Dobson spectrophotometer #17: past, present and future

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Abstract

The Dobson spectrophotometer, which was developed in the late 1920s, measures atmospheric total column ozone. This paper presents the history of Dobson spectrophotometer #17 (D#17), which arrived in New Zealand in 1950. D#17 has been in operation at Kelburn in Wellington (1951 – 1970), Invercargill (1970 – 1987), and Arrival Heights in Antarctica (1988 - present). D#17's history includes a flooding, several overhauls, a semi-automation, and finally a complete automation. In the early days the main reasons for measuring total ozone were to develop an ozone climatology, and to investigate the relationship between ozone and the weather. From the mid-1970s the focus of ozone measurement largely changed to studying ozone trends (which includes Antarctic ozone depletion). This requires a traceable calibration history, which is discussed in detail. Plots of the D#17 total ozone record are provided.

1. Introduction

2018 marks 30 years of operation of Dobson spectrophotometer #17 (D#17) at the New Zealand atmospheric laboratory at Arrival Heights (77.83° S, 166.66° E; Figure 1) in Antarctica. But the history of D#17, and of ozone measurement in New Zealand, goes much further back in time than that. The Dobson spectrophotometer (Dobson, 1931), which was developed in the late 1920s by Dr G.M.B Dobson of Oxford University, is used to measure atmospheric total column ozone. The Dobson spectrophotometer is still widely regarded as being the standard instrument with which to measure atmospheric total column ozone from the ground. There are approximately 100 Dobson spectrophotometers currently operating around the world.

The Dobson spectrophotometer actually measures the relative intensity of solar radiation between selected wavelength pairs in the range of 300-350 nm. These measurements are then used to calculate the total amount of ozone between the instrument and the top of the atmosphere (i.e. total column ozone). The method of total ozone calculation can be found in Komhyr (1980). The units of measurement are Dobson Units (DU), with 100 DU being equivalent to a 1 mm thick slab of ozone at Standard Temperature and Pressure.

The precision of the Dobson spectrophotometer is considered to be ±1% (Evans et al., 2017). The accuracy of the instrument, which has been investigated by Basher (1982), is difficult to quantify as it depends on instrument-specific characteristics and observing conditions. Basher

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(1982) estimates that under good operational conditions the accuracy is 3% or better.

2. Early ozone measurements in New Zealand

From the 1920s through to the 1960s the main reasons for measuring ozone were to develop an ozone climatology, and to investigate the relationship between ozone and the weather (Staehelin et al., 2018). New Zealand was involved in some early ozone measurements: a Féry quartz spectrograph was in operation at the Canterbury College in Christchurch, under the supervision of Dr C. Farr, from August 1928 to August 1929. The spectrograph was on loan from Dr Dobson, and was part of a "global" ozone monitoring network of five instruments (Dobson, 1930); the other instruments were in Switzerland, California, Egypt, and India. Dr Dobson invited local meteorologists to contribute short discussions on the relationships of daily ozone variations with meteorological conditions in their own regions. Dr E. Kidson, who was Director of the New Zealand Meteorological Service (NZMS), did this for the Christchurch measurements and his report is included in Appendix 2 of Dobson (1930).

3. Brief History of Dobson #17

Three prototypes of the Dobson spectrophotometer were made in the early 1930s. The first production run of 20 Dobson spectrophotometers was planned for 1936, at a cost of £385 each. Due to its involvement in the Christchurch ozone measurements, the NZMS was invited to place an order in this initial run and so avoid the higher costs for the instruments later on. The instruments were to be manufactured by R & J Beck Ltd of London, and the tests and calibration of the instruments were to be carried out by Dr Dobson at the Oxford ozone laboratory.

In 1937 the NZMS, which at that time was part of the Department of Scientific and Industrial Research (DSIR), gained approval to purchase a Dobson spectrophotometer, and so that is when the story of D#17 began. The order was placed by the DSIR, and the instrument was expected to arrive in New Zealand in 1938. However difficulties with calibrating the instrument, due to inclement weather at Oxford, significantly delayed its completion. In 1939, at the beginning of World War II, the New Zealand Government was approached to see if D#17, which still had not been dispatched to New Zealand, could be lent to the British Meteorological Office for the duration of the war to assist with "urgent defence investigations". The New Zealand Government agreed to that.

In 1947, after the end of the war, it was decided that D#17 would be overhauled and recalibrated before being sent to New Zealand. This work was done by Dr Dobson at Oxford. It took another two years for the replacement parts to be supplied, and D#17 was finally ready to be shipped to New Zealand at the end of 1949.

