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(NASA-CR-155561) PERFORMANCE EVALUATION OF
ELECTROCHEMICAL CONCENTRATION CELL
OZONESONDES (Drexel Univ.) 28 p HC A03/MF
A01

N78-16340

CSCL 14B

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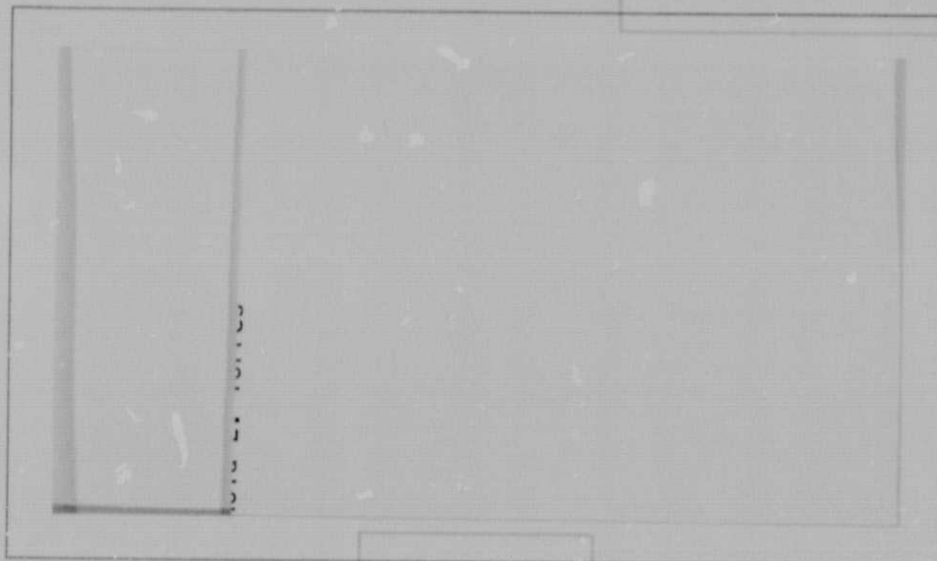
Drexel
University

Performance Evaluation of

Electrochemical Concentration Cell Ozonesondes

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ABSTRACT

Laboratory calibrations of more than a hundred Electrocnemical Concentration Cell (ECC) Ozonesondes have been determined relative to UV-photometry. The average intercept and slope, 0 ± 5 nb and 0.96 ± 0.06, respectively, indicate reasonable agreement with UV photometry, but with considerable variation from one ECC ozonesonde to another. The time required to reach 85% of the final reaction to a step-change in ozone concentration was found to average 51 seconds. Application of the individual calibrations to 20 sets of 1976 flight data reduced the average of the differences between ozonesonde and Dobson spectrophotometric measurements of total ozone from 3.9 to 1.3%. A similar treatment of a set of 10 1977 flight records improved the average ECC-Dobson agreement from -8.5 to -1.4%. Although systematic differences were reduced, no significant effect on the random variations was evident.

INTRODUCTION

Electrochemical concentration cell (ECC) ozonesondes were developed by Komhyr (1,2) for use in obtaining vertical profiles of atmospheric ozone. The ECC sensor is based on an iodine/iodide redox cell in which ozone is consumed in the oxidation of iodide ions to molecular iodine. The newly formed iodine is rapidly converted back to the iodide form in a cell reaction driven by the iodide concentration differential between the anode and the cathode compartments. An electrical current proportional to the mass flow-rate of ozone into the cell is thus generated in the cell circuitry.

Although ECC ozonesondes have been commercially available[*] and extensively used for several years, there is relatively little published information concerning the accuracy and precision of these instruments. Komhyr reported in one of the early development publications (2) that "several" ECC sensors tested relative to a UV-calibrated ozone source agreed with the source calibration to within ±5%. Komhyr also gave the results of a test, involving six sensors, to determine the consistency from one sensor to another. Deviations about the means of 1.2, 1.7, and 4.5 percent were observed at ozone levels of 4.95, 12.90, and 19.87 pphmv, respectively (2).

The significant increase in attention focused upon stratospheric ozone in recent years has suggested the need for more thorough evaluations of instruments used in atmospheric ozone soundings. Since atmospheric soundings are carried out with a variety of sensors developed around several different chemical and physical principles, it is essential that their interrelations be known. Although dual instrument flights are useful and informative, it is important that laboratory studies be carried out using standards of proven performance.

This report describes some of the results of a program initiated, with the cooperation of NASA's Wallops Flight Center, to evaluate performance characteristics of the ECC ozonesonde. A part of this program involved the installation of a calibration laboratory through which each ozonesonde was processed prior to its flight.

ECC ozonesondes calibrations were carried out relative to UV pho-

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tometry, using a Dasibi[*] ozone monitor as a convenient transfer standard. Recent studies (3,4) have shown good agreement between UV photometry and two other absolute methods of measuring ozone, long-pathlength infrared absorption and gas-phase titration. The ozonesonde calibration data should thus be of considerable interest to users of ECC ozonesondes, both to establish absolute accuracy and to better interpret experiments involving more than one type of sensor.

The results of calibrating over one hundred ECC ozonesondes, some more than once, are reported here. Statistical data is presented to illustrate the precision or repeatability from one ECC ozonesonde to another. Some preliminary results of a study designed to evaluate the effects of upper-atmosphere environments on ECC ozonesonde performance are presented.

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[*] Dasibi Environmental Corp., 616 E. Colorado St., Glendale, Ca. 91205

EXPERIMENTAL

UV Ozone Photometer. A diagram of the UV photometer is shown in Figure 1. A three meter absorption cell was constructed from 2.54 cm id glass tubing. Quartz windows were attached at the ends with epoxy cement. Inlet and outlet tubes were located approximately one cm from the ends.

A vycor-jacketed low-pressure mercury lamp (replacement lamp for Dasibi ozone instrument) and two type G-774-330 Oriel Corporation band-pass filters were used to produce and isolate 254-nm light. Although AC operation of the mercury lamp necessarily introduces ripple into the detected signal, DC operation results in a progressively decreasing output. To enhance both long- and short-term signal stability, the lamp was powered with a 1 kilohertz power supply (Figure 2). The detector output signal was filtered with a 1.4 s time constant. The lamp was further stabilized by enclosing it in an aluminum block and regulating its temperature with a Model 72 RFL Industries proportional controller.

