INSTRUCTION MANUAL

EN-SCI Corporation

MODEL 2ZV7-ECC
ATMOSPHERIC
OZONE SOUNDING SYSTEM
DMT DOC-0325

Comprised of

(1) *EN-SCI Corporation* Model 2ZV7 ECC Ozonesondes, with *Innovative System Designs* V7 Interface Electronics

(2) *InterMet Systems* iMet-1-RSB 403 MHz GPS Meteorological Radiosondes

(3) *EN-SCI Corporation* Model DAS-2 403 MHz Portable Data Acquisition and Processing System

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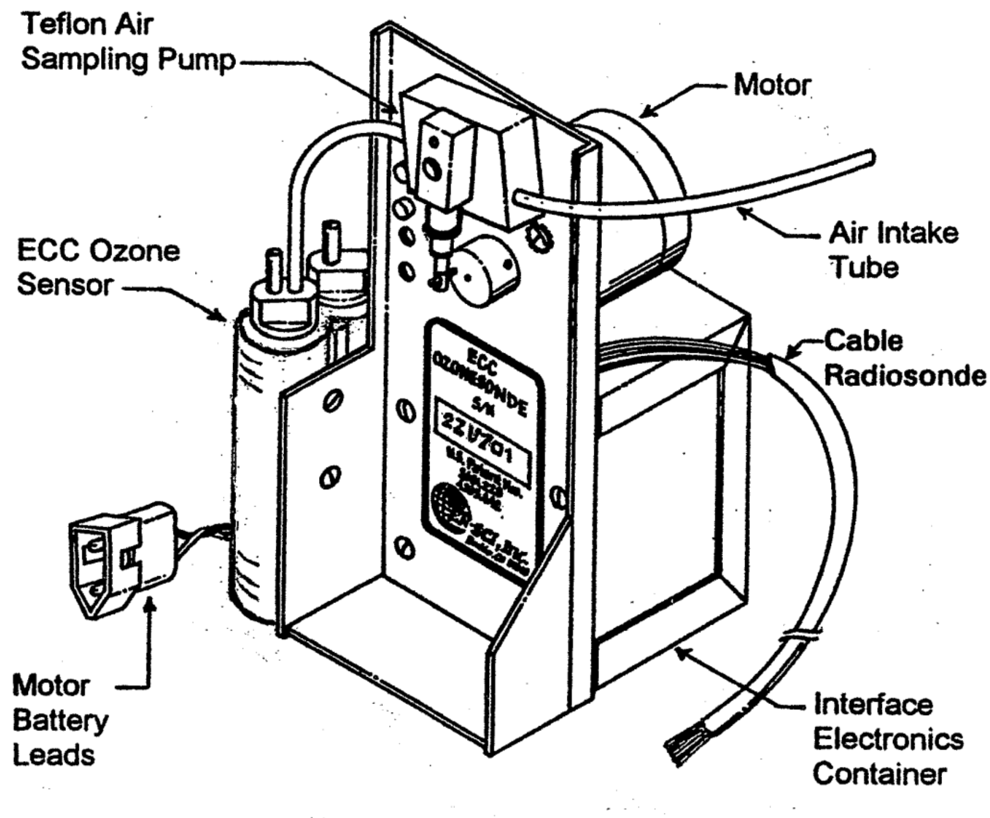
MODEL KZ-ECC ATMOSPHERIC OZONE SOUNDING SYSTEM

1.0 Introduction

The EN-SCI Corporation Model 2ZV7-ECC atmospheric ozone sounding system is designed for ozone measurements from balloon platforms, with real-time data acquisition and processing. Ozone is measured with a Model 2ZV7 electrochemical concentration cell (ECC) ozonesonde [Komhyr, 1969] coupled through V7 interface electronics to a meteorological radiosonde. Data are acquired with a portable, tripod-mounted, 403 MHz Yagi antenna with built-in pre-amplifier, connected to a 403 MHz receiver by means of a 15-m long coaxial cable. Data processing, using supplied software (open source code), is accomplished during balloon flight with a personal computer connected via a 1200 baud modem to the 403 MHz receiver.



Balloon-borne Model 2ZV7 ECC
(Electrochemical Concentration Cell) Ozonesonde

The Model 2ZV7 electrochemical concentration cell (ECC) ozonesonde is lightweight, compact, inexpensive, and of simple design. It is readily prepared for use, and is potentially capable of yielding highly accurate ozone measurement data. As shown in the diagram on the previous page, the sonde consists of a rigid mainframe on which is mounted a motor-driven Teflon/glass air sampling pump, a thermistor for measuring pump temperature, an ozone sensing electrochemical concentration cell, and an electronics box containing V7 interface circuitry which couples the ozone sensor to an InterMet Systems iMet-1-RSB GPS 403 MHz meteorological radiosonde (or, optionally, an iMet-1-RSA or an iMet-1-RSC) radiosonde. For ascent into the stratosphere, the instrument is encased in a molded polystyrene weatherproof box. Measured parameters telemetered to a ground receiving station are ozone, sonde pump temperature, sonde pump motor voltage and current, air pressure, air temperature, and humidity. (Wind data are calculated from GPS data.) Instrument size is 7.6 x 7.9 x 13.3 cm, and weight is 323 g, including an 18 V lithium battery. Dimensions and weight of the polystyrene flight box are 19.1 x 19.1 x 25.4 cm and 200 g, respectively. Total package weight is 523 g.

The ozone sensor of the ECC ozonesonde is made of two bright platinum electrodes immersed in potassium iodide (KI) solutions of different concentrations contained in separate cathode and anode chambers. The chambers are linked with an ion bridge that, in addition to providing an ion pathway, retards mixing of the cathode and anode electrolytes thereby preserving their concentrations. The electrolytes also contain potassium bromide (KBr) and a buffer whose concentrations in each half cell are the same. Driving electromotive force for the cell, of approximately 0.13 V, is provided by the difference in potassium iodide concentrations in the two half cells. Thus, an external battery is not needed to drive the cell.

When ozone in air enters the sensor, iodine is formed in the cathode half cell according to the relation

$$2KI + O_3 + H_2O \rightarrow 2KOH + I_2 + O_2. \quad (1)$$

The cell converts the iodine to iodide according to

$$I_2 + 2e \rightarrow 2\,I^- \quad (2)$$

during which time two electrons flow in the cell's external circuit. Measurement of the electron flow (i.e., the cell current), together with the rate at which ozone enters the cell per unit time, enables ozone concentrations in the sampled air to be derived from

$$p_3 = 4.307 \times 10^{-3}(i_m - i_b)T_p t \quad (3)$$

where p_3 is the ozone partial pressure in nanobars, i_m is the measured sensor output current in microamperes, i_b is the sensor background current (i.e., the residual current emanating from the cell in the absence of ozone in the air) in microamperes, T_p is the pump temperature in kelvins, and t is the time in seconds taken by the sonde gas sampling pump to force 100 ml of air through the sensor. As a volume mixing ratio in air, the measured ozone is derived from

$$O_3(ppbv) = 1000p_3/P = 4.307(i_m - i_b)T_p\, t/P \qquad (4)$$

where O_3(ppbv) is the measured ozone in parts per billion by volume and P is the ambient air pressure in millibars.

Air is forced through the ECC sensor by means of a non-reactive pump fabricated from TFE Teflon impregnated with glass fibers. A unique design permits pump operation without ozone-destroying lubricants. O-rings fitted externally on the pump cylinder press against thin, flexible portions of the cylinder to maintain an air-tight seal between the piston and cylinder. Pumping efficiency for such pumps varies with ambient air pressure, and depends upon pump leakage, the pump dead volume, and the pump head (the back pressure exerted on the pump by the sensor cathode electrolyte).