Figure 1: Map showing the location of the three sites where Dobson #17 has been operated (black). The other sites mentioned in this paper are shown in blue.

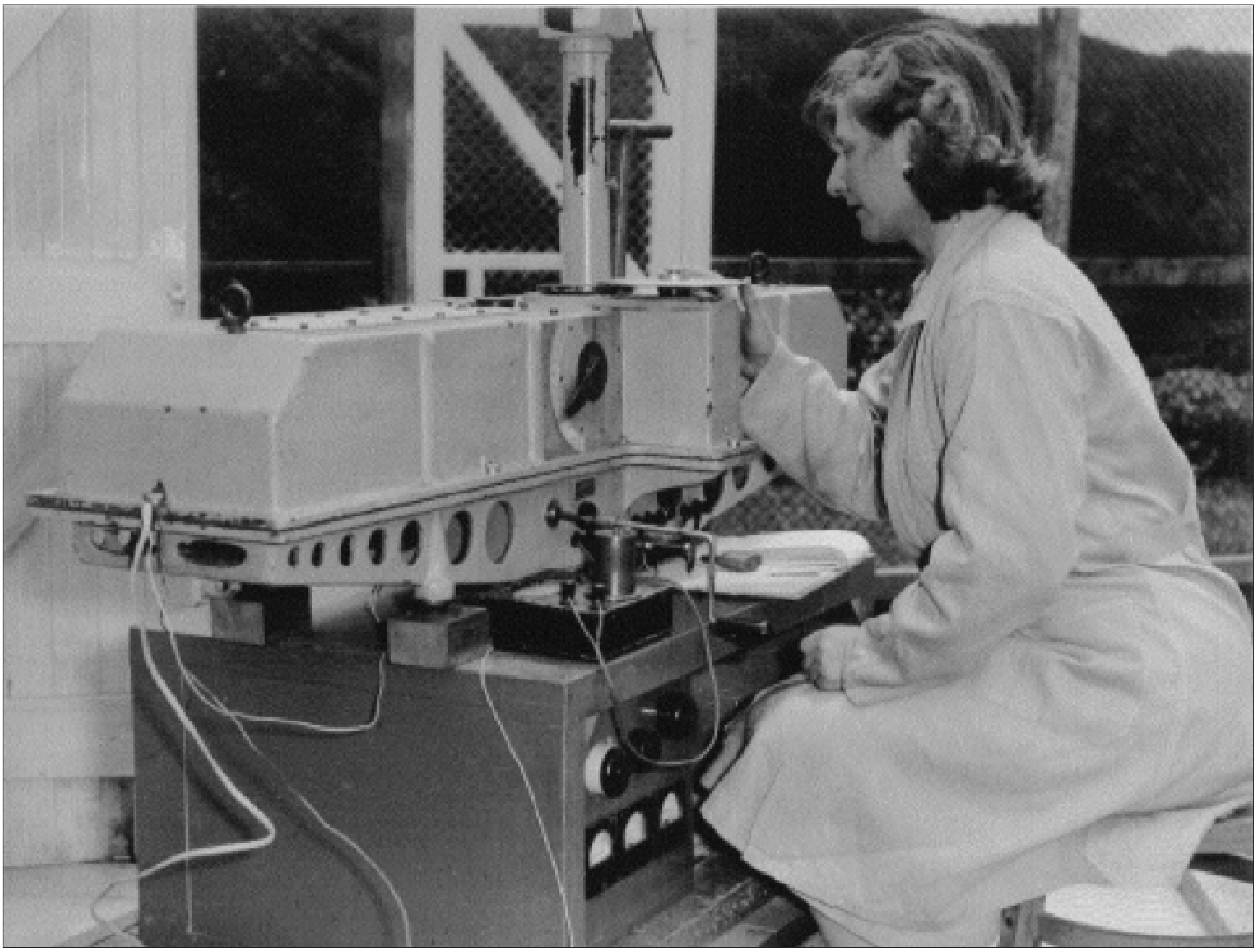

Figure 2: Edith Farkas operating Dobson #17 at Kelburn, about 1960.

So D#17 finally arrived in New Zealand in 1950, 13 years after the initial purchase. It was set up at the Dominion Physical Laboratory at Gracefield, Wellington, and some initial tests and ozone measurements were made there. By this time, the NZMS had become attached to the Air Department (de Lisle, 1986). So the ownership of D#17 was transferred from the DSIR to NZMS, and the instrument was set up at the NZMS office in Kelburn (41.28° S, 174.68° E; Figure 1), Wellington in July 1951.