Before entering the absorption cell, the 254-nm light was collimated using a 25-cm focal length quartz lens. The light exiting the absorption cell was detected by a Hamamatsu R166 photomultiplier tube in a Model PR-1402-RF Products for Research housing. The PM tube was operated at -350 volts with a Model S-326 NJE Corporation power supply. The filtered signal was manually read with a 5½-digit Model 8300A Fluke digital multimeter.

Ozone was generated by passing zero-grade air at 5 l./min. through a quartz cell positioned adjacent to a two-inch low-pressure mercury lamp (Ultraviolet Products). An adjustable lamp shield allowed control of the ozone concentrations over the range 0-200 ppbv.

Ozone concentrations were computed from the UV data using the relation

1)
$$[O_3](ppbv) = \frac{10^9 \, T}{273 P k L} \, \log \frac{I_o}{I}$$

where

    T = temperature in degrees Kelvin

    P = total pressure in atmospheres

    k = absorption coefficient - 135 cm^{-1} atm^{-1} (3)

    L = pathlength in centimeters

    I_o = intensity with ozone-free air

    I = intensity with ozonated air.

Detector readings with ozone in the cell were sandwiched between readings taken with ozone-free air in the cell. To account for a slow drift in the detected signal, the time of each measurement was recorded. Linear regressions of I_o data, taken before and after I data, were used to calculate I_o corresponding to the time at which I was measured.

ECC Ozonesonde Calibration Apparatus. The equipment used in calibrating the ECC ozonesondes is shown in Figure 3. Zero-grade air was ozonated using a generator similar to that described above. A 4 l./min. flow-rate of air containing ozone in the range 0-250 ppbv was directed into a glass manifold system having several sampling ports. A Dasibi Environmental Corporation Model 1003AH ozone monitor and either one or two ECC ozonesondes simultaneously sampled the contents of the manifold. These instruments collectively consumed about one half of the 4 l./min. manifold flow, the remainder being vented.

The ozonesonde was electronically coupled to a 1680 MHz meteorological radiosonde for data transmission to a nearby receiver. The detected signal was converted to an analog voltage and recorded on a strip-chart recorder.

Calibration Procedure. Prior to calibration each ozonesonde underwent the pre-flight preparations suggested by the manufacturer (5,6). Ozone concentrations of about 0, 120, 250, 200, 160, 80, 50 and 0 ppbv (in that order) were used in the calibrations. Ozone concentrations were derived from the recorded data in the same manner as from flight records (5,6). A BASIC language program carried out the data reduction and statistical analysis.

Following the calibration, the radiosonde was disconnected and a 5 mv recorder connected across the 1 KΩ cell load resistor. The ozone concentration was then stepped form 0 to 120 ppbv and, after 10 minutes, back to 0 ppbv. The time dependence of the sensor signal following the step changes in ozone levels was used to determine the response time of the sensor.

Environmental Chamber. The chamber used to simulate vertical temperature profiles was constructed by lining a 30 X 30 X 30 inch plywood box with one-inch sheets of styrofoam. The chamber was cooled by the injection of liquid CO_2. To avoid the ingestion of solid CO_2 particles by the

ozonesonde intake system, a 300 cm^3 min^{-1} (STP) flow of dry air was brought into the chamber and through a 10-foot section of 0.25 inch OD copper cooling coil. The ozonesonde intake tube was positioned into the open end of the coil tube. Small thermocouples were used to monitor temperatures of the chamber, the air exiting the cooling coil, the air inside the ozonesonde container, and the ozonesonde inlet gas just prior to entering the pump.

The chamber system was interfaced to a PDP8/E minicomputer which monitored the chamber temperature and controlled the liquid CO_2 valve. Under computer control, a 110 minute "flight" was simulated with respect to the chamber temperature, while recording the thermocouple signals on a pair of dual-channel strip-chart recorders.

RESULTS AND DISCUSSION

Ozonesonde Problems.   A large number of ozonesondes calibrated in early 1977 had extremely long response times, from 8 to considerably greater than 10 minutes for 90% response to step changes in ozone levels. Replacing the cathode solution with solution from the same stock bottle from which the original was drawn markedly shortened the response time, to the order of one minute (Figure 4). Upon standing overnight the response time lengthened considerably. It would thus appear that these sensor cells were seriously contaminated during the manufacturing process. Although the cathode solution is generally changed just before flight, it is uncertain what effects, if any, this problem would have on the sensors' performance. Fifteen of these ozonesondes, listed in Table 1, were flown before analysis of their calibration data was started. When the data was processed, it was discovered that the ozonesondes were still far from equilibrium each time the ozone concentration was shifted to the next level. Consequently there is no valid calibration data available for these instruments.

Table 1 also lists 8 other ozonesondes for which calibration data was not processed. The records of two ozonesondes exhibited such extremes of electronic noise that meaningful data could not be obtained. Electronic noise pickup caused considerable problems during one period, but the manufacturer seems to have resolved the problem by minor circuitry changes and by recommending an increased separation between the ozonesonde and radiosonde.

Data for the remaining six ozonesondes in Table 1 were not processed for reasons of human errors at the time of calibration. These generally involved failure to record temperature data, or not allowing the ozonesonde sufficient time to reach equilibrium following a change in ozone concentration.

In addition to the items discussed above, which resulted in the loss of calibration data, lesser mechanical or electronic problems requiring replacements or repairs frequently occurred. A survey of 100 worksheets for 3A series ozonesondes indicated that some type of problem existed in one out of five of this sample group. Most of these problems (11) involved poor contact between the wiper and stationary portion of the commutator switch. The remaining problems were distributed in such areas as defective sensor cells or pumps and poor solder connections.

The problems mentioned in this section include only those involving ozonesondes for which calibrations were attempted. It does not include any for which written records were not made.