The Innovative System Designs' V7 interface electronics, which couple the ozone sensor to the 403 MHz InterMet GPS radiosonde, permit use of inexpensive ground equipment for ozone (and meteorological) signal data receiving and processing. Data from the ozonesonde are measured by the V7 interface, which then formats the data into an asynchronous text message that is sent to the radiosonde at 9600 baud. Multiple ozonesondes may be daisy-chained together when using the V7 interfaces. The radiosonde compresses the received ozonesonde data and transmits it to the ground receiving station. The output from the receiver on the ground is demodulated by a 1200 baud modem and sent to a computer through a serial USB port for real-time data processing. Data are sent from the V7 interface to the radiosonde at 1-second intervals.

The V7 interface includes 8 channels of analog input (0 – 5.0 VDC) with 10-bit resolution. Over-sampling provides an effective resolution of 14-bits by measuring each channel over 500 times per second. Four of the eight available channels are used to measure the ozonesonde data, leaving four channels available for future use. The analog to digital converter (ADC) uses a very accurate and stable reference voltage so that no adjustments or calibrations are required to achieve an accuracy of +/-0.1% throughout the flight. The ECC cell current-to-voltage conversion is performed by an auto-zeroing amplifier for ultra low offsets. Full scale current is fixed at 10.0 uA, which translates to a resolution of 0.0006 uA/bit.

Current software provided includes the **O3** program for data acquisition and display of real-time flight data, the **V7TXT** program for converting the flight data into ASCII format after the flight is finished, and the software drivers for the 1200 baud modem. Installation of the modem drivers should be performed before plugging the modem into the USB port.

WARNING:

The cable from the receiver to the modem input should not be connected when plugging the modem into the USB port. If there is an active serial data stream coming from the modem when it is plugged into an USB port, the Windows operating system will identify the modem as a serial mouse and send the mouse pointer randomly around the screen.

As indicated earlier, equipment required on the ground is minimal: a Yagi antenna with a preamplifier, a receiver, modem, and a PC (or any other personal computer equipped with an RS232 serial port). This allows the operator to select from a variety of equipment for the ground system.

Instructions in this manual give details concerning preparation of an EN-SCI Corporation Model 2ZV7 ozonesonde for flight, and present basic information about data processing. Data acquisition and processing instructions, including software and software information, are provided in an accompanying **O3 Reference Manual**, **Version 1.30, October, 2008** [J. Wendell, 2008], or in updated versions of the **O3** manual.

2.0 Preparing the Model 2ZV7 ECC Ozonesonde for Flight

Note 1. Preparation of the ozonesonde for flight should always be performed in a clean environment where smoking is prohibited; otherwise the performance of the instrument may be adversely affected.

Note 2. Tubing connections to the sonde pump are made with pressure-fitted Teflon tubing. Should the fit appear to be too loose, enlarge the Teflon tube using a clean, awl-shaped tool of outside diameter slightly larger than the inside diameter of the tube. Use small strips of sand paper with which to grasp the Teflon tubing firmly when making or breaking pump connections.

2.1 Advance Preparation 3 Days to 1 Week Prior to Flight Time

The first step in preparing the ozonesonde for use is to check the overall performance of the instrument, and to charge the sensor with sensing solution (Appendix A). Initial charging of the sensor should be done 3 days to 1 week before flight time in order to attain a low sensor background current. (For information on preparing an instrument for use and flying it the same day, see section 2.4.) An EN-SCI Corporation Model KTU-2 ozonizer/test unit (Appendix B) is used for checking on the overall sonde performance. The unit consists of a high ozone source for conditioning the sonde air intake tube, pump, and sensor air intake tube with ozone; a variable low ozone source for conditioning the sonde sensor charged with sensing solution, and for checking on the sensor background current and response time; a 12 VDC power supply for operating the sonde motor; electrical meters for use in checking on the sonde motor/sensor characteristics; and an 18 VDC power supply for powering the 403 MHz ground receiving station antenna pre-amplifier during cold weather operation, when necessary.

Proceed as follows in advance preparation of the instrument for use. The preparation should be performed in a clean room at a temperature of 20-25° C.

(a) Remove the sonde from its polystyrene flight box and connect the Teflon air intake tube packed with the instrument to the sonde pump.

(b) Connect the ozonesonde battery power leads to the ozonizer/test unit's 12 VDC output power supply terminals. Pull the ECC sensors' air intake tube away from the pump. Next insert the pump air intake tube into the NO-LO OZONE port of the unit. With all ozonizer/test unit switches, except the 18 VDC power supply switch and the UV lamp switch, turned ON, operate the sonde pump for 10 minutes (during which time clean, ozone-free air will be passed through the pump. After the 10-minute interval, check the current drawn by the sonde (pump motor and V7 interface board) at about 12.3 VDC. The current should be less than 100 mA. (The current drawn by the interface board is about 8 mA.) If the current is larger, the fit between the piston and cylinder may be too tight and may cause excessive frictional heating. Continue operating the pump for an additional 20 minutes to see if the current decreases. If it does not, take remedial action as outlined in Appendix C. A properly adjusted pump will draw less than 90 mA of current, and develop at least 50 cm (~20 inches) of Hg pressure and 45 cm (~18 inches) of Hg vacuum. Measure the pressure and vacuum developed by the pump with a pressure/vacuum gauge.

(c) With proper pump performance attained, remove the sonde air intake tube from the NO-LO OZONE port of the ozonizer/test unit, and insert it snugly into the HI OZONE port of the unit. (The connection must be snug since the sonde pump draws highly ozonized air from the unit.) Next remove the top plug with air intake tube from the sensor cathode chamber, and re-connect the air intake tube to the pump. Now turn OFF the AIR PUMP switch, but turn ON the UV LAMP switch, and pull out the OZONE CONTROL tube as far as possible out of the chassis. Conditioning of the sonde Teflon tubing, pump, and sensor air intake tube (but not the sensor cathode chamber) with high ozone now begins. Blue light visible through a hole in the front of the OZONE CONTROL tube indicates that the UV lamp is ON. During the conditioning avoid direct breathing of the ozonized air coming out of the sensor air intake tube. Condition with high ozone for 30 minutes.

(d) After conditioning with high ozone is completed, push the OZONE CONTROL tube as far as possible into the ozonizer/test unit chassis, turn ON the AIR PUMP switch, and withdraw the sonde air intake tube from the HI OZONE port and insert it into the NO-LO OZONE port. Ozone-free air will now be passing through the pump and sensor air intake tube to flush out the ozone. Continue flushing for 3-5 minutes.

(e) Now unplug the sensor leads from the sonde electronic interface board, and plug them into the sensor cable connector of the ozonizer/test unit. Then charge the sensor with sensing solution as follows:

The sensor cathode must always be charged first to allow cathode solution to permeate the sensor's ion bridge. Using a Teflon-tipped syringe especially reserved for use with cathode sensing solution, inject 3.0 ml of the solution into the sensor cathode chamber. This is the chamber containing the large platinum screen. When re-installing the top plug of the cathode, make sure that the air intake tube is correctly centered within the cathode chamber by inserting the tube carefully over a thin Teflon rod projecting out of the bottom plug of the sensor cathode chamber. Rinse the syringe with distilled water prior to storage. Note: Do not attempt to fill or empty the sensor cathode through the short air exhaust tube of the cathode chamber top plug; otherwise the platinum screen may be damaged (distorted), leading to sensor malfunction.

