WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH

No. 157

JOSIE-1998

Performance of ECC Ozone Sondes of SPC-6A and ENSCI-Z Type

2004

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WMO TD No. 1218

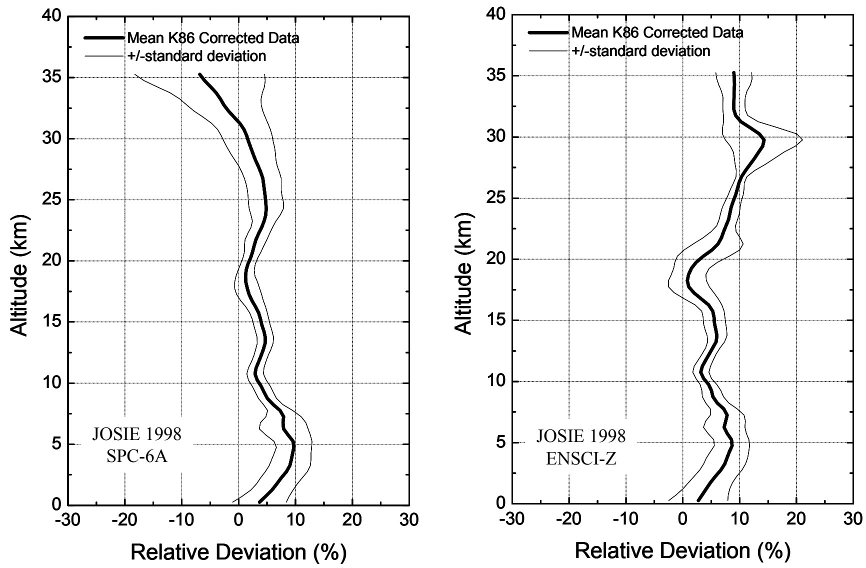
Executive Summary

Ozone sounding records provide the longest time series of the vertical ozone distribution between the surface and 30-35 km altitude. Up to an altitude of 20 km ozone sondes constitute the single data source with long term coverage for the derivation of ozone trends with sufficient vertical resolution, particularly in the altitude region around the tropopause. Consistency of instruments with regard to their quality and characteristics is a pre-requisite to assure consistent sonde measurements. [*SPARC-IOC-GAW Assessment of Trends in the Vertical Distribution of Ozone*, 1998]. As part of the quality assurance (QA) plan for ozone sondes that are in routine use in the Global Atmosphere Watch programme of the World Meteorological Organization the environmental simulation facility at the Research Centre Juelich [*http://www.fz-juelich.de/icg/icg-ii/esf/*]) is established as World Calibration Centre for Ozone Sondes. The facility enables control of pressure, temperature and ozone concentration and can simulate flight conditions of ozone soundings up to an altitude of 35 km, whereby an accurate UV-photometer serves as a reference. In the scope of this QA-plan for ozone sondes since 1996, JOSIE (= Juelich Ozone Sonde Intercomparison Experiment) activities [*http://www.fz-juelich.de/icg/icg-ii/josie/*] have been conducted at the simulation facility to assess the performance of ozone sondes of different types and manufacturers.

Ozone sondes have gone through several modifications since they were first manufactured, which adds uncertainty to trend analysis. Routine testing of newly manufactured ozone sondes will help to ensure more confidence in observed trends in the future. Therefore, JOSIE-1998 has been primarily focused on the checking of the quality of the instrument performance over a sample of 26 randomly selected ECC-sondes (13 SPC-6A and 13 ENSCI-Z), which were provided by the different ECC-sonde users in the GAW ozone sounding network. All tested ECC-sondes were subject to the same preparation, operating, and data correcting procedures described by *Komhyr* [1986]. The simulation profiles of pressure, temperature and ozone concentration were at typical mid-latitude conditions [*Smit and Kley*, 1998].

Comparison of the sondes with the UV-photometer show that in the troposphere and lower stratosphere up to 20 km altitude both sonde types have a rather similar performance. Below 20 km altitude a precision of ±(3-4)% has been consistently observed while both sonde types tend to overestimate ozone by about 5-10 %, particularly in the troposphere. In the middle stratosphere above 25 km altitude, the sonde types starts to deviate from each other quite significantly. The precision of the SPC-6A sonde decreases with altitude to about ±(5-10)% while the observed bias changes sign with altitude from about +5% at 25 km into -8% at 35 km[1]. This is in contrast to the ENSCI-Z sonde type that exhibits a precision of ±(4-5)% and a rather large positive bias of about 10% up to 35 km altitude. It has to be noted that the ENSCI-manufacturer presently recommends a different concentration for the cathode sensing solution than was used by *Komhyr* [1986] which would lower the ozone readings by about 5% if used.[*Johnson et al*., 2002]