Calibrations and Intercomparisons of Dasibi Instruments. The work to be discussed here involves four Dasibi Environmental Corporation ozone monitors, one of which is located at Drexel University, and three of which are at NASA's Wallops Flight Center. It is convenient to define the following symbols:

DD = Drexel Dasibi, Serial #1390
WD1 = Wallops Dasibi, Serial #1190, NASA #W21896
WD2 = Wallops Dasibi, Serial #1706, NASA #W23415
WD3 = Wallops Dasibi, Serial #1715, NASA #W23414

Although the Dasibi instrument is based on UV absorption, it does not represent an absolute technique for measuring ozone. Because of several design considerations, the pathlength and cell temperature are not precisely definable. Consequently a front-panel control (SPAN) is made available which can be used to adjust the instrument's calibration to match an external calibration source.

The SPAN control of Dasibi instruments manufactured at the time DD and WD1 were produced was factory set relative to the 1% neutral buffered potassium iodide method (7), following reference method guidelines set forth by the U.S. Environmental Protection Agency (8). Studies have since shown that the NBKI method reads as much as 30% too high, depending on the procedure (3). In recognition of this, the SPAN control of newer Dasibi instruments such as WD2 and WD3 is set by the manufacturer relative to UV photometry.

To determine the absolute calibration of the older units DD and WD1, the UV photometer, described in a earlier section of this report, was constructed. The Drexel unit, with SPAN at the factory setting of 68.6, was calibrated over the range 10 to 175 ppbv. The possibility of ozone losses in the system was checked by taking points both upstream (72) and downstream (62) of the absorption tube.

A linear regression of the upstream data gives

2) $[O_3]_{DD} = -10 \pm 1 + (1.286 \pm 0.014) [O_3]_{UV}$,

while the downstream data yields

3) $[O_3]_{DD} = -12 \pm 1 + (1.299 \pm 0.011)[O_3]_{UV}$

where concentrations are expressed in ppbv and uncertainties represent one standard deviation. Since the upstream and downstream results are the same within experimental uncertainties, they were combined to produce

4) $[O_3]_{DD} = -11 + 1.293 [O_3]_{UV}$

The negative intercept is thought to originate from electronic noise generated within the Dasibi instrument during switching of a solenoid, and has been substantially reduced in newer instruments (7). An offset control has also been added to allow the user to null out this intercept. The large slope is probably due to a combination of NBKI calibration and compensation for the negative intercept.

Since the Wallops instrument WD1 was used in the ECC ozonesonde calibrations, it was calibrated relative to the Drexel Dasibi by simultaneously coupling both instruments to an ozone generator. Four comparisons were carried out over a 19 month period, taking an average of 33 data points over the range 2 to 340 ppbv. The mean result was

5) $[O_3]_{WD1} = 2 \pm 5 + (1.000 \pm 0.013) [O_3]_{DD}$

where ppbv concentration units are used and uncertainties represent one standard deviation about the mean intercept and the slope. Combining equations 4) and 5) gives

6) $[O_3]_{WD1} = -9 + 1.29 [O_3]_{UV}$.

To substantiate the UV calibration of the Drexel Dasibi and the use of the latter as a transfer standard between UV photometry and Wallops Dasibi WD1, consider the results of intercomparisons involving the older WD1 and two newer instruments, WD2 and WD3, the SPAN controls of which were factory set relative to UV photometry. During a three month period WD2 was calibrated against WD1 twice (averaging 23 data points over the range of 3 to 350 ppbv), while WD3 was calibrated against WD1 three times (averaging 55 data points over the range 6 to 310 ppbv). The results were:

7) $[O_3]_{WD2} = 6 \pm 1 + (0.796 \pm 0.003) [O_3]_{WD1}$

and

8) $[O_3]_{WD3} = 6 \pm 1 + (0.804 \pm 0.011) [O_3]_{WD1}$.

Combining equation 6) with each of equations 7) and 8) gives

9) $[O_3]_{WD2} = -1 + 1.03 \, [O_3]_{UV}$

10) $[O_3]_{WD3} = -1 + 1.04 \, [O_3]_{UV}$

The two newer instruments with calibrations factory set relative to UV photometry, are thus seen to be in agreement, within propagated errors, with the Drexel UV photometer.

ECC Ozonesonde Calibrations. The results of applying equation 6) to the ECC ozonesonde vs WD1 Dasibi data are given in Table 2. When the intercepts and slopes are averaged, the result is

11) $[O_3]_{ECC} = 0 \pm 5 + (0.96 \pm 0.06)[O_3]_{UV}$

where ozone concentrations are now expressed as nanobars partial pressure and the uncertainties represent one standard deviation about the mean. The agreement between ECC and UV when large numbers of calibrations are averaged, is reasonably good. Although this appears to contradict earlier references to a disagreement between neutral buffered KI methods (in which category the ECC ozonesonde belongs) and UV photometry, it should be recalled that NBKI methods are dependent upon several variables including composition of the sensing solutions. The composition of the solutions recommended (5,6) for use in ECC ozonesondes was originally chosen for agreement between total ozone obtained using ozonesondes and that obtained from Dobson ozone spectrometers (9).

Although the ECC ozonesonde was shown above to closely follow UV photometry on the average, the variations from one sonde to another could be of some concern to users of these instruments. In order to determine how much of the apparent variations are real and how much are due to outside factors such as drifts in the calibration equipment, 46 calibrations were carried out in pairs (listed in Table 3). During dual calibrations, two ozonesondes and the WD1 Dasibi simultaneously sampled the ozonated airstream. Variations between pair slopes and between pair intercepts should therefore be indicative of real sonde-to-sonde differences.

The average deviations between pair slopes and between pair intercepts observed among the ozonesondes listed in Table 3 were found to be 0.045 and 3.1 respectively. If the 46 slopes and the 46 intercepts are

averaged, the standard deviations about the means are found to be 0.041 and 2.6. The scatter from one sonde to another within a simultaneously calibrated pair is then essentially the same as the scatter observed between sondes calibrated at different times. The observed variations between ECC ozonesondes thus appears to be real, with relatively little contribution from outside sources.