Next, after waiting 2 minutes to allow the cathode sensing solution to permeate the sensor’s ion bridge, use a syringe especially reserved for dispensing anode solution to inject 1.5 ml anode sensing solution into the sensor anode chamber. Rinse the syringe with distilled water prior to storage.

(f) After charging the sensor with solution, run the sonde on ozone-free air for 5-10 minutes. The sensor current, as observed on the ozonizer/test unit microammeter should be low, 0.5 μA or less. Now set the ozonizer/test unit OZONE CONTROL tube position for a low ozone output—one that produces a sensor current of 5 μA. Continue input of ozonized air into the sensor for 10 minutes while periodically adjusting the OZONE CONTROL tube position as needed. At the end of the 10-minute interval, abruptly push the OZONE CONTROL tube as far as possible into the ozonizer/test unit front panel to begin the flow of ozone-free air through the sensor. Read the microammeter current 1 minute later; it should then have decreased from the original value of 5 μA to 1.5 μA or less, indicating satisfactory ECC sensor performance.

(g) Continue running the sonde on ozone-free air for 10 minutes. Then turn off all ozonizer/test unit switches, and disconnect the sonde from the unit. Prior to storage of the sonde until flight day, add 2.5 ml cathode sensing solution to the sensor cathode chamber to fill it about 3/4 full. Re-insert the sensor cathode chamber air intake tube into the sensor, and store the sonde in a dark, clean-air environment at a temperature of 20-25° C until the day of the flight.

IMPORTANT! Prior to storage, also, short the ECC sensor leads together with a shorting plug. This will allow a sensor cleaning action to proceed during storage. (Do not re-plug the sensor into the sonde's electronic interface board for storage since the unpowered board's input impedance may be high, and proper sensor cleaning action would not proceed.)

2.2 Instrument Preparation on the Day of Release - Option A: Using the KTU-2 Ozonizer/Test Unit

The preparation should be conducted in a clean room at a temperature of 20-25° Celcius.

(a) Remove the top plug from the sensor cathode chamber and remove all solution from the chamber. Now rinse the chamber by injecting into it 3.0 ml fresh cathode solution, then removing the solution completely from the chamber. Finally, refill the chamber with 3.0 ml cathode solution. (Note: For soundings of duration less than 3-4 hours, made primarily to measure tropospheric ozone, 2.5 ml cathode sensing solution may be used, instead. Sensor response time will then be improved.) Replace the top plug.

Next, remove the top plug from the sensor anode chamber and remove all anode solution from the chamber. Re-fill the chamber with 1.5 ml of fresh anode solution. Replace the anode plug.

(b) Connect the ECC sonde motor and sensor leads to the ozonizer/test unit, and insert the sonde air intake tube into the NO-LO OZONE port of the unit to a distance of about 7 cm. Set the controls so that ozone-free air passes through the air pump and sensor. Next, turn on the UV LAMP switch to warm up the lamp. Continue passing ozone-free air through the sensor for a total of 10 minutes. At the end of the 10-minute interval, record the sensor background current (which generally should be less than 0.05 μA). Save this information as part of your raw data file (e.g., i_{b1} = 0.05 μA).

(c) Next, pull the OZONE CONTROL tube out of the ozonizer/test unit a distance such that, after several minutes, the sonde sensor output current becomes approximately 5 μA. Continue passing an equivalent of 5 μA ozone current through the sensor for a total of 10 minutes. Periodically adjust the position of the OZONE CONTROL tube so that at the end of the 10-minute interval the ECC sensor current is exactly 5.0 μA.

(d) Now check the ECC sensor response time as follows: Using a stopwatch, at time t = 0 quickly push the ozonizer/test unit OZONE CONTROL tube all the way into the instrument chassis and turn the UV LAMP switch OFF. As the ECC sensor current continues to fall, record the current for times t = 0, 0.5, 1, 3, 5 and 10 minutes as shown in the example on the following page giving typical measurement results at 20° C. Record also the room temperature at which this test was performed. Save all the information as part of the raw data file. Sensor response time R, is satisfactory if

$$R = 100[(i_{m(t=0)} - i_{m(t=1)})/i_{m(t=0)}] \geq 80\%. \quad (5)$$

t	Sensor Current, i_m
0 min.	5.00 μA
0.5	1.61
1	0.82
3	0.25
5	0.20
10	0.10

For the above example, R = 83.6%. Sensor response time becomes faster as sensor temperature increases.

(e) After the sensor response time check is completed, continue running the ozonesonde on ozone-free air for another 10-15 minutes. During this time re-connect the ECC sensor leads to the V7 interface board. Connect the ozonesonde to the InterMet radiosonde. Activate your data acquisition system for operation in the "Calibration" mode to begin receiving and recording the radiosonde and ozonesonde data by computer. (See Appendix E for configuration of the data acquisition system). This procedure will enable you to check for satisfactory performance of the ozone-radiosonde instrument package as-a-whole. At this stage, the ozonesonde should still be operated without its flight box at a room temperature of 20-25° C, and powered by the ozonizer/test unit's 12 VDC power supply. Power the InterMet radiosonde with an auxialliary 6 V battery power supply. As the sonde is continuing to be run on ozone-free air, perform a sonde pump air flow rate according to instructions given in Appendix D. Check to insure that the pump motor voltage is about 12.3 volts. Record the pump motor voltage and current (which should be less than about 110 mA). Record also the pump air flow rate and the room temperature, and save all information as part of the raw data file. Now enter into your computer raw data file all pertinent ozonesonde and radiosonde calibration data, instrument serial numbers, station name, release date, etc. At the end of the final 10-minute ozone-zero air conditioning period, record in the raw data file, also, the ECC sensor background current (i_{b2}) which should generally be less than about 0.1 μA.

(f) Now turn off power to the ozonizer/test unit. (By this time inflation of the flight balloon and preparation of the flight train should have been completed.) Install the ECC sonde into its flight box together with the sonde pump motor battery, but do not activate the battery. Activate the radiosonde by plugging the leads connector of the 2-cell lithium battery pack, located within the radiosonde, into its mating connector mounted on the radiosonde electronics board. Tape the radiosonde to the ozone instrument flight box (see Appendix F for configuring the instrument package for flight). Affix a return address/reward notice to the cover so that the instrument could be returned to your laboratory should it be recovered by someone.

(g) Now carry the ozonesonde package outdoors, and suspend it from a pole (or set it on a platform) at a height of about 1.5 meters above the ground, with the sonde air intake tube pointing into the wind. Connect the sonde pump motor battery leads to begin ECC ozonesonde operation. Activate the 403 MHz ground receiving equipment for operation in the “Surface Ozone Measurement” mode to measure and record surface ozone data for 10 minutes.

In very warm weather, the surface ozone measurement should be made with the cover off the sonde weatherproof box to prevent excessive heat build-up within the box. Tape the cover on to the box prior to instrument release (see method of taping shown in Appendix F).

(h) Finally, attach the ozonesonde instrument package to the balloon train and release the balloon.

2.3 Instrument Preparation on the day of Release - Option B: Using a Calibrated Ozone Source

Note: Follow these instructions for instrument preparation on the day of release instead of those given in Section 2.2 if you have available a calibrated ozone source such as, e.g., a Dasibi or a Thermo Environmental Instruments (TEI), Inc., ozone calibrator.

Preparation should be performed in a clean room at a temperature of 20-25° C.

