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Data Set Description:

PI	Gerald Nedoluha
Instrument	Ground-based 110 GHz microwave spectrometer
Site(s):	Mauna Loa, Hawaii
	Lauder, New Zealand
Measurement Quantities:	Mixing ratio profile of O3

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DOI: The following DOI was issued for the MOPI1 Lauder dataset for Bernet et al. (2021): https://evdc.esa.int/publications/genbpqv-7z42/ under the creative commons license https://creativecommons.org/licenses/by-nc-sa/4.0.

Reference Articles:

Parrish, A., B.J. Connor, J.J. Tsou, I.S. McDermid, and W.P. Chu (1992): "Ground-based Microwave Monitoring of Stratospheric Ozone", J. Geophys. Res., Vol 97 (D2), p.2541-2546, February 20, 1992.

Parrish, A. (1994): "Millimeter-wave Remote-Sensing of Ozone and Trace Constituents in the Stratosphere", Proceedings of the IEEE, 82 (12), p.1915-1929, December, 1994.

Connor, B.J., A. Parrish, J.J. Tsou, and M.P. McCormick (1995): "Error Analysis for the Ground-based Microwave Ozone Measurements During STOIC", J. Geophys. Res., Vol 100 (D5), p.9283-9291, May 20, 1995.

Tsou, J.J., B.J. Connor, A. Parrish, R.B. Pierce, I.S. Boyd, G.E. Bodeker, W.P. Chu, J.M. Russell III, D.P.J. Swart, T. McGee (2000): “NDSC millimeter wave ozone observations at Lauder, New Zealand, 1992-1998: Improved methodology, validation, and variation study”, Journal of Geophysical Research 105(D19): 24263-24281.

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Parrish, A., et al. (2014): “Diurnal variations of stratospheric ozone measured by ground-based microwave remote sensing at the Mauna Loa NDACC site: measurement validation and GEOSCCM model comparison”, Atmos. Chem. Phys., 14, 7255–7272.

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Bernet, Leonie, Ian Boyd, Gerald Nedoluha, Richard Querel, Daan Swart, and Klemens Hocke (2021): “Validation and trend analysis of stratospheric ozone data from ground-based observations at Lauder, New Zealand”, Remote Sens. 2021, 13(1), 109; https://doi.org/10.3390/rs13010109.

Instrument Description:

The instrument is a microwave spectrometer observing atmospheric thermal emission at 110.8 GHz from the ground. It consists of a cryogenic heterodyne receiver and spectrometer, and records the spectral lineshape of an ozone rotational transition every 20 - 30 minutes. To eliminate systematic instrumental artifacts such as differences in gain across the spectrometer's bandwidth, observations are made in a switched mode, the instrument looking alternately at the zenith (reference beam) and at about 10 to 20 degrees elevation (signal beam). Observations continue 24 hours a day whenever weather permits. An ozone mixing ratio profile as a function of pressure can be retrieved from each of the ozone spectra obtained. Averages of the spectral data over about 6-hour periods are processed routinely.

MOPI1 (Lauder) and MOPI2 (Mauna Loa) used a filterbank spectrometer consisting of 120 channels over 626 MHz. The filters were 10 MHz wide in the line wings, and progressively narrowed (5 MHz, 1 MHz, 250 kHz, 125 kHz, and 50 kHz (MOPI2 only) closer to the line center, where greater resolution was needed. The MOPI3 (Mauna Loa) backend consists of a Fourier Transform spectrometer (FTS) with 16384 channels over 1 GHz, providing 61 kHz resolution. Please refer to the Measurement History section for important details regarding measurements made with the AC240 FTS between Jan 1st, 2016 and May 8th, 2017. The next generation MOPI4 and MOPI5 instruments are in the process of being commissioned. MOPI5 is deployed and currently undergoing testing at Mauna Loa. The main change in these new systems is the transition to room temperature receivers.

Algorithm Description:

An ozone mixing ratio profile (ppmv) from 56hPa to 0.05hPa (or 20 - 68 km) is retrieved for every 6-hour period (although actual integration times may vary from 40 minutes to 6 hours depending on atmospheric conditions), using a semiempirical optimal estimation retrieval method based on Rodgers (Rev. Geophys. 14, 608, 1976). For every 24-hour continuous observation, up to four ozone profiles (two for daytime and two for nighttime) per day result, and are reported to the NDACC database. We have also generated hourly retrievals for the Mauna Loa time-series for studies of diurnal ozone variability (Parrish et al., 2014) that are available on request. While the additional channels available with the FTS can provide some additional information relative to the filterbank spectrometer, in the v6 retrieval these channels are mapped, as closely as possible, to the frequencies of the filterbank spectrometer.

L0/L1: L0 measurements, consisting of the raw data collected by the instrument logging program, are housed on the Bryan Scientific Consulting LLC server 'Zenith', at NRL and locally on each machine.

<u>Expected Precision/Accuracy of Instrument:</u>
The general expected precision is 4 - 6%, and accuracy 5 - 9%, for nightime ozone profiles and daytime ozone profiles in the stratosphere. The accuracy of ozone profiles in the lower mesosphere could go up to 12 - 17% for nighttime profiles and 17 - 22% for daytime profiles. The precision, accuracy, and vertical resolution for each ozone profile at each retrieved pressure level are reported in the data set. Uncertainty estimates for Mauna Loa are discussed in Connor et al. (1995) and for Lauder in Tsou et al. (2000).