It is of interest to compare 1976 data from Table 2 with that obtained in 1977. The 1976 data, obtained using 2A series ozonesondes, averages to

12) $[O_3]_{ECC} = 4 \pm 8 + (0.95 \pm 0.08) [O_3]_{UV}$

while that of 1977, obtained for the most part with a 3A series ozonesondes, averages to

13) $[O_3]_{ECC} = -2 \pm 3 + (0.96 \pm .06) [O_3]_{UV}$.

A substantial improvement in precision is obvious. The cause of this change is not clear, but several minor changes in both the ozonesonde design and preflight preparation procedure (5,6) were made.

Multiple Calibrations. An effort was made to determine calibration stability for the ozonesondes. Several units (indicated by multiple listings in Table 2) were calibrated more than once, from two days to three months apart. The variation observed in the slope of a particular ozonesonde was found to average 4.6%, compared to an overall 7.0% variation observed when the multiple calibrations were all averaged together. Comparable figures for the intercepts are 2.7 and 4.7 nb, respectively. Time variations in a particular ozonesonde's calibration are thus seen to be somewhat less than the variation from one ozonesonde to another; indicating at least a moderate stability. It is difficult to judge precisely how much of the variations are due to real calibration changes and how much are simply the result of propagated errors from the several sources associated with the use of this instrument.

Other ECC Ozonesonde Calibrations. In addition to the large number of ozonesonde calibrations discussed above, 12 calibrations were carried out relative to WD3 (SN1715, NASA W23414). Although the calibration of this instrument can be related to the Drexel UV photometer through equation 10), the extra propagation of errors involved probably makes this approach

less reliable than depending upon the factory's calibration (relative to UV). The results of these calibrations are therefore treated separately and listed in Table 4. These results average to

14) $\qquad [O_3]_{ECC} = 5 \pm 4 \text{ nb} + 0.99 \pm 0.06 \; [O_3]_{Desibi}$

Response Times. Table 2 lists the times required for the ozonesondes to complete 85% of their reaction to a step change in ozone. The mean value obtained in these measurements (51 seconds) is a little more slug-gish than earlier measurements indicated (2), resulting in a diminished ability to resolve the fine structure in the vertical ozone profile. The response curve is not exponential, but more closely follows the form

15) $R = \dfrac{k_1 t}{1 + k_2 t}$

where R is the time-dependent response following a step change in ozone, and the k's represent constants.

Application of Calibrations to Atmospheric Soundings.   The following paragraphs will describe the results of applying the ECC ozonesonde vs UV photometry calibrations to data obtained during atmospheric soundings from Wallops Flight Center. Of particular interest is the influence of calibrations on the agreement between total ozone derived from ozonesondes and that obtained from Dobson spectrophotometric measurements. At the time of this writing, sufficient information to carry out this comparison was available for 30 soundings, 20 from 1976 and 10 from 1977 flights.

The total ozone values listed in Table 4 are those provided by WFC.

Also listed are the Dobson readings and the deviation of the ozonesonde total ozone from the Dobson data.

The ECC ozonesonde data was corrected to UV by means of the relations

17) $[O_3]_{ECC} = A_0 + A_1 [O_3]_{UV}$

and

18) $d\Omega \text{ (atm-cm)} = \frac{1}{550} [O_3] \, dlogP$

where ozone concentrations are expressed in nb and Ω represents total ozone. The A_0 and A_1 terms in equation 17) represent the intercepts and slopes, respectively, from Table 2. Thus, letting Ω_{ECC} represent the total ozone obtained by integrating between 1 and 1000 mb,

19) $\Omega_{ECC} = \frac{1}{550} \int_{P=1}^{P=1000} [O_3]_{ECC} \, dlogP$

$= \frac{1}{550} \int_{P=1}^{P=1000} (A_0 + A_1 [O_3]_{UV}) \, dlogP$

$= \frac{3A_0}{550} + A_1 \, \Omega_{UV}$

Rearranging equation 18) to

20) $\Omega_{UV} \text{ (atm-cm)} = \frac{1}{A_1} \left[\Omega_{ECC} \text{ (atm-cm)} - \frac{3A_0}{550} \right]$

allows a simple calculation of the UV-corrected total ozone. Table 5

lists the results of correcting the total ozone data to UV by means of equation 20).

Applying the UV correction reduces the average percentage difference between the ozonesonde total ozone and the Dobson value from 3.9 ± 9.6 to $1.3 \pm 17.6\%$ for the 1976 data. The increased variation about the mean after the correction is made principally results from two of the twenty ozonesondes (2A359 and 2A348) which deviated from the Dobson by 40 and 48%. The reason for this discrepancy is unclear, but if these two points are omitted from the data set, the figures change to $3.2 \pm 9.7\%$ for uncorrected sonde data, and $1.9 \pm 10.6\%$ for UV corrected data.

Applying the UV corrections also significantly reduces the average difference between 1977 sonde and Dobson total ozone values from $-8.5 \pm 8.2\%$ to $-1.4 \pm 7.3\%$. The corresponding quantities for all data (1976 and 1977) averaged together are $-0.3 \pm 10.8\%$ (uncorrected) and $0.4 \pm 14.8\%$ (corrected).

The data given in Table 5 and summarized above demonstrate that the UV corrections significantly reduce systematic differences between ozonesonde and Dobson total ozone values. The random variations remain of the same order. The latter is probably a consequence of accumulated uncertainties associated with calibration instabilities, data acquision and reduction (ozonesonde and Dobson), and integration of the ozone profiles.

Environmental Effects on Performance. The use of equation 16) to compute ozone concentrations from flight data is based on the assumption that the gas being sampled, perhaps initially at -50° C, warms to the level of T_B (perhaps 20° C) during a residence time of less than 0.1 second in the inlet tube. To test this assumption, the chamber described in an earlier section of this report was used to simulate a vertical temperature profile approximating that encountered during a typical ozonesonde flight.

Some very preliminary results from this experiment suggest the possibility that ozonesondes may indicate ozone values about 3% too high at altitudes above 200 mb. More careful experiments along these lines are planned, along with the construction of a chamber capable of simultaneously simulating temperature and pressure profiles.