(a) First turn ON the calibrated ozone source instrument (e.g., the TEI ozone calibrator) to let the instrument warm up for at least one-half hour. The ozone output of the calibrator should be set to zero.

(b) While the TEI ozone calibrator is stabilizing, remove the top plug from the ozonesonde sensor cathode chamber and remove all solution from the chamber. Rinse the chamber by injecting into it 3.0 ml fresh cathode solution, then removing the solution completely from the chamber. Finally, refill the chamber with 3.0 ml cathode solution and replace the cathode plug. (Note: For soundings made primarily to measure tropospheric ozone, 2.5 ml of cathode sensing solution may be used, instead (see Sec. 2.2 (a)). Sensor response time will then be improved.)

Now remove the top plug from the sensor anode chamber and remove all anode solution from the chamber. Re-fill the chamber with 1.5 ml fresh anode solution. Replace the anode plug.

(c) Next, plug the ECC sensor leads and the radiosonde connector cable into the interface board. Connect the 12 and 18 volt d.c. power cables from the model KTU-2 ozonizer/test unit to the ozonesonde and radiosonde, but do not power the ozonizer/test unit yet.

(d) While the TEI ozone calibrator is continuing to stabilize setup your data acquisition system; enter the radiosonde calibration data into a file in the computer if that had not been done earlier; inflate the flight balloon; and prepare the balloon train (parachute, reel, etc.).

(e) After the TEI ozone calibrator has been operating for at least 1/2 hour, obtain ECC ozonesonde flight calibration constants as follows: First insert the sonde air intake tube about 5 cm into the ozone output manifold of the TEI instrument. Secure it there with a piece of masking tape taking care not to impede air flow. Now turn the ozonizer/test unit ON to provide power to the ozonesonde and radiosonde. Activate the ***O3*** data acquisition and processing software, and enter required information (station, time, ozone instrument and radiosonde serial numbers, etc.) into the computer. Set operation to the "Calibrate" mode and begin recording the ECC sensor background current. Record the current for 5-10 minutes, or until the readings settle to a low value.

(f) Now adjust the ozone control on the TEI ozone calibrator for an ozone output given by

$$O_3\ (\text{ppbv}) \approx (1.8 \times 10^5)/P \qquad (5)$$

where P is the mean station pressure in hPa. (This correspond to a an ECC sensor output current of about 5 μA.) Continue to operate the TEI instrument in this mode for 10 minutes.

(g) After the 10 minutes are up, quickly adjust the TEI instrument to give zero ozone output. This will begin final measurement of the ECC sensor background current as well as provide information on sensor response time. Continue running the sonde on zero (ozone-free) air for 10 minutes. Then as the instrument continues to run on ozone-free air, perform a pump air flow rate measurement according to instructions given in Appendix D. Finally, after not less than 15 minutes of run time to obtain stable background current, disconnect power from the ozone instrument and the radiosonde.

(h) Enter into the computer the pump air flow rate, t, as well as the lowest sensor background current, i_{b2} , obtained near the end of the time of the background current measurement.

(i) Now insert the sonde into its polystyrene flight box together with the sonde pump motor battery, but do not activate the battery to operate the sonde pump. (If a water activated battery is used, it should have been water activated 10-15 minutes before this time (see Appendix F). Activate the radiosonde battery, and tape the radiosonde to the ozone instrument flight box (see Appendix F for configuring the instrument package for flight). Affix a return address/reward notice to the box cover so that the instrument could be returned to the laboratory should if be found by someone.

(j) Carry the ozonesonde package outdoors and suspend it from a pole (or set it on a platform) at a height of about 1.5 meters above the ground, with the sonde air intake pointing into the wind. Connect the sonde pump battery leads to activate the sonde for a 10-minute surface ozone measurement. For this measurement, set the computer output to operate in the "Surface Ozone" mode.

In very warm weather, the surface ozone measurement should be made with the cover off the sonde weatherproof box to prevent excessive heat build-up within the box. Tape the cover to the box prior to instrument release.

(k) Finally, set the computer software to operate in "Flight" mode. Attach the ozonesonde instrument package to the balloon train, and release the balloon.

2.4 Preparing and Flying an ECC Ozonesonde on the Same Day

The ECC ozonesonde can be prepared and flown on the same day, but the background current may be slightly higher than normal. In preparing the instrument for such use, follow instructions given in section 2.1 (a)-(g). After charging the sensor with sensing solution, pass ozone-free air through the sensor for 10 minutes, then replace the cathode solution with fresh solution. Run the instrument again on ozone-free air for 10 minutes to achieve a sensor background current of 0.1-0.2 μA. (The solution replacement may have to be repeated.) If possible let the instrument then stand without use for several hours. At the end of that time, proceed with preparing the instrument for flight according to the instructions given in section 2.2 (a)-(e).

3.0 The Balloon Train

ECC ozonesondes are generally flown with 1200 g or 1500 g rubber balloons that attain maximum pressure altitudes of 20-7 hPa depending on balloon size, quality, and stratospheric temperatures. Such balloons should be inflated to barely float weights of 2000 and 2300 g, respectively. Adjust the inflation weights, if necessary, to attain average balloon ascent rates of about 300 m/min. Somewhat more helium (or hydrogen) may be required when stratospheric temperatures are very cold or the flights are made at night. Commercially available plastic balloons may also be used. These attain higher burst altitudes than do rubber balloons when flown in the cold temperatures of the Arctic or Antarctic polar night.

The ozonesonde should be suspended during flight about 30 m below the balloon. Cord wound on a ratchet-type reel facilitates balloon release. In cold climates, attach a snap-type clip to the reel cord for quick connection of the ozonesonde package to the balloon train.

If a release is made in a populated region, a parachute of diameter about 1.5 m should be suspended by a cord 5-10 m below the balloon. When conducting ozone soundings from a flight control area (e.g., in the vicinity of an airport), check with your local aviation authority for regulations regarding balloon releases.

4.0 Sonde Battery Power

Lithium batteries are provided for powering the Model 2ZV7 ECC ozonesondes. The battery must be located in the instrument compartment of the flight box to prevent excessive cooling of the battery and, hence, excessive voltage drop. (Water-activated batteries may also be used.) For more detailed instructions concerning battery usage, see Appendix G.

5.0 Data Processing

As indicated previously, ***O3*** software and source code are provided by EN-SCI Corporation for processing the Model 2ZV7 ECC sonde data. The software is based on data processing instructions [Komhyr, 1986] that have been used by many research institutions since the mid 1980s. Some questions remain regarding several aspects of the data processing, including the method of applying sensor background current corrections, and uncertainties associated with recommended sonde pump efficiency corrections. A World Meteorological Organization (WMO) sanctioned effort is currently under way at several laboratories to resolve the problem with the various types of sondes currently in use. However, it will most likely be a year or two before final, definitive WMO instructions are provided to users that will standardize data processing procedures.

5.1 Sensor Background Current

Although small (generally $\leq 0.1\ \mu A$), ECC sensor background current may be of appreciable magnitude when compared with sensor output current due to ozone in the high troposphere or above 5 hPa in the stratosphere. Various researchers have used several methods of treating the background current when processing their sonde data, none of which is completely satisfactory.