The early measurements at Kelburn were performed by Elizabeth Porter, who tragically lost her life in December 1953 in the Tangiwai train disaster (https://iwonderweather.co.nz/story/women-in-weather/6388/keyword/women). The measurements continued at Kelburn, with increasing involvement from Edith Farkas (Figure 2) who had begun working for NZMS in 1953. This was her first scientific job in New Zealand, after arriving as a refugee from Hungary several years earlier (McGlone et al., 1990; https://iwonderweather.co.nz/story/women-in-weather/6388/keyword/women).

In 1962 the measurement programme was suspended due to the poor condition of D#17. The performance of the instrument had gradually deteriorated over time, until finally it became completely unserviceable. In 1963 it was decided to overhaul D#17, and resume the measurement programme for the International Quiet Sun Years (Pomerantz, 1963), which took place from January 1964 to December 1965. This overhaul was performed

Figure 3: Dobson #17 at Invercargill with (left to right) Tony Veitch, Bob Horridge, Edith Farkas, Dick Holloway, Mike Criglington (all NZMS); in late 1970s or early 1980s.

by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Melbourne, Australia. Again there were major delays in obtaining replacement parts, and D#17 was finally back in operation at Kelburn in January 1965. Edith Farkas led the D#17 measurement programme from 1965 through to her retirement from NZMS in 1986.

D#17 remained in operation at Kelburn until June 1970, when it was moved to the NZMS Invercargill office (46.43° S, 168.35° E; Figure 3) which was at the airport. The move was made to help to fill in the latitudinal gap in the Australian network, which had Dobson spectrophotometers at Melbourne (37.67° S, 144.83° E) and Macquarie Island (54.50° S, 158.94° E).

In 1974 D#17's electronics were upgraded to Komhyr's (Komhyr and Grass, 1972) design. This involved replacing the amplifier, commutator, low voltage and high voltage power supplies with solid state components.

D#17 was badly damaged by floodwaters during the January 1984 Southland flood, when the Invercargill airport was flooded to a height of 2.5m (hwe.niwa.co.nz/event/January_1984_Southland_Flooding). D#17 required a complete overhaul to get it operational again, and so it was sent to the National Oceanic and Atmospheric Administration (NOAA) Dobson Laboratory in Boulder, Colorado, USA. During this rebuild, D#17's optical wedge was replaced with one of a more robust design (Evans et al., 2017). D#17 was back in service in Invercargill in June 1985.

In January 1987 another Dobson spectrophotometer was installed in New Zealand. Dobson #72 (D#72), which was part of the NOAA automated Dobson network, was installed at the DSIR station at Lauder (45.04°S, 169.68°E) in order to complement the other stratospheric measurements that were being made at the site. It made no sense to have New Zealand's two Dobsons operating in such close proximity to each other (Invercargill and Lauder are approximately 180 km apart). So NZMS conducted a review to decide where the best place to continue measurements with D#17 would be.

Figure 4: Dobson #17 at Arrival Heights after incorporation of the WinDobson software (February 2015), with (left to right) Kate McKenzie (Antarctica New Zealand), Sylvia Nichol (NIWA), Wills Dobson (NIWA), Koji Miyagawa (NOAA).

The Antarctic Ozone Hole had been discovered in 1985 (Farman et al., 1985; Chubachi, 1985), and so it was decided to move D#17 from Invercargill to the New Zealand Antarctic Research Programme (now known as Antarctica New Zealand) laboratory at Arrival Heights to contribute to investigations into Antarctic ozone depletion. Arrival Heights is very close to the American McMurdo station which, with the discovery of the Ozone Hole, had become a real hub for ozone depletion related measurements. There wasn't a Dobson operating in the McMurdo region, so the installation of D#17 at Arrival Heights in January 1988 was a welcome addition to the measurement programmes in the region. This included the ground-based measurements of nitrogen dioxide (an ozone depleting substance), which had been started by DSIR at Arrival Heights in 1982 (McKenzie and Johnston, 1982).

In 1992, the ownership of D#17 and operation of D#72 came under the one organisation when the National Institute of Atmospheric Research (NIWA) was formed as part of the reforms of the New Zealand government science sector. D#17 and D#72 are still in operation at Arrival Heights and Lauder respectively.