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Table 1. Ozonesondes for which calibration data were not processed.

Slow response	Missing data	Electronically noisy
3A001	2A076	2A097
3A002	2A244	2A321
3A003	2A363	
3A004	2A364	
3A005	2A365	
3A006	2A372	
3A007		
3A008		
3A009		
3A010		
3A011		
3A013		
3A017		
3A018		
3A019		

Table 2. ECC Ozonesonde calibration relative to ultraviolet absorption
          at 254 nm.

Sonde #	Calib Date	Intercept (nb)	Slope	85% Response Time (S)
2A093	8/31/76	1.1	0.983	
2A099	7/7/76	-3.1	0.940	
2A201	5/11/75	4.4	1.007	
2A202	6/22/76	1.9	0.896	
2A205	4/21/76	9.0	0.826	
2A223	6/2/76	-5.5	0.914	
2A224	6/8/76	12.4	0.971	
2A226	4/27/76	17.2	0.980	
2A227	10/26/76	4.2	0.913	
2A228	5/25/76	17.6	0.941	
2A229	5/4/76	9.9	0.962	
2A230	5/20/76	4.0	0.902	
2A233	4/7/76	13.9	0.909	
2A235	6/8/76	0.1	0.966	
2A235	6/11/76	0.4	1.001	
2A235	6/15/76	2.2	0.878	
2A237	5/17/77	-0.4	0.941	24
2A239	5/20/76	10.9	0.916	
2A239	8/24/76	1.1	0.916	
2A242	7/27/76	14.1	0.948	
2A253	7/13/76	-0.7	0.998	
2A255	6/29/76	4.8	1.014	
2A257	7/13/76	5.3	0.971	
2A258	4/13/76	5.0	0.971	
2A322	5/9/77	-1.3	0.999	52
2A329	8/17/76	-2.6	0.963	
2A338	10/1/76	-11.0	1.002	
2A340	3/29/77	-4.3	0.987	
2A341	5/10/77	-0.1	0.999	36
2A347	8/10/76	2.8	0.750	
2A347	8/17/76	4.6	0.808	
2A348	10/26/76	22.3	1.255	
2A359	10/5/76	-8.7	0.978	
2A359	10/12/76	-8.1	0.935	
3A012	6/13/77	-5.1	0.955	54
3A033	4/5/77	-0.1	1.806	57
3A034	4/11/77	-7.3	1.045	57
3A035	4/19/77	-3.3	0.997	72
3A038	5/6/77	-3.3	1.036	40
3A038	7/1/77	-0.8	0.959	54
3A038	7/20/77	-1.9	1.040	36
3A040	5/6/77	-0.5	1.038	52
3A041	4/5/77	-3.3	0.964	
3A041	5/9/77	-1.4	1.020	
3A041	5/17/77	-4.9	0.979	51
3A041	6/10/77	-3.2	0.987	48

Sonde	Calib. Date	Intercept (nb)	Slope	85% Response Time
3A041	6/22/77	7.9	0.948	60
3A041	7/8/77	-1.7	0.879	108
3A042	4/20/77	-2.6	0.991	74
3A043	4/20/77	-0.5	0.971	71
3A047	4/25/77	-0.4	1.087	155
3A048	5/6/77	-2.6	0.948	
3A050	7/18/77	-2.6	0.968	114
3A051	4/29/77	-4.9	0.952	
3A052	5/16/77	-3.9	0.949	30
3A053	5/5/77	-1.1	0.982	51
3A054	5/13/77	1.6	0.761	36
3A055	5/12/77	-1.6	0.857	42
3A057	5/12/77	-4.9	0.984	60
3A060	5/25/77	-1.9	0.863	66
3A061	5/11/77	-5.8	0.867	42
3A061	6/21/77	-2.5	0.920	
3A062	5/12/77	-6.3	0.980	39
3A063	5/12/77	-0.8	0.875	72
3A064	5/11/77	-1.6	0.936	48
3A064	6/14/77	-1.4	0.995	54
3A065	5/10/77	-5.3	0.958	62
3A066	5/11/77	-4.1	0.963	44
3A067	6/6/77	-4.0	0.941	42
3A068	6/7/77	-3.9	0.980	42
3A069	6/8/77	-3.2	1.014	42
3A070	6/8/77	0.5	0.929	48
3A071	6/7/77	-0.1	0.964	51
3A072	6/9/77	-2.7	0.952	36
3A073	6/28/77	0.4	0.936	33
3A074	6/9/77	-3.3	0.959	54
3A075	6/8/77	-4.3	0.980	42
3A076	6/9/77	-3.5	0.923	48
3A077	6/27/77	-2.4	1.018	36
3A078	6/9/77	-3.5	0.902	60
3A079	6/27/77	-3.2	0.982	54
3A080	6/10/77	-3.3	0.914	54
3A083	6/13/77	-3.5	0.983	36
3A084	7/5/77	-4.6	0.997	36
3A085	6/10/77	-4.7	0.991	54
3A086	7/5/77	-1.1	0.956	42
3A087	7/5/77	-2.5	1.016	36
3A088	6/16/77	3.1	0.890	48
3A089	6/16/77	-4.0	1.016	48
3A090	6/17/77	1.0	0.978	54
3A091	6/20/77	-1.4	1.006	42
3A092	6/20/77	-1.4	0.995	30
3A093	6/20/77	-2.4	0.952	30