Komhyr [1969] suggested that the background current i_b, resulted largely from a residual sensitivity of the ECC sensor to oxygen. The procedure originally adopted in processing the sonde data, therefore, was to assume that the measured background current (see section 2.2(e), where $i_b = i_{b2}$) decreased with altitude (or air pressure) in proportion to the rate at which oxygen entered the sensor. Special treatment and preconditioning of ECC sensor platinum electrodes in recent years, however, has significantly reduced sensor background current compared to values observed in the past. The newer sensors exhibit little, if any, sensitivity to oxygen. A more appropriate treatment of the background current when processing the sonde data is, therefore, to assume that the background current measured just prior to instrument release remains constant during balloon flight. The ECC sensor current due to ozone at all altitudes then becomes $i_m - i_b$ where $i_b = i_{b2}$. This method of treating sensor background current is recommended, and is incorporated into the software used in processing the data.

Another method suggested for accounting for background current is that described above, but to use instead the background current determined for a sensor that had been charged with sensing solution, conditioned, and stored for several days; then its background current measured prior to passing any ozone through it. The merit of this method has yet to be ascertained.

Finally, it is possible that the sensor background current varies with the ozone concentration being measured. Because a standard method of applying ECC sensor background current corrections has not been universally accepted, it is important that the currents i_{b1} and i_{b2}, as well as a brief description of how these values were used in data processing, be recorded in the raw and processed data files for each sounding. With such information permanently stored, it will be possible in the future to optimize the quality of the sonde data through data reprocessing should a consensus be arrived at on how best to treat the background current.

5.2 Pump Efficiency Corrections

The efficiency of ECC ozonesonde air sampling pumps decreases with altitude. Measured ozone amounts must, therefore, be corrected for the efficiency loss. Ozone data pump correction factors recommended for use in the past have been those determined from tests made in an environmental chamber using a bag inflation technique [Komhyr, 1986]. More recently Komhyr et al. [1994] employed a pump efficiency measurement technique based on the premise that pumps working against no back pressure pump at nearly 100% efficiency at all pressures: The method yielded “Table Mountain” pump efficiency correction factors given in Table 1 below.

Table 1. Table Mountain Corrections to Ozone for Pump Efficiency Decrease With Altitude

Pressure (hPa)	C.F.	Pressure (hPa)	C.F.
1,000	1.000	20	1.041
200	1.000	15	1.048
150	1.002	10	1.066
100	1.007	7	1.087
70	1.013	5	1.124
50	1.018	3	1.240
30	1.029		

These are closely similar to those used previously for ambient air pressures down to about 7 hPa, but larger at 7-3 hPa. Use of these revised pump efficiency correction factors is recommended.

While the correction factors given in Table 1 for low pressures may be underestimates of true values, their use in data processing is intended to compensate roughly for an improvement in pumping efficiency that occurs at higher altitudes as pump head decreases due to evaporation of sensor cathode electrolyte, for the increased sensitivity of the ECC sensor to ozone that occurs as the sensor cathode electrolyte concentration increases due to evaporation, and for a slight increase in sensor background current that occurs following measurement of high ozone by the sensor in the region of the ozone maximum.

It is important to include in the raw and processed data files for each ozone sounding the pump efficiency correction factors used in processing the data. This will allow improvement of the processed sonde data in the future should more definitive pump efficiency information become available.

5.3 Pump Temperature Thermistor Characteristics

The thermistor employed for measuring Model 2ZV7 ECC ozonesonde pump temperature is Fenwal Electronics, Incorporated, Uni-Curve thermistor, P/N 192-103LET-A01. Uni-Curve thermistors are interchangeable, have a nominal resistance of 10,000 ohms at 25° C, and a temperature tolerance over the temperature range 0-70° C of ±0.2° C. For data processing, the R-T characteristics of the thermistors are incorporated into the ***O3*** data processing software.

5.4 Normalization of ECC Ozonesonde Data to Dobson Spectrophotometer Total Ozone

It has been the general practice to normalize ozonesonde ozone profile data to quasi-simultaneously obtained Dobson spectrophotometer total ozone. The method employed, for ozone soundings attaining a pressure altitude of at least 15 hPa, involves determining a normalization factor from the ratio of the Dobson spectrophotometer total ozone and total ozone determined from integration of the sonde profile assuming a constant ozone mixing ratio above balloon-burst height to 1 hPa pressure altitude. With Dobson spectrophotometer total ozone measured on the Vigroux [1953, 1967] ozone absorption coefficient scale during 1987-1992, numerous ECC ozone soundings yielded a mean normalization factor of close to 1.0, with a standard deviation of about 0.05. The ECC sonde's response to ozone is sensitive to the concentration of KI used in the sensor's cathode electrolyte. During development of the instrument, a 1% KI cathode electrolyte was chosen for use since it yielded approximately 1:1 stoichiometry in the conversion by the ECC sensor of ozone to iodine.

On January 1, 1993, new ozone absorption coefficients were adopted for use with Dobson spectrophotometers [Komhyr et al., 1993], based on the measurements of Bass and Paur [1985]. The new coefficients yield ozone values 2.6% lower than did the Vigroux coefficients. Because, also, pump efficiencies have improved in recent years, ECC ozonesondes employing 1% KI cathode sensing solution tend to overestimate ozone even more. Laboratory tests [W.D. Komhyr, EN-SCI Corporation, Boulder, Colorado, unpublished data, 1996] with a Thermo Environment Instruments (TEI), Inc., standard ozone source, with calibration traceable to the primary ozone standard of the U.S. National Institute for Standards and Technology (NIST), have indicated that the use of 1/2% KI cathode ozone sensing solution (see Appendix A) in ECC sensors results in improved measurements of ozone. ECC ozonesondes employing the less concentrated solution yield integrated total ozone amounts that agree closely with Dobson spectrophotometer total ozone.

A number of questions remain regarding the normalization procedure. For example, the validity of the assumption of constant ozone mixing ratio at atmospheric pressures less than 15 hPa needs re-examination. It may be more appropriate to use climatological high-altitude ozone data derived from satellite observations for normalization of the ECC sonde ozone profiles.

6.0 Data Archiving

Canada collects and publishes ozone data on a worldwide basis under sponsorship of the World Meteorological Organization (WMO). Data collection and publication arrangements are described in WMO Guide Book No. 2 [1981], that is available free of charge from the Canadian Atmospheric Environment Service to meteorological services and research organizations that have a reciprocal arrangement with the Atmospheric Environment Service for exchange of publications (automatically including all groups that supply ozone data and all those who regularly subscribe to the issues of "Ozone Data for the World"). Individual copies of the Guide Book are available to other organizations and individuals, for a small fee, payable to the Receiver General of Canada.

The mailing address for archiving of the ozone data is:

World Ozone Data Centre
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
Canada M3H5T4

The data should be forwarded to Canada for publication on a bi-monthly basis, as soon as possible, after the end of February, April, June, August, October, and December. The frequency of publication of the data depends on the clarity of the entries on the data sheets transmitted and the promptness with which the data are supplied.

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Appendix A: Preparation of ECC Sensor Sensing Solution

ECC sensor solution should be prepared from reagent-grade chemicals and double or triple distilled water.

(1) Cathode Solution

To 500 ml distilled water add:

5.00 g		KI
12.50 g		KBr
0.63 g		$NaH_2PO_4 \bullet H_2O$
2.50 g		$Na_2HPO_4 \bullet 12H_2O$
	or	
1.87 g		$Na_2HPO_4 \bullet 7H_2O$

Shake vigorously to dissolve the chemicals, then add distilled water to make up 1000 ml of cathode sensing solution.

(2) Anode Solution

Fill a 100-ml plastic bottle one-half full with 50 ml cathode solution (prepared as described above). Add 70 g KI crystals to the solution, and shake vigorously to dissolve the crystals. Some crystals will remain undissolved, indicating that the solution is saturated.