4. Changing methods of operation with Dobson #17

As already mentioned, the total ozone measurements are made by measuring solar ultraviolet radiation. When Dobson #17 was at Kelburn and Invercargill it was operated in the usual manner by storing it indoors and then wheeling it outside on a trolley to make the measurements, as shown in Figures 2 and 3. This method is not very suitable for Antarctic operation due to the cold and windy conditions. A periscope system, using the design of Olafson (Komhyr, 1980; pers. comm. 1987), has been used for the Arrival Heights operation (Figure 4) so that Dobson #17 can be operated from within the laboratory. Also at Arrival Heights from April through to August the sun is too low in the sky to use sunlight to make the measurements, so during those months the measurements have been made using reflected moonlight instead.

Since D#17 has been in operation at Arrival Heights, it has undergone two significant instrument automations. In 2005 a digital encoder system, developed by NOAA (Evans, 2008), was incorporated into the instrument which semi-automated the data collection. Up until this point the whole measurement process was basically the same as it had been for the preceding 65 years, with measurement times and instrument dial readings being written down by hand onto measurement log sheets. In the very early days, the calculations to derive the total ozone values were done by hand, using these hand-recoded values and various look-up tables (Komhyr, 1980). In later years these calculations were performed using computers with the hand-recorded values being transcribed into input files. The 2005 automation resulted in the measurement times and instrument dial readings being recorded directly into computer input files by the digital encoder system.

The second automation of D#17, which took from November 2014 to January 2015 to complete, incorporated automation controls directly into the instrument so that the measurements are now driven by the automated WinDobson software. D#72 has been running the WinDobson software since 2012.

The WinDobson package (Miyagawa, 1996), which was developed by the Japan Meteorological Agency, provides a standardized approach to operation, quality assurance and data analysis of Dobson observations. The WinDobson automation provides more consistent results from consecutive measurements. This standardized measurement approach is particularly useful at a station like Arrival Heights, where the instrument operators change annually; more than 60 operators have worked with D#17 over its 30 years of operation at Arrival Heights.

5. Dobson #17 measurements

The calibration history of D#17, from 1965 through to 1987, is summarised in Farkas (1989), and presented in more detail in Nichol and Coulmann (1990). Both Farkas (1989) and Nichol and Coulmann (1990) restricted their analysis to data from 1965 onwards i.e. the period after the overhaul of D#17 by CSIRO in 1963/1964. As part of the 1963/1964 overhaul, D#17 was compared directly with Regional Standard Dobson #105. These instrument comparisons are a method of transferring calibrations from one instrument, usually a well-calibrated Regional Standard, to another instrument (Komhyr, 1980). They provide traceability to the world standard, and thereby improve consistency of measurement across the world network. No such comparisons had been carried out during the period 1950 to 1962, and so the D#17 data for that period were excluded from the Farkas (1989) and Nichol and Coulmann (1990) analyses.

As ozone research became more oriented towards the analysis of long term behaviour, there were increased international efforts to ensure good instrument calibration status and standardisation of measurement techniques, so instrument comparisons became much more frequent. D#17 was compared with Regional Standard Dobsons in Australia in 1978, and in Canada in 1981. D#17 was compared with the World Standard Dobson in Boulder, Colorado in 1985, after it had been overhauled. Since 1991, D#17 has been compared with the Regional Standard Dobson in Australia at approximately 5-yearly intervals.