Sonde	Calib. Date	Intercept (nb)	Slope	85% Response Time
3A094	6/22/77	-2.3	0.947	42
3A095	6/21/77	-1.9	0.976	48
3A096	6/21/77	1.5	0.972	48
3A097	6/22/77	-1.5	0.987	54
3A098	6/22/77	3.5	0.830	48
3A099	6/23/77	4.1	0.923	51
3A100	6/23/77	-6.0	0.997	48
3A101	6/23/77	-3.2	1.025	54
3A102	6/23/77	2.5	0.964	48
3A103	6/24/77	-3.0	0.991	60
3A104	6/24/77	-7.1	0.971	60
3A105	6/27/77	-3.0	0.976	36
3A106	6/27/77	-2.3	0.976	54
3A107	6/27/77	-3.9	0.997	39
3A108	6/27/77	-0.4	0.933	36
3A130	6/30/77	-1.0	0.967	48
3A132	7/1/77	-5.8	0.921	42
3A133	7/1/77	4.4	0.939	60
3A134	6/30/77	-3.2	0.979	42
3A135	6/30/77	2.1	0.909	60
3A136	6/30/77	0.4	0.925	54
3A137	6/29/77	-4.8	0.989	57
3A138	6/29/77	0.0	0.963	48
3A139	6/29/77	-1.8	0.970	48
3A140	7/1/77	-2.3	0.979	48
3A141	6/30/77	-0.9	0.920	45
3A142	6/30/77	1.0	0.989	48
3A143	7/1/77	-2.5	0.976	48
3A144	7/1/77	1.1	0.913	60
3A145	7/8/77	-0.5	1.112	66

Table 3. ECC Ozonesondes used in dual calibrations.

3A101	3A065
3A102	2A341
3A141	3A094
3A142	3A097
3A130	3A070
3A134	3A075
3A079	3A072
3A107	3A074
3A077	3A076
3A108	3A078
3A086	3A080
3A087	3A085
3A084	3A099
3A145	3A100
3A140	3A132
3A143	3A133
3A038	3A103
3A144	3A104
3A135	3A105
3A136	3A106
3A061	3A062
3A096	3A063
	3A064
	3A066

Table 4. ECC ozonesonde calibration relative to Wallops Dasibi instrument SN 1715.

Sonde #	Calib. Date	Intercept (nb)	Slope	85% Response Time (s)
3A146	7/21/77	8.5	1.091	42
3A147	7/21/77	10.6	0.990	48
3A148	7/21/77	1.2	1.051	48
3A149	7/22/77	2.0	0.983	36
3A150	7/22/77	2.8	0.977	42
3A151	7/23/77	4.9	0.973	60
3A152	7/23/77	5.3	0.893	48
3A153	7/24/77	7.9	1.023	60
3A154	7/25/77	6.8	0.987	53
3A155	7/25/77	5.9	0.927	63
3A156	7/26/77	6.6	0.921	48
3A157	7/27/77	-4.8	1.012	51

