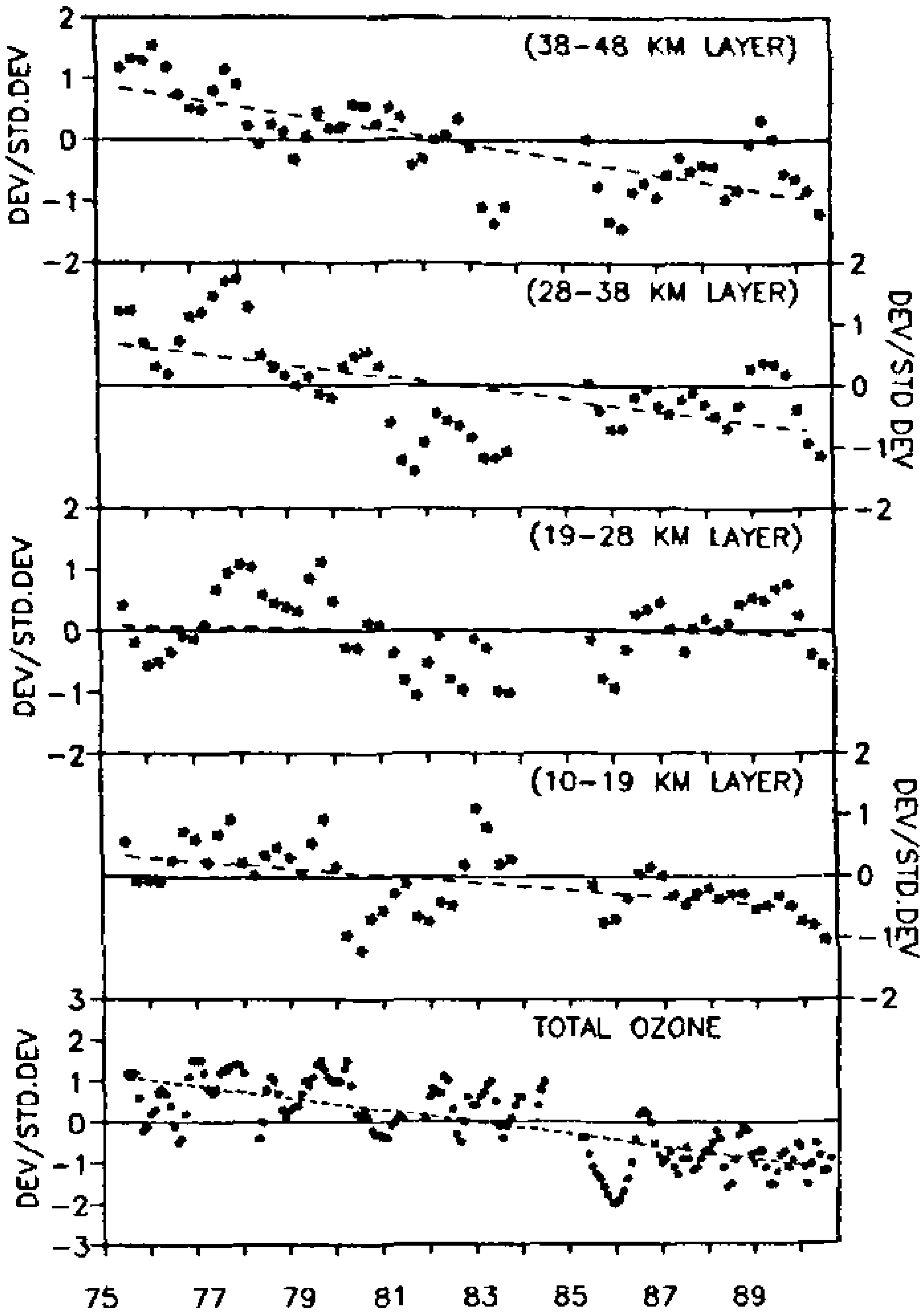

Figure 3. Normalized monthly mean total ozone and seasonal mean Umkehr layer partial pressure variations at Invercargill and Lauder. All series have been smoothed by centrally weighted 3-term running means.

Antarctic total ozone observations

The No. 17 Dobson instrument was shifted to Antarctica, and ozone observations made, under the supervision of the New Zealand Meteorological Service, at Arrival Heights (77.8°S, 166.7°E) since January 1988. Results of the observations have been used to determine the spring time ozone depletion and its year-to-year variations over the McMurdo region[45].