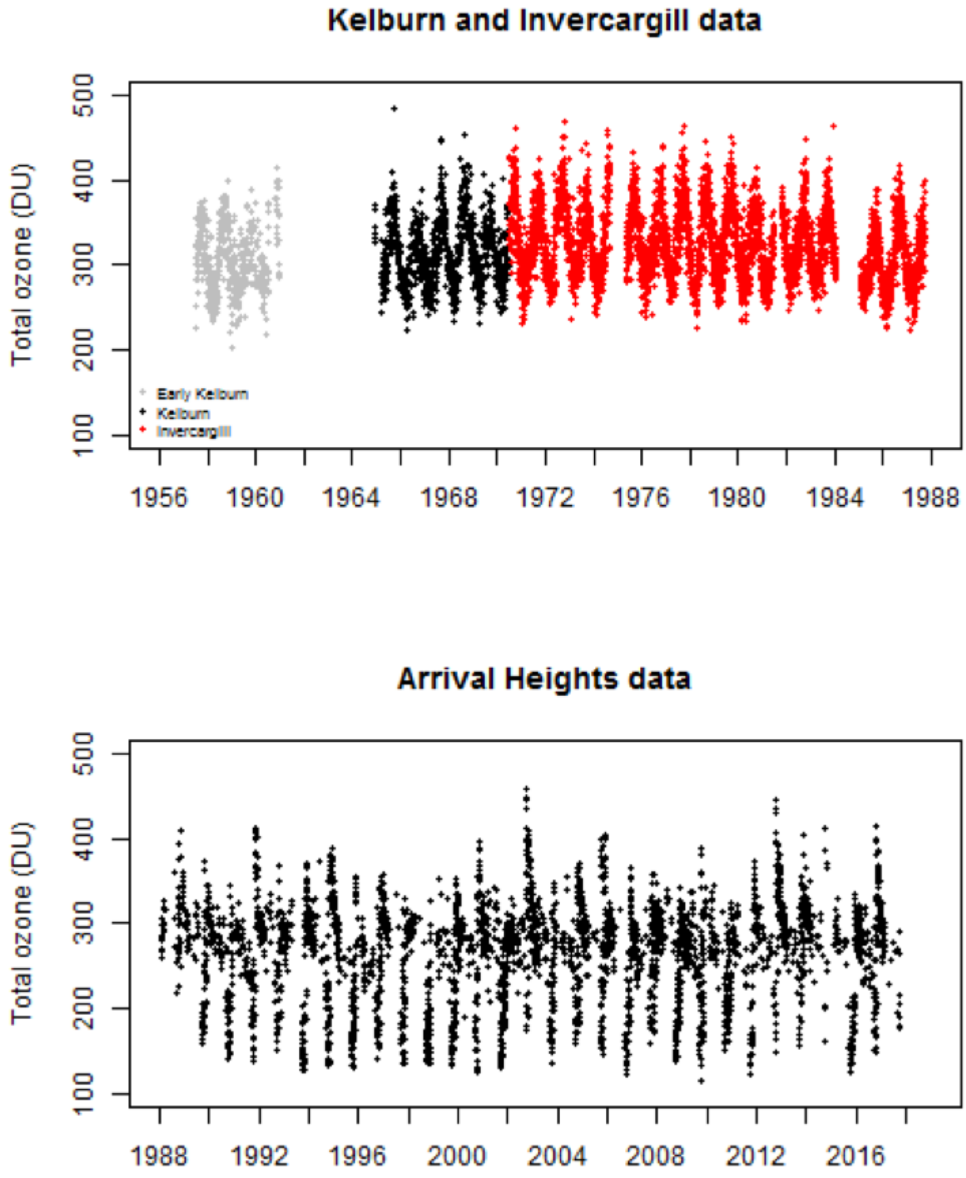

Figure 5: Daily total ozone data from Dobson #17 for Kelburn (grey and black, top panel), Invercargill (red, top panel) and Arrival Heights (bottom panel). NB the Kelburn data from 1957-1960 (in grey, top panel)) are included but they are not considered to be well-calibrated data.

Figure 5 shows the D#17 measurements from 1957 to 2017. Although the data from 1957 to 1961 are not well calibrated data, they have been included in Figure 5 for the sake of completeness. There is a 1-year gap in the Invercargill record from February 1984 through to February 1985, which was caused by the flood damage to D#17. Nichol and Coulmann (1990) found D#17 to be well calibrated on both sides of the data gap. The Kelburn (1957-June 1970) and Invercargill (June 1970-1987) data show typical mid-latitude behaviour with a seasonal minimum in late summer/early autumn, with values around 280 Dobson Units (DU), and seasonal maximum in springtime, with values around 370 DU.

The Arrival Heights data (Figure 5) show a seasonal pattern with a minimum in September or October, which is due to the Ozone Hole. The seasonal maximum occurs in late November or early December, when the Ozone Hole breaks up. The lowest ozone value recorded at Arrival Heights with D#17 is 115 DU (on 29 September 2009).

The D#17 data are available from the World Ozone and Ultraviolet Data Centre (https://woudc.org/) and the Network for the Detection of Atmospheric Composition Change (http://www.ndsc.ncep.noaa.gov/data/).