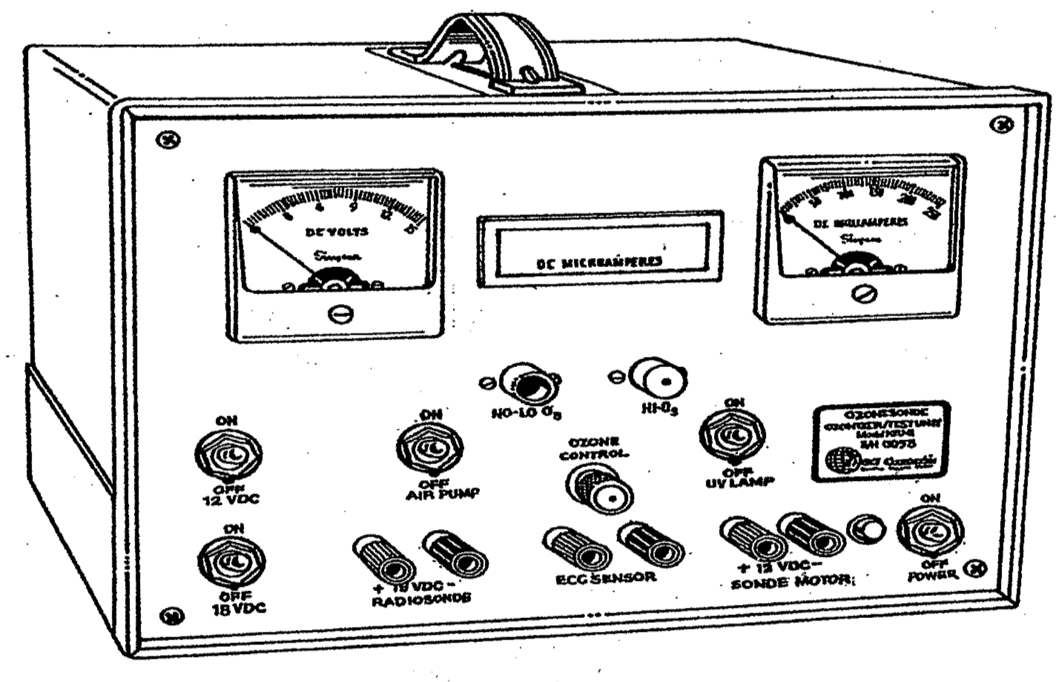
(3) Storage

Store the cathode and anode sensing solutions in a dark place at 20° to 25° C. After several months of storage old solution should be discarded and new solution prepared for use.

Appendix B: Model KTU-2 Ozonizer/Test Unit

The EN-SCI Corporation Model KTU-2 ozonizer/test unit has been designed for conditioning ECC ozonesondes with ozone, and for checking the performance of the sondes prior to release by balloon. A diagram of the unit is shown below. It measures 36 x 28 x 21 cm, and weighs 9 kg. Components of the unit are:

(1) A HI OZONE source for conditioning the sonde pump and dry sensor with ozone;



Model KTU-2 Ozonizer/Test Unit

(2) A NO-LO OZONE source, for checking on the sensor background current and for conditioning ozone sensors charged with sensing solution;

(3) A 12 VDC sonde pump motor power supply and meters for checking on the motor voltage and current drain;

(4) A microammeter (0-10 μA) for measuring the sonde ECC sensor output current;

(5) An 18 VDC power source for powering the Model DAS-2 403 MHz ground station antenna pre-amplifier during cold weather operation.

Appendix C: Reconditioning Model Z ECC Ozonesondes

(1) Improving Pump Performance

Prolonged storage of ECC ozonesondes prior to use, or submission of the instruments to extreme temperature changes during storage, may alter the pump characteristics of the instruments. It is important that, during use, the fit between the pump piston and cylinder is not too tight to avoid excessive frictional heating. An indication of the fit of the piston-cylinder assembly is the current drawn by the pump motor, which should be less than 90 mA.

If the pump motor current is greater than 90 mA when the instrument is first operated, continue operating the pump for 10-30 minutes during which time the motor current should decrease to an acceptable level. If it does not, take the following remedial action:

Remove the pump piston from the cylinder, taking care to note how the piston is oriented relative to the cylinder in order that it may be replaced later <u>without 180° rotation</u>. Rub the cylindrical surface of the piston forcefully with clean, lint-free tissue paper moistened with methyl alcohol or distilled water. Re-assemble the pump, and operate it for 15-20 minutes. The pump current should decrease. The process may have to be repeated once or twice.

If the high current persists, clamp the brass portion of the cylinder in a hand-held electric drill. Using a strip of black, wet/dry No. 400 grit sand paper laid over a rigid, flat-surfaced strip of metal of size about 2x10 cm to form a sanding block, draw the sanding block in a linear motion under the piston but in contact with it as the piston is being rotated by the drill. A thin uniform film of material removed from the surface of the piston will become visible on the sand paper. Do not over-sand. Now clean the sanded piston with methyl alcohol, and re-install it into the pump. Run the pump for 10 minutes to check on the pump current, which should have decreased. Repeat the process, if necessary, to attain a pump current of less than 90 mA after 10-20 minutes of pump operation. Check for adequate pressure and vacuum developed by the pump.

(2) Reconditioning a Recovered Ozonesonde

Remove the ozonesonde from its polystyrene flight box, and discard the sonde batteries. Clean all the external instrument parts of sensing solution residue or grime that may be present.

Discard the air intake tube; replace it with a new tube made from Teflon spaghetti, size AWG No. 12.

Remove the sensor from the sonde, and thoroughly wash the cathode and anode chambers under running tap water. Rinse with distilled water, then fill the anode chamber one-half full and the cathode chamber full with distilled water. Let stand for several hours. After several hours or more, rinse the sensor chambers several times with distilled water, and clean the sensor cathode and anode top plugs and tubing with distilled water and finally methanol. Let the sensor remain unassembled for several hours to dry before re-assembling it for use.

Disassemble the Teflon gas sampling pump, taking care to note the orientation of the piston relative to the cylinder for future similar re-assembly. Using a razor blade and a pointed knife, gently scrape any impurities from the pump base piece, cylinder, and piston that may be present. Wash all Teflon parts first with tap water, then with distilled water, and finally with methanol. After re-assembling the pump into its original configuration, activate the pump motor and squirt 1-2 cm^3 of methanol into the operating pump for final cleaning.

Using a stroboscope, check the pump motor speed. It should be nearly constant and approximately 2400 r.p.m. over the voltage range of 10-15 volts. Check, also, to ensure that the sonde pump develops sufficient pressure and vacuum (see section 2.1(b)) when operating at 12.3 VDC and drawing less than 100 mA current.