[1] *Above 25 km altitude the negative bias and the decrease of precision of the SPC-6A sondes was mainly due to the contribution of four sondes from one stock, which showed systematically larger (negative) deviations from the UV-Photometer compared with the results obtained from the other tested SPC-6A sondes. However, the identified four sondes did pass all pre-, in-, and post-flight quality screening tests usually applied at the field site in order to check the reliability of the ozone sonde performance and the measured vertical ozone profile.*



JOSIE-1998 comparison of ECC-sondes of different manufacturers (left diagram: Model Type SPC-6A and right diagram: Model Type ENSCI-1Z) with the UV-photometer. Average (thick line) plus/minus one standard deviation (thin line) of the relative deviations of the individual sonde readings from the UV-photometer for the two ECC-sonde types. All tested ECC-sondes were subject to the same preparing (cathode sensing solution: 1% KI, full buffer), operating, and data correcting procedures described by Komhyr [1986].

A key conclusion from the observed JOSIE-1998 results is that the performance characteristics of the two ECC-sonde types are significantly different in the middle stratosphere above 25 km. The origin of the observed differences is not really understood. Large sources of uncertainty exist with regard to the corrections applied for the degrading pump efficiency at lower pressures or the choice of the chemical composition of the sensing solution in the cathode cell [*Johnson et al.,* 2002]. However, the results clearly demonstrate that small changes in instrument construction can significantly change its performance. Caution has to be taken when making instrumental changes. JOSIE-1998 demonstrates the need to validate ozone sondes on a routine basis. Furthermore, there is an urgent need for the homogenization of the standard operating procedures (SOP) for pre-launch preparation and post-flight data processing.

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1. INTRODUCTION

A widely used method to measure in-situ upper air ozone up to altitudes of 30-35 km is through use of small, lightweight and compact balloon borne sondes [*Smit*, 2002]. Up to an altitude of about 20 km ozone sondes constitute the single most important data source with long term data coverage for the derivation of ozone trends with sufficient vertical resolution, particularly in the important altitude region around the tropopause [*SPARC-IOC-GAW Assessment of Trends in the Vertical Distribution of Ozone*, 1998, *WMO-Scientific Assessment of Ozone Depletion 1998, 2002*]. Furthermore, in the lower/middle stratosphere up to 30-35 km altitude ozone sondes are of crucial importance to validate and assess satellite measurements for their long term stability. There is an urgent need for improved data quality that must be achieved by intercalibration and intercomparison of existing ozone sonde types as well as agreement through procedures for data processing and analysis.

Since 1996 the environmental simulation facility at the Research Centre Juelich [*Smit et al.*, 2000] is established as World Calibration Centre for Ozone Sondes (WCCOS) to assess the performance of the different types of ozone sondes that are commonly used within GAW (=Global Atmosphere Watch). Major task of WCCOS is to serve as a facility for quality assurance (QA) of ozone sondes operated in the WMO/GAW-Programme. The simulation chamber of the facility enables control of pressure, temperature and ozone concentration and can simulate flight conditions of ozone soundings up to an altitude of 35 km., whereby an accurate UV-photometer serves as a reference (See also Table 1). The simulation facility is described in detail by *Smit et al.* [2000] and at http://www.fz-juelich.de/icg/icg-ii/esf/.

Test room volume is 500 liter (80x80x80 cm) capable to test 4 sondes simultaneously

Computer controlled simulation according "real" atmospheric conditions:

- a.) Pressure: 10-1000 hPa
- b.) Temperature: 200-300 K
  - dynamic: Rate = ± 2 K/min
  - static: Fluctuations < 0.1-0.2 K
- c.) Ozone: 5-10000 ppbv (0.1-30 mPa)

Ozone Reference:

Dual Beam UV-Photometer:

- response: 1 s
- precision: ±0.025mPa ,
- accuracy: ± 2 % (0-25 km), ±3.5% (30-35km)

Table 1: Specifications of Environmental Simulation Chamber (ESC) of World Calibration Centre of Ozone Sondes (WCCOS). A detailed description by Smit et al. [2000] and http://www.fz-juelich.de/icg/icg-ii/esf/].

The Jülich Ozone Sonde Intercomparison Experiment (JOSIE) [*Smit et al.,* 1998, http://www.fz-juelich.de/icg/icg-ii/josie], performed in 1996, was the first GAW activity towards implementing a global quality assurance plan for ozone sondes in routine use today around the world. JOSIE-1996 showed that there is a permanent need to validate ozone sondes on a routine basis. Ozone sondes have gone through several modifications since they were first manufactured, which adds uncertainty to trend analysis. Routine testing of newly manufactured ozone sondes on a regular basis and establishing standard operating procedures for different sonde types will help to ensure more confidence in observed trends in the future. At present more than 80 percent of the GAW-ozone sounding network are using sondes of the ECC (=Electrochemical Concentration Cell) type [*Komhyr*, 1969], which are manufactured by either Science Pump Corporation (Model type: SPC-6A) or Environmental Science Corporation (Model type: ENSCI-Z). The JOSIE-1998 activities have been exclusively focused on the quality check of the instrumental performance of ECC-sondes from these two manufacturers.