<u>Notes on Version 6 Processing:</u>
This version incorporates corrections to the spectral baseline based on measurements of this baseline made regularly through the timeseries of both instruments. For the instrument at Mauna Loa the spectral baseline has remained largely unchanged through the timeseries, and the effect on the retrievals is small compared with the previous processing versions. For the instrument at Lauder there were significant changes to the baseline during 1994-1995 and 2003-2004, as described below, resulting in steps in the timeseries in earlier versions. These biases are reduced in this processing version to the extent that we no longer suggest applying offsets to the ozone profiles.

<u>Notes on Version 5 Processing (not available on NDACC):</u>
This version incorporates several changes over Version 4 - most significantly the extension of the forward model from ~80 km to ~110 km - which fixes the problem present in the v4 datasets (especially Mauna Loa) above about 60 km (see below).
Other changes include:
Improved characterization of the individual filters; New temperature profiles consisting of a composite of NCEP/NCAR reanalysis, NCEP, Lidar average or climatology, and MSISE-00 model profiles are used in the forward model. Analysis of the various temperature measurements has been undertaken to attempt to ensure homogeneity of the temperature time-series.

<u>Known Issues with Version 5 dataset</u>
Changes in the spectral baseline characteristics are apparent in the Lauder time-series, and are not currently accounted for. The most obvious changes in the spectral baseline occur during the period

when the Lauder instrument was tested and serviced at the Table Mountain Facility during 1994 to 1995, and after the receiver failed in 2003. Between 1994 and 1995 there is a step of the order of 4 to 6% in the ozone retrieval at the lowest reported altitudes (56 hPa and 42 hPa). After the instrument was repaired in 2004, a step in the time-series is present between 42 and 18 hPa. Boyd et al. [2007] have determined approximate offsets based on averaging before and after differences between the Lauder MWR and ozonesonde, lidar, and GOMOS during this period. For the purposes of time-series analysis, therefore, data at these levels should be used with caution. Work is currently being undertaken to attempt to better characterize the spectral baselines of both instruments, and this is expected to be implemented in the upcoming version 6 level processing.

Notes on Version 4 Processing (not available on NDACC):
This is a uniformly processed dataset with the exception of the period September 1993 to October 1994 at Lauder which contains less spectral information near the line center, resulting in higher retrieval errors at high altitudes. At low altitudes (56 hPa and, to a much lesser extent, 42hPa) there is a small drift in the retrieved ozone values due to changing characteristics of the spectral baseline with time.

This version contains a problem which mostly affects the Mauna Loa measurements above about 60 km, resulting in ozone retrievals that are too high at 75 km and too low at 65 km. This is due to a combination of the filter configuration of the instrument at Mauna Loa and the altitude range covered by the forward model.

The filter configurations in the Lauder and Mauna Loa instruments are essentially identical except for one important difference. Included in the filter sets in both instruments is a pair of filters located at offsets of + and - 125 kHz from the ozone line center, with bandwidths of 50 kHz. That is, they pass signal primarily between -150 and - 100 kHz, and between +100 and +150 kHz with respect to the line center, but reject most of the signal from the line center itself. In the Mauna Loa instrument only, there is one additional channel that has a bandwidth of 250 kHz and is centered on the line center. That channel dominantly sees signal from the "core" of the line that is mostly missed by the channels at +/- 125 kHz.

This version uses a 36 level model during the retrieval, with the highest level at .01 hPa, or about 80 km. In reality, the Mauna Loa instrument sees the signal contributed by ozone above that level, if there is any, but the Lauder instrument mostly does not see that contribution, because it lacks the central channel. Above about 75 km the pressure broadening of ozone is smaller than the Doppler broadening so the measurement can't distinguish where the signal is coming from above that altitude. The retrieved profile at .01 hPa is therefore influenced by any ozone above, which makes the measured signal in the line core larger than the amount calculated from the a priori by the forward model. The Mauna Loa retrieval therefore tends to overestimate the ozone amount at .01 hPa, (with a corresponding over-compensation at 0.1 hPa) and to do so more than the Lauder one, because the latter mostly does not see the line core signal.

Version 4 ozone measurements above about 60 km should not be used for comparison purposes at Mauna Loa.

Measurement History:

MOPI1:

July 1989	-	June 1992	:	Table Mountain, CA
July 1992	-	August 1992	:	Observatory of Haute Provence, France
October 1992	-	October 1994	:	Lauder, New Zealand
November 1994	-	March 1995	:	Table Mountain, CA (instrumentation test)
April 1995	-	November 200	:	Lauder, New Zealand
December 2003	-	April 2004	:	Amherst, MA (receiver repair and upgrade)
May 2004	-	October 2016	:	Lauder, New Zealand

Decommissioned on October 11th, 2016

MOPI2:

August 1994	-	July 1995	:	Table Mountain, CA (instrumentation test)
August 1995	-	May 2015	:	Mauna Loa, HI

MOPI3:

May 2015 - May 2017 : Mauna Loa, HI. The MOPI2 receiver is retained but the optics panel has undergone modification and the filterbank spectrometer is replaced with an AC240 FTS. There is a low bias associated with the AC240 spectrometer (Sauvageat et al., 2021). To account for this, spectra have been scaled by 1.047 as part of the calibration before doing the retrieval. These retrievals, covering the period January 1st, 2016 to May 8th, 2017 were submitted to NDACC in September 2020.

May 2017 - October 2022 : Mauna Loa, HI. FTS replaced with model U5303a, which removes the bias associated with the AC240 spectrometer. MOPI3 was shutdown in October 2022, with the intention of replacing it with MOPI5, however this was disrupted due to a volcanic eruption on Mauna Loa in November 2022 resulting in loss of power and access to the site.

MOPI5:

June 2024 onwards : Mauna Loa, HI. Power restored to the MWR building via solar panels allowing the installation of MOPI5 to be completed. Currently undergoing testing and diagnostics.