6. Changing focus of ozone research

From the mid-1970s, when the possible link between ozone depletion and increasing chlorine in the atmosphere was first put forward (Molina and Rowland, 1975), the focus of ozone measurement largely changed to studying ozone trends. The first real evidence of ozone depletion came with the discovery of the so-called Antarctic Ozone Hole (Farman et al., 1985; Chubachi, 1985). The first reported Antarctic Ozone Hole measurements were from the Dobson spectrophotometer at Syowa (69.00° S, 39.58° E) station, where values dropped to about 210 DU during October 1982 (Chubachi, 1985). The significance of those measurements, which were presented at the Ozone Commission Symposium in Halkidiki in 1984, was not fully recognized at the time. Farman et al. (1985) presented measurements from the Dobson spectrophotometers at Halley Bay (75.61° S, 26.20° W) and Argentine Islands (65.25° S, 64.27° W) stations for the period 1957 through to 1984. Those measurements clearly showed that the October total ozone values for the period 1980-1984 were much lower than for the period 1957-1973.

A later study, using ozone measurements made by satellites, showed a decrease in total column ozone on a global scale (Stolarski et al., 1991). Data from the Dobson network also indicated that the total column ozone had decreased on a global scale since 1979 (McPeters and Komhyr, 1991), although to a lesser extent than suggested by the satellite data. Analysis of the Invercargill measurements (Farkas, 1989; Nichol and Coulmann, 1990) show a decrease of about 0.8% per year from 1980 to 1987, which is very similar to that reported for the Australian Dobson stations (Atkinson and Easson, 1989) over the same period.

The study of ozone trends requires good quality ozone time series, preferably extending back in time over decades, and thus builds on the hard work of numerous researchers over many years. The importance of the work by the early researchers was not always fully recognised at the time, as for example is indicated in the acknowledgements in Stolarski et al. (1991): "We would also like to thank Arlin Krueger, the Principal Investigator for TOMS, who persisted for many years when nobody cared about the TOMS data".

In 1988, the World Meteorological Organisation (WMO) recognised 26 ozone researchers for the major contribution they had made to ozone research over the preceding 30 years (Bojkov and Fabian, 1989). One of those recognised was Edith Farkas who, as already mentioned, worked with D#17 from the mid-1950s through to her retirement from NZMS in 1986. Over that time she established a regular and reliable ozone measurement programme with D#17, and produced many publications. She published the first measurements from D#17 (Farkas, 1954 and 1958), and her last publication (Farkas, 1989), which analysed the Kelburn and Invercargill total ozone measurements for the period 1965 to 1987, was published after her retirement from NZMS.

7. The Montreal Protocol

As already stated, in the mid-1970s it was postulated that there was a link between ozone depletion and increasing chlorine in the atmosphere (Molina and Rowland, 1975). International concern about the ozone layer increased over time, and resulted in the signing of the Vienna

Convention on the Protection of the Ozone Layer in 1985. This was an agreement to do something about ozone depletion. It set up the framework which led to the Montreal Protocol, which set targets for reducing the production and consumption of ozone depleting substances. The Montreal Protocol was signed in 1987 and it came into effect in 1988. As a result, atmospheric concentrations of ozone depleting substances reached a maximum in the late 1990s, and have been declining since then (Staehelin et al., 2018)

Ozone measurements, including those from the Dobson network, feed into the WMO/United Nations Environmental Program Scientific Assessments of Ozone Depletion (e.g. WMO, 2014), which measure the success of the Montreal Protocol. We intend to keep D#17 operating at Arrival Heights to monitor Ozone Hole developments. The D#17 measurements have been used in modelling studies (Bodeker et al., 2001; Nichol et al., 2003; Oman and Douglass, 2014; Fogt and Zbacnik, 2014) and satellite validation studies (Wood et al, 2002; Bramstedt et al., 2003; Kuttippurath et al., 2018).

Acknowledgements

D#17 has been in operation in New Zealand (and territories) for nearly 70 years. There have been at least 100 people who have worked with the instrument over that time, which is too many to name individually, and also the names of many of those involved in the early years are unknown to us. However we would like to acknowledge those that we do know about. First and foremost, we sincerely thank Edith Farkas for her great work and commitment in establishing a reliable measurement programme. Many of the details about the early operations with D#17 come from her notes. Thanks are also due to the staff at the NZMS Invercargill office, including Dick Holloway and Keith Herrick. The measurements at Arrival Heights have been very well supported by Antarctica New Zealand with logistical and technical support (involving at least 60 operators). Tom Clarkson and Stephen Wood (NIWA) also contributed to the Arrival Heights operation. There are also many international collaborators who have worked with D#17; in recent times they have been: Bob Grass and Walter Komhyr (NOAA) for the 1984 overhaul; Jim Easson and Steve Rhodes (Australian Bureau of Meteorology) for Dobson inter-comparisons; Bob Evans and Koji Miyagawa (NOAA) for the instrument automations.

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