2. DESIGN OF JOSIE-1998

JOSIE-1998 is dedicated to the quality assurance of the instrumental performance of the ECC-sonde type from different manufacturers. The primary goal is to check the quality of the instrumental performance over a sample of 26 randomly selected ECC-sondes, representing the different model types and provided by the different ECC-sonde users in the GAW-sounding network.

For the JOSIE-98 quality check two types of ECC-sondes have been used which are manufactured by different manufacturers:

1. SPC-6A: Manufactured by Science Pump Corporation, New Jersey, USA
2. ENSCI-Z: Manufactured by Environmental Science Corporation, Colorado, USA

A total of 26 ECC-sondes, 13 sondes of each model type (SPC-6A and ENSCI-Z[2]), have been randomly picked from the stocks of new ECC-sondes supplied by different sounding sites of the GAW-sounding network. All selected ECC-sondes were brand new, in the original packing of the manufacturer, while the manufacturing date was after January 1., 1997.

All tested ECC-sondes are subject to the same preparing (cathode sensing solution: 1% KI, full buffered), operating, and data correcting procedures described by *Komhyr* [1986]. From Figure 1, displaying the JOSIE 1996 comparison of ECC-sondes operated by 4 different ozone sounding laboratories, it was concluded that the ECC-sondes perform best with regard to precision and accuracy if operated by the procedures described by *Komhyr* [1986] and applied by FZJ [3] and AES [6] (See middle diagrams). This means that, in the troposphere and lower/middle stratosphere up to 35 km altitude, the precision is within ±(3-4)% and the accuracy about ±(4-5)%. The different performance characteristics obtained by CMDL [2] and CNRS [7] were caused by the use of different operating procedures. JOSIE-1996 clearly demonstrated that even a small change of the operating procedures can have a significant impact on the overall performance of the sonde and that caution has to be taken before any change of operating procedures of sondes. JOSIE-1996 indicated that the observed differences between the ECC-sondes are for a large fraction due to differences in the preparation and correction procedures applied by the different laboratories.

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2 *The production of SPC-5A sonde type has been stopped in January 1996 and thus excluded from JOSIE-98*

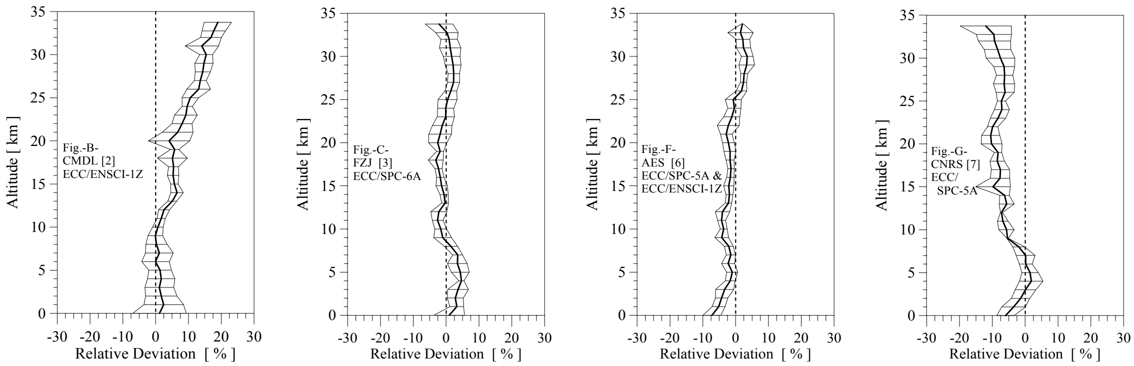

Figure 1:JOSIE-1996 comparison of ECC-sondes. Average (thick line) plus/minus one standard deviation (thin line) of the relative deviations of the individual sonde readings from the UV-photometer for each participating ECC-sounding laboratory obtained from six simulation runs. For details see Smit and Kley [1998].

3. EXPERIMENTAL DETAILS OF JOSIE-1998

3.1 Pre-, In- and Post-Flight Procedures

Procedures for the preparation and handling of the sondes are briefly as follows:

(1) All ECC-sondes were operated according the procedures described by Komhyr, 1986.

(2) All ECC-sondes were prepared in the laboratory prior to their simulation runs using the same equipment.

(3) All ECC-sondes used the same interfacing electronics (see chapter 2) to the data acquisition system (=DAS) of the facility.

(4) Preparation of the sondes, simulation runs, data processing, data validation, data analysis and data evaluation were carried out by the staff of the facility.