Sonde #	Flight Date	Ω_{DOB} (atm-cm)	Ω_{ECC} (atm-cm)	$\dfrac{100(\Omega_{ECC}-\Omega_{DOB})}{\Omega_{DOB}}$	$\Omega_{ECC \cdot UV}$ (atm-cm)	$\dfrac{100(\Omega_{ECC \cdot UV}-\Omega_{DOB})}{\Omega_{DOB}}$
2A233	04/07/76	0.324	0.324	-0.0	0.273	-15.7
2A258	04/14/76	.363	0.344	-5.1	.326	-10.2
2A229	05/05/76	.371	0.459	23.7	.421	13.5
2A230	05/20/76	.356	0.322	-9.5	.333	-6.5
2A239	05/20/76	.356	0.398	11.7	.428	20.2
2A228	05/26/76	:431	0.446	3.5	.372	-13.7
2A223	06/03/76	.391	0.351	-10.2	.417	6.6
2A224	06/09/76	.358	0.433	20.8	.376	5.0
2A235	06/16/76	.303	0.288	-4.9	.314	3.6
2A202	06/23/76	.332	0.333	0.2	.359	8.1
2A255	06/30/76	.324	0.335	3.3	.304	-6.2
2A099	07/07/76	.321	0.326	1.5	.365	13.7
2A257	07/14/76	.344	0.359	4.3	.340	-1.2
2A253	07/21/76	.317	0.308	-2.7	.313	-1.3
2A242	07/28/76	.325	0.351	8.0	.290	-10.8
2A347	08/18/76	.339	0.311	-8.2	.355	4.7
2A093	09/01/76	.319	0.350	9.8	.350	9.7
2A359	10/13/76	.297	0.343	15.6	.415	39.7
2A227	10/27/76	.330	0.368	11.4	.378	14.5
2A348	11/18/76	.309	0.323	4.5	.160	-48.2
2A340	03/30/77	.300	0.276	-7.9	.304	1.3
2A237	07/06/77	.335	0.279	-16.6	.299	-10.7
3A033	04/06/77	.354	0.332	-6.3	.306	-13.6
3A034	04/19/77	.359	0.358	-0.3	.381	6.1
3A035	04/20/77	.365	0.378	3.6	.397	8.8
3A043	04/27/77	.478	0.458	-4.2	.474	-0.8
3A048	05/11/77	.500	0.483	-3.4	.525	5.0
3A053	05/18/77	.387	0.347	-10.3	.360	-7.0
3A054	05/25/77	.326	0.252	-22.6	.320	-1.8
3A060	06/22/77	.352	0.291	-17.3	.349	-0.9
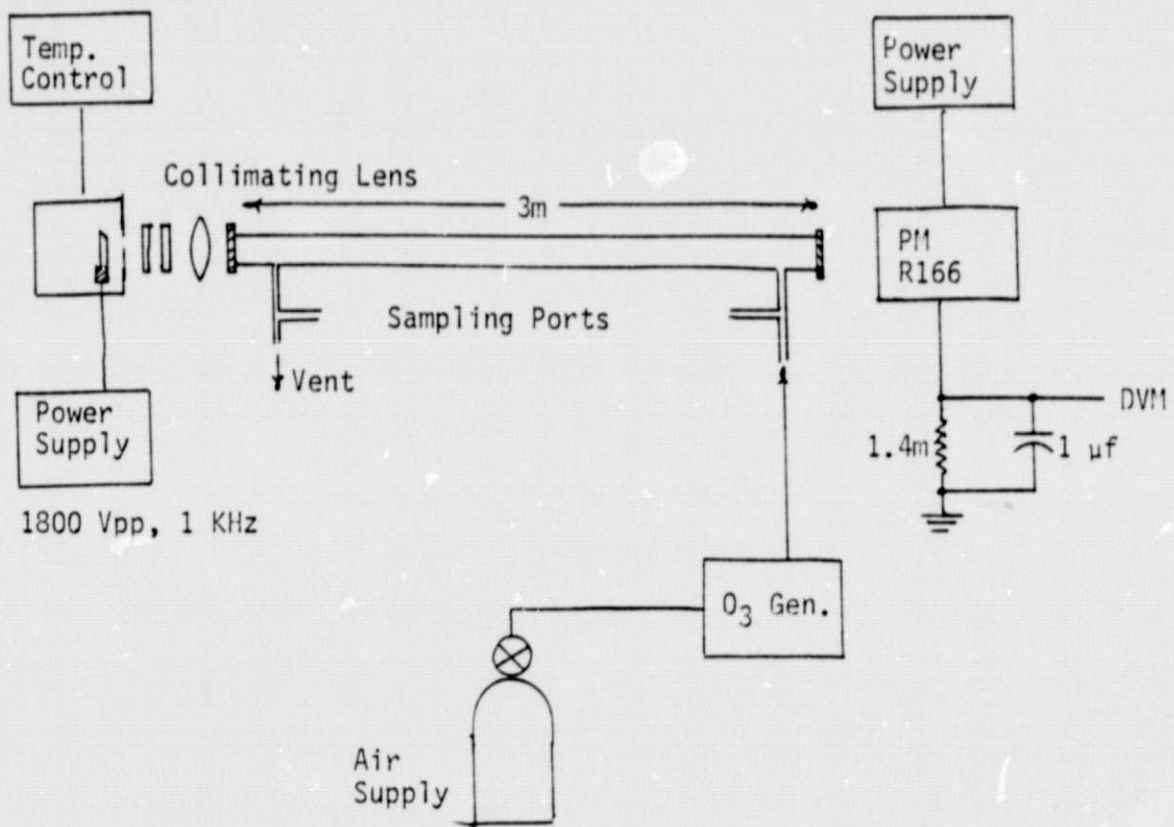
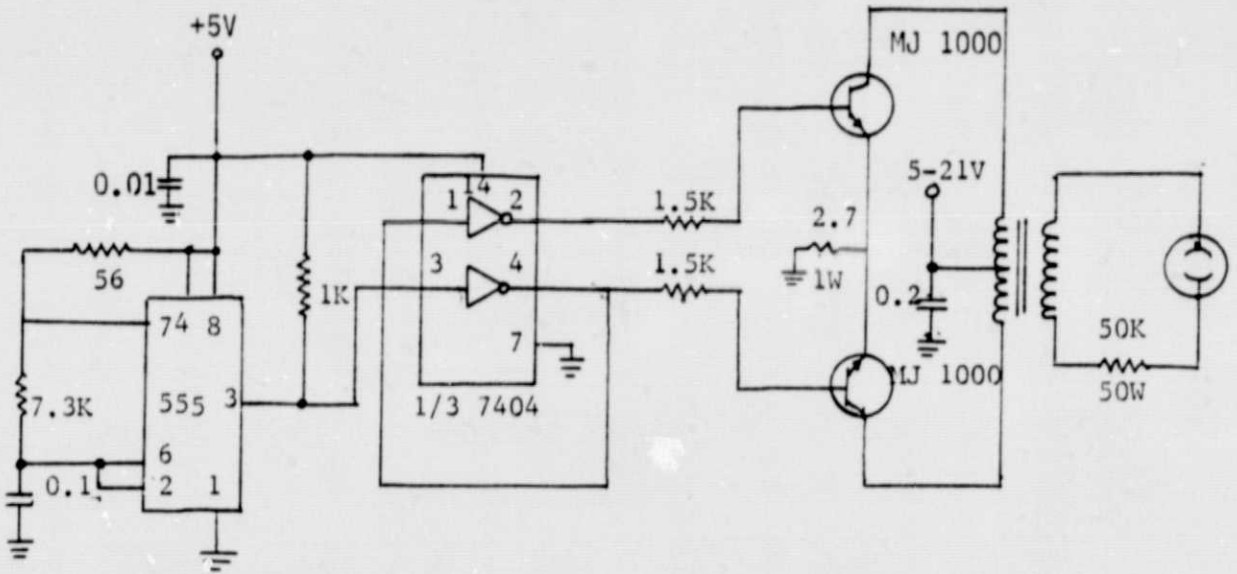Figure 1. Ultraviolet absorption photometer for ozone calibrations.