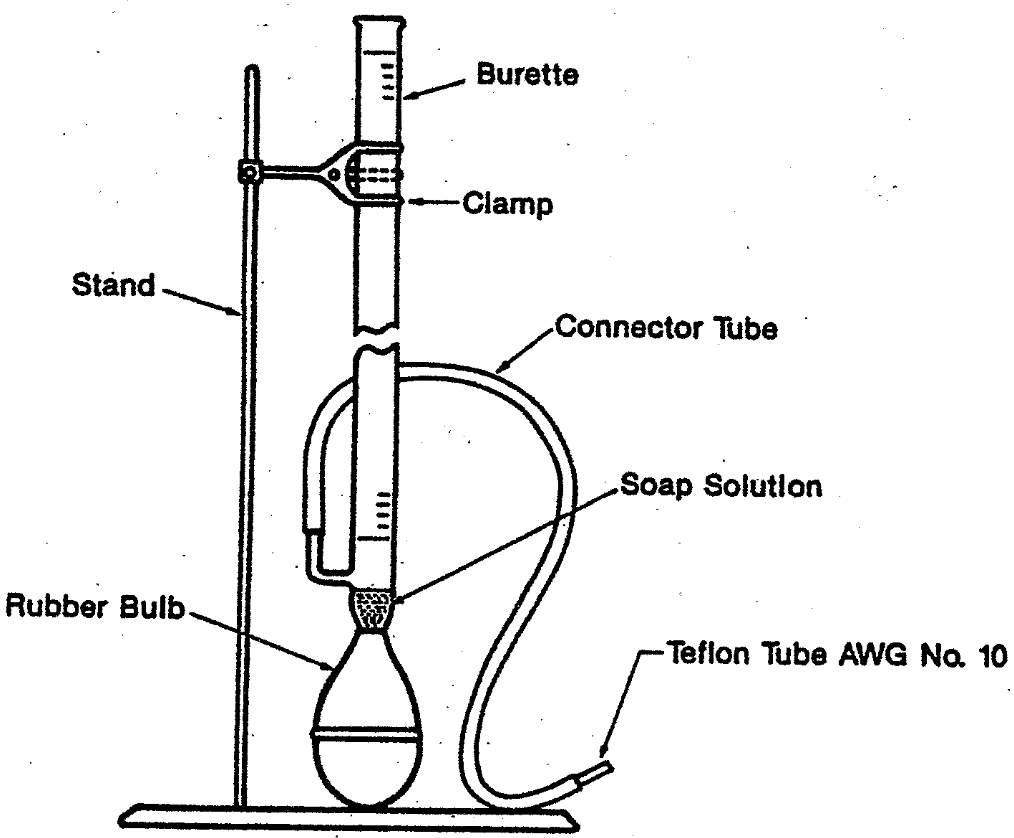
(3) Ozonesonde Reconditioning

Customers are encouraged to recondition their own ozonesondes. Technical advice and instrument components needing replacement are available from the instrument manufacturer.

Appendix D: Measurement of Ozonesonde Air Flow Rate

(1) Equipment required:

Burette with filling tube, 100-ml capacity;
Rubber bulb, 60-ml capacity;
Stop watch;
Burette stand with clamp;
Tygon tubing, approximately 60 cm long, 0.32 cm internal diameter;
Teflon tubing, thin wall, approximately 2.54 cm long, AWG No. 10;
Soap bubble solution; it may be made by adding 1 teaspoon of liquid detergent and 1 teaspoon of glycerol to 1 cup of water.



Apparatus for measurement of ECC ozonesonde pump air flow rate.

(2) Arrange the apparatus as shown in the diagram on the previous page. Fill the rubber bulb and burette with soap bubble solution to just below the filling tube of the burette as shown. (Maintain the soap solution at about the level indicated at all times by periodically adding distilled water or more soap solution to the apparatus.)

(3) The sonde pump air flow rate measurement is made with the ECC sensor charged with sensing solution. To make the measurement, connect the apparatus to the sensor cathode air-exhaust tube. This is done by slipping the Teflon-tipped connector tube of the apparatus over the short Teflon tube protruding from the top plug of the sensor cathode chamber.

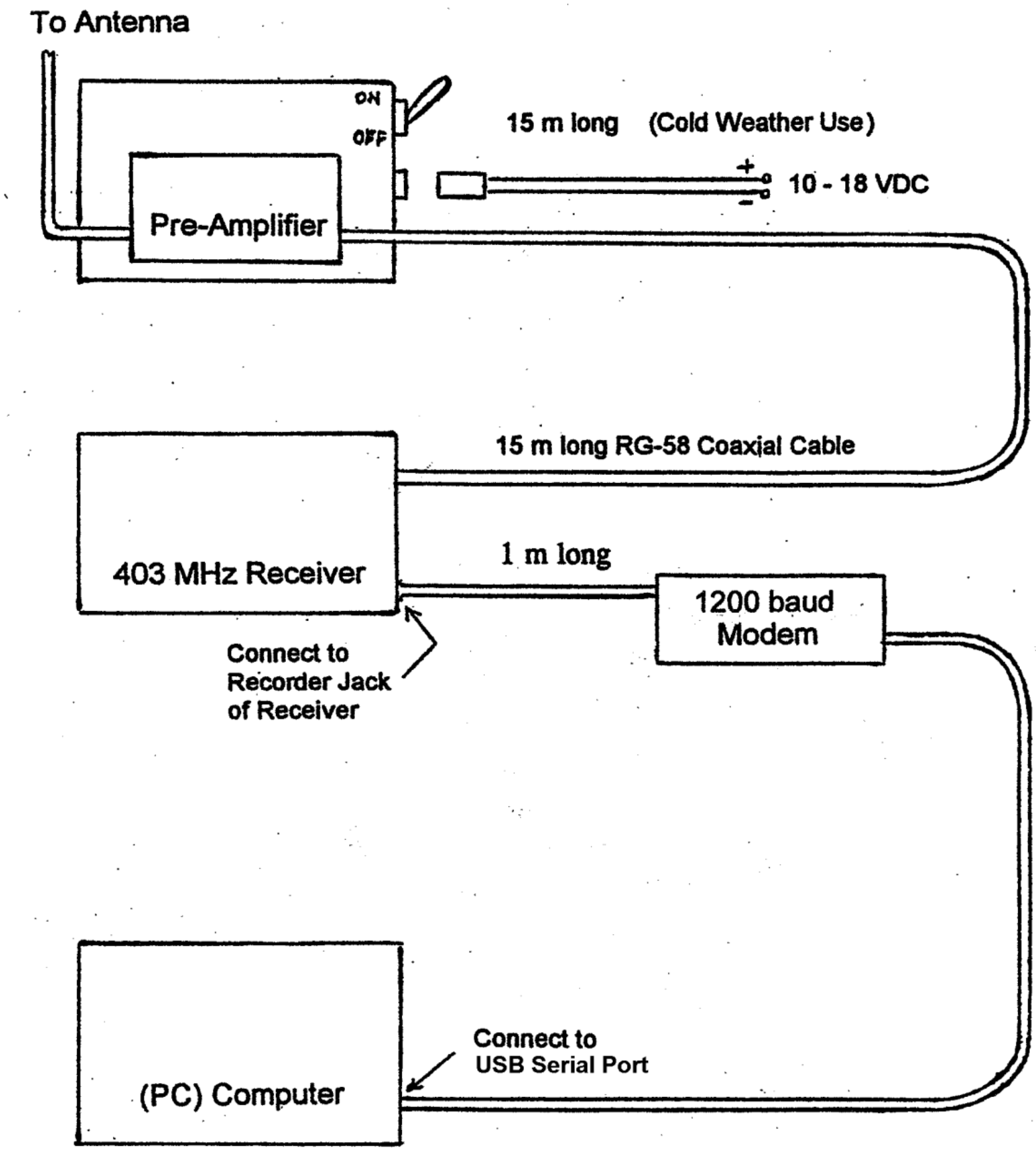
With the sonde air pump operating, squeeze the rubber bulb slightly to cause several soap bubbles to rise up the burette. Repeat the process several times until bubbles reach the top of the burette without breaking.

Now cause one bubble to form, and using a stop watch determine the time t required to displace the bubble 100 ml. Repeat the measurement several times to obtain a mean value. Record the result in the raw data file for the instrument and ozone sounding to be made.