(5) Sensing solutions (cathode and anode) were prepared according the receipt given by Komhyr's handbook, 1986 (Cathode solution: 1% KI + full buffer & KBr, Anode solution: cathode solution saturated with KI). The solutions (in dark bottles) were stored at a temperature of about 4-6°C in a (dark) refrigerator. Before using the sensing solutions were at room temperature.

(6) Each sonde was prepared within 4±1 day prior to the simulation experiment according the guidelines of the 3-7 days in advance preparation described in the handbook by *Komhyr* [1986].

(7) The prepared sonde(s) were stored in a dry, dark place at room temperature.

(8) At the day of the simulation experiment the sondes were prepared according the handbook by *Komhyr* [1986]. The period between the end of the preparation and the start of the simulation was always less than 2 hours.

(9) The simulation started at a pressure of 1000±2hPa and a test room temperature 20±2°C.

(10) When these conditions were achieved, then the pump motors of the sonde have been turned on.

(11) The time period between pump activation and start of simulation run was always between 5 and 10 minutes.

(12) During each simulation run 4 sondes, 2 pieces of SPC-6A and 2 pieces of ENSCI-Z, were tested simultaneously. For each simulation run each of the 4 selected sondes were selected from a different stock of sondes, while it was ensured that at least 2-4 sondes of each stock had participated in the JOSIE-1998 quality check.

(13) The simulation profile of pressure, temperature and ozone concentration at typical mid-latitude conditions, similar to the mid-latitude profile used during JOSIE-1996 [*Smit and Kley,* 1998].

(14) The pump temperature was measured by a UUA 41J1 Fenwall thermistor that was taped at the outside of the Teflon block of the pump near to and at the same height as the tube outlet from the block (going to the cathode cell).

(15) To investigate the response time and the background characteristics of the sondes during the simulation run ozone was set temporarily (period ≈ 150-200 sec) to zero level. This zero-step response was performed two times during the simulation run: once in the tropospheric part at a simulated altitude between 4 and 7 km (simulation time between 800 and 1400 second) and once in the stratosphere at an altitude between 16 and 19 km (simulation time between 3200 and 3800 second).

(16) High graded purified synthetic air was used for the sonde preparation as well as for the ozone profile simulation.

3.2 Pre-& Post-Flight Preparation ECC-Sondes

Each ozone sounding is made with a new instrument, which has therefore to be characterized well prior to flight. Consistency of the flown instruments with regard to their quality and characteristics, but also uniform operating procedures, is a pre-requisite to assure consistent sonde measurements. Therefore, before each simulation flight the different components of the sondes were carefully prepared and checked in the laboratory following the guidelines of *Komhyr* [1986] for the ECC-sonde.

The performance of the ECC-ozone sensor is checked for:

a) Background current after the sensor was flushed for 10 minutes with ozone free air. This was determined before and after the sensor had been exposed with ozone.
b) Conversion efficiency by comparison sonde readings with an ozone UV-photometer (Type: Thermo Electron Model 49-103, USA) at different ozone pressures (ca. 0, 2.5, 5, 10, and 20 mPa).
c) Volumetric flow rate of the gas sampling pump, which was determined with a bubble flow meter [*Komhyr,* 1986].
d) Response time[3] obtained from a downward ozone step signal at an initial level of about 20 mPa.
e) Electrical current pump motor as a measure of the pump friction.

After the simulation experiment the pump flow rate and electrical current of the pump motor were measured again. The results of the pre-and post flight performance checks are summarized in Figure 2 and Table 2. Both ECC-sonde types showed very consistent results.

[3] *The response time* τ_{Res} *on a downward response is defined as the time required, that the signal S(t) decayed by a factor 1/e of its initial value S(0) , whereby* $S(t) = S(0) * Exp[-t/\tau_{Res}]$

The background currents of the SPC-6A and ENSCI-Z sondes were of the same magnitude and showed the same typical behavior of getting significantly larger after exposure with ozone. This enhancement effect of the background current from values of about 0.04 µA before ozone exposure to values of about 0.11 µA after exposure of ozone is most likely due to “memory” effects of the ECC-sensor caused by residuals from the reaction of ozone in the sensing cathode solution. However, the origin of this enhancement effect is not understood very well at the present [*Johnson et al*, 2002]. The conversion efficiency of both sonde types, i.e. ratio ECC-ozone sonde to UV-ozone photometer, is very close to 1.00 for all tested sondes. No significant changes of the pump flow rate or the electrical current of the pump motor of all tested sondes were observed between the pre-and post flight check. The pump flow rate of the ENSCI sonde is about 5% lower than the SPC6A-sonde, such that the response times of ENSCI sondes tend to be a little larger compared to the SPC6A. However, from Figure 2 it is depicted that all tested sondes from both manufacturers show a very good performance during their pre-and post- flight checks.