Figure 2. Partial schematic for lamp power supply for ultraviolet
absorption ozone photometer.
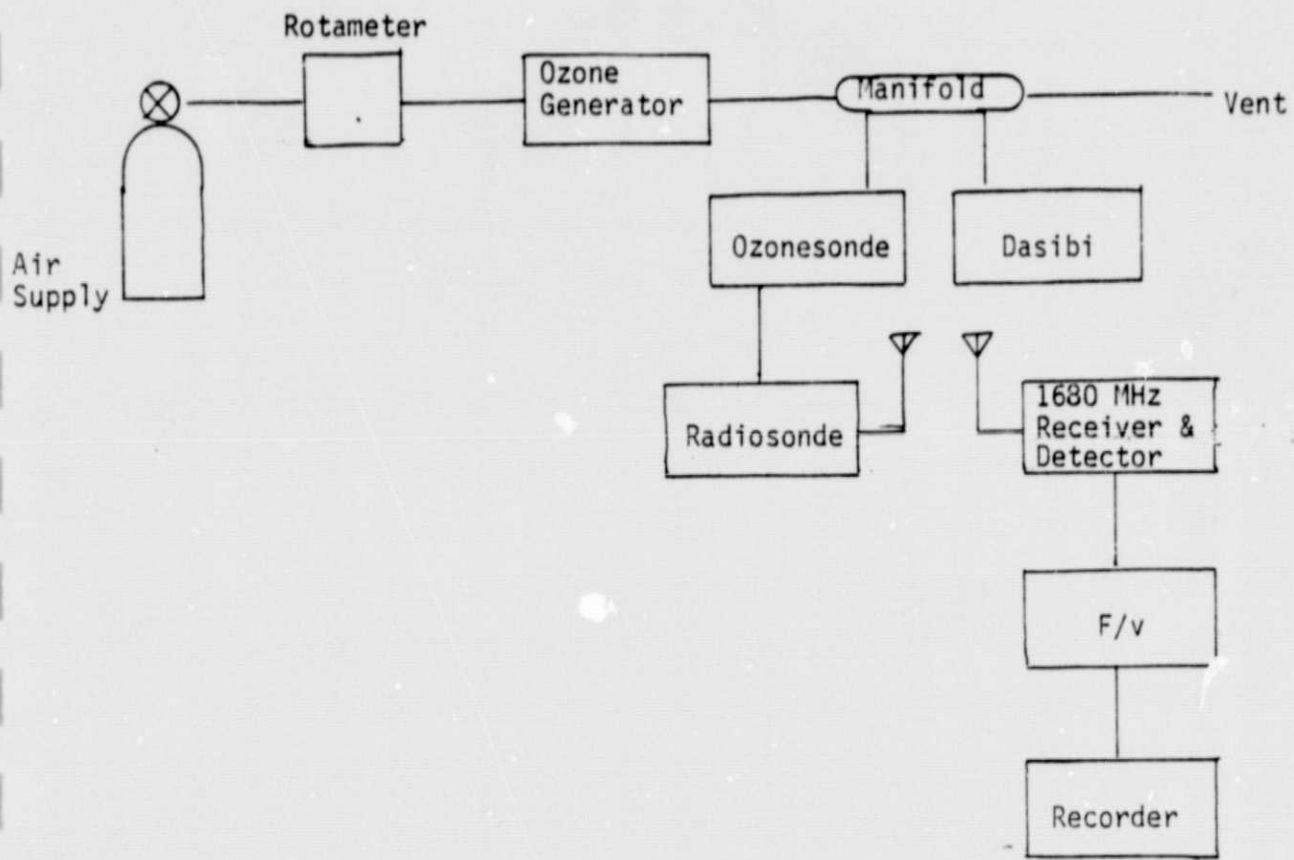
Figure 3.   ECC Ozonesonde Calibration Apparatus
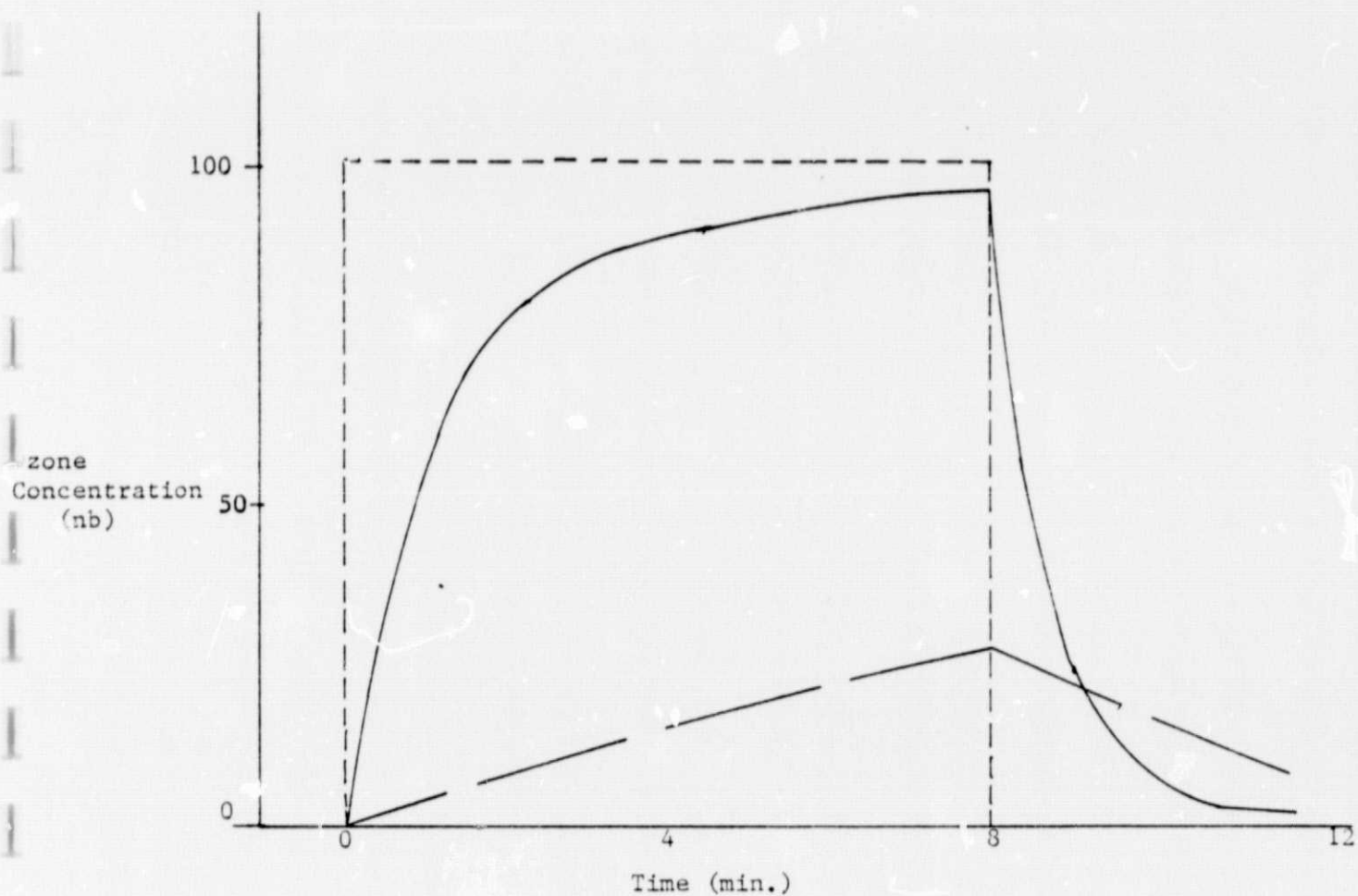
Figure 4. Response of ECC ozonesonde (2A239) with contaminated sensor cells to step changes in ozone concentration.