NOTE: Because the ambient air, if not saturated with moisture, will pick up moisture from the cathode sensing solution, a more precise air flow rate measurement can be made by using air pre-saturated with moisture for measurement.

Appendix E: Data Acquisition System Configuration

The various components of the data acquisition system should be configured as shown schematically below.



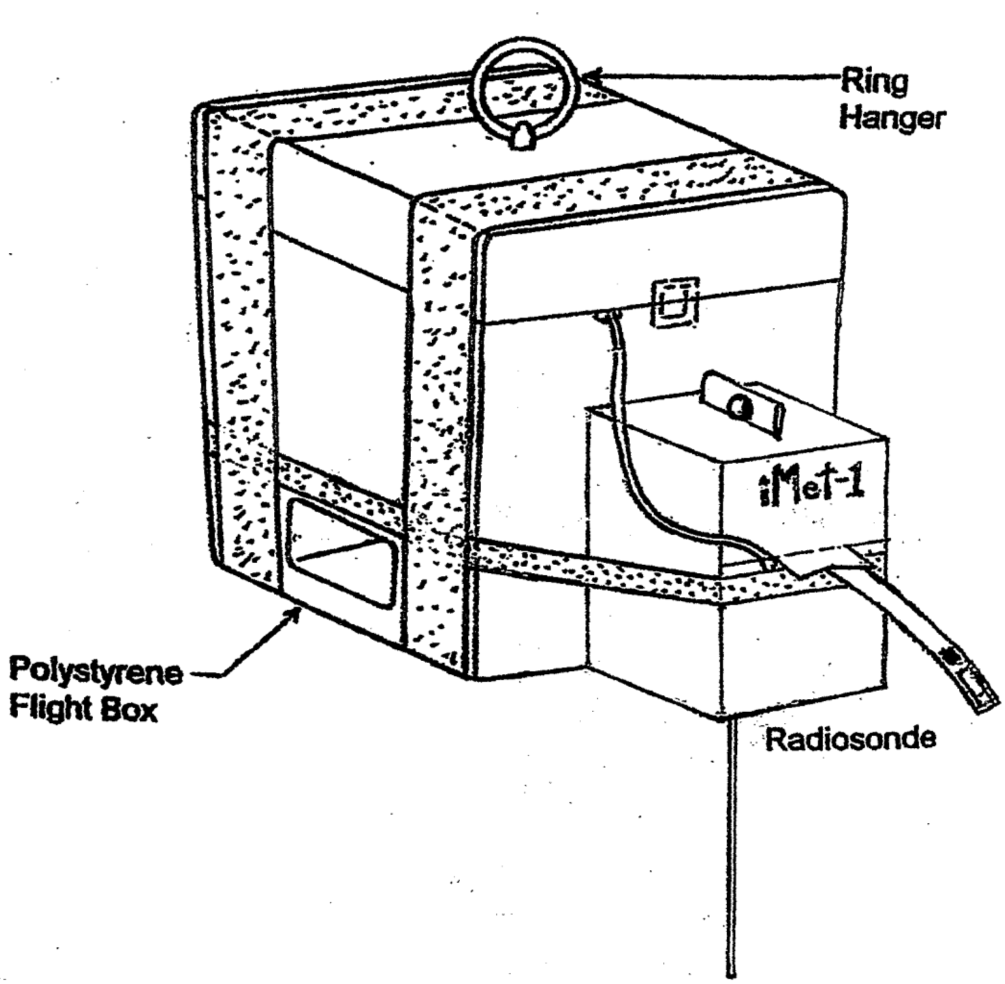
Interconnection of the Data Acquisition Equipment

A pre-amplifier is built into the antenna, and is self contained in that it is powered by two 9V batteries. A switch is provided to turn the battery power ON or OFF. To conserve battery power KEEP THE SWITCH IN THE OFF POSITION AT ALL TIMES EXCEPT WHEN THE PRE-AMPLIFIER IS IN USE. Replacement batteries are 9V lithium batteries, ULTRALIFE Type U9VL or equivalent. (Replacement 9V alkaline batteries can also be used.) Check the voltage periodically at the pre-amplifier red and black wire terminals. The voltage should be greater than about 10 VDC.

When operating the antenna in very cold weather, the batteries may fail to provide the needed voltage. A 15-m long conductor cable is supplied for use under such conditions, to supply 12-18 VDC external power to the pre-amplifier. Power may then be drawn from the EN-SCI Corporation Model KTU-2 ozonizer/test unit.

Appendix F: Flight Box Configuration

The ozonesonde environmental box and the iMet-1 radiosonde should be assembled together for balloon flight as shown in the diagram below.



Ozone Instrument Flight Package

Fasten the radiosonde instrument to the polystyrene flight box using double-sided sticky tape in the position shown above. Reinforce the connection between the two instrument boxes with a 1" (2.52cm) wide duct tape, as shown above. (This method of connecting the two instruments for flight permits access to the radiosonde battery compartment for, e.g., battery activation and for radiosonde carrier frequency selection (402, 403, 404, or 405 MHz) during instrument check-out prior to flight). Fasten the ozonesonde box cover, also as shown above, to the polystyrene flight box using 2-inch (5.08 cm) wide duct tape. Allow for about a 10-inch (25.4 cm) overlap in each tape band to ensure secure fastening even at extremely cold stratospheric temperatures.

The flight box is supplied with a ring hanger. The ring hanger is located at the vertical center of gravity of the flight box in order to maintain the flight package approximately level during balloon ascent.

To prevent excessive cooling, lithium batteries used to power the ozone instrument should be flown inside the ozone instrument compartment of the polystyrene flight box, and not in the battery compartment near the bottom of the box that is reserved for locating water-activated batteries. Using the double sided sticky tape taped to the bottom of the battery, stick the battery to the base plate of the ozonesonde, adjacent to the ECC sensor and below the sonde pump.

Sonde box internal temperature at flight termination (balloon-burst altitude) should ideally be between 10 and 5 °C, though satisfactory instrument performance will continue to temperatures as low as -1 to -2 ºC. (Sonde pump temperatures are about 5 °C higher than sonde box temperatures.) If a sonde is to be flown when stratospheric temperatures are unusually cold, as within the polar vortex during winter, make certain that the initial box temperature at launch, including battery temperature, is between 25 and 30 ºC. Also, if using a lithium battery to power the sonde, fill the battery compartment of the flight box with insulation, and tape the opening closed. This will retard battery heat loss and help maintain sonde box temperature above freezing. To conserve even more heat, also tape up the box ventilation port located on the side of the box opposite to the side to which the radiosonde is taped. (Under conditions of extremely cold temperatures, it may be necessary to install an additional heat source into the flight box.)

In very warm weather, the ventilation port should be left open to prevent excessive heat build-up within the sonde. If more ventilation is needed, a second hole may be punched through the sonde box wall (and reinforced, e.g., with a 0.25" D (0.64-cm D) plastic "straw"). The hole should be located on the side of the box to which the radiosonde is taped, next to the radiosonde and about 3.25" (~27 cm) above the bottom of the box.

If using a water-activated battery, locate the battery in the flight box battery compartment. Because the battery dissipates considerable heat during operation, it should generally be flown within the battery compartment taped only partially closed. Water activation of the battery , according to manufacturer's instructions, should begin about 15 minutes prior to the time of intended use of the battery. During this time the battery should be placed under load (use a 100 ohm, 2 watt resistor) in order to facilitate battery power build-up.