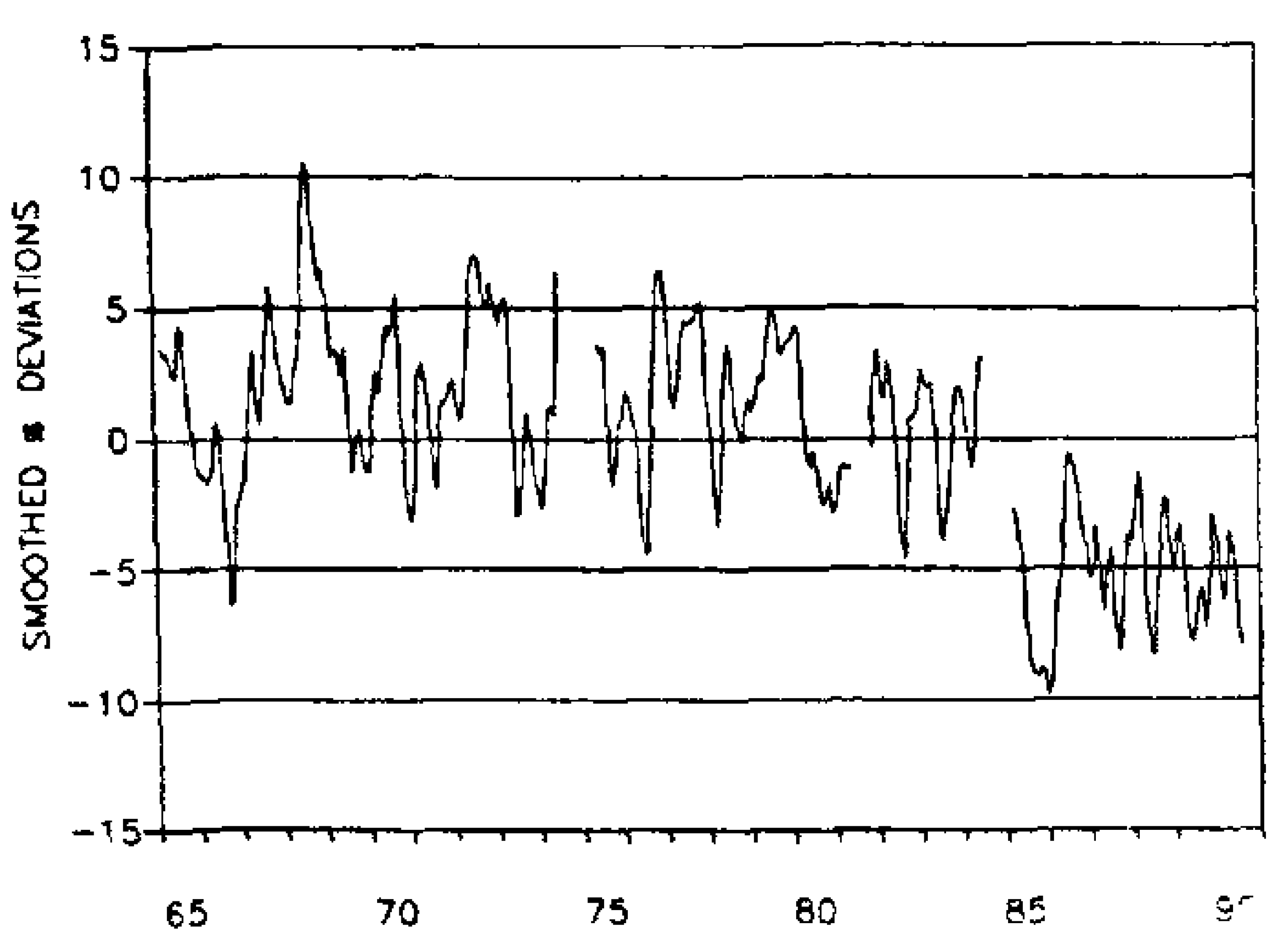

Figure 2. Variations of monthly mean total ozone deviations at Invercargill and Lauder. The deviations were smoothed by centrally weighted 3-term running means. Ticks on time scale represent January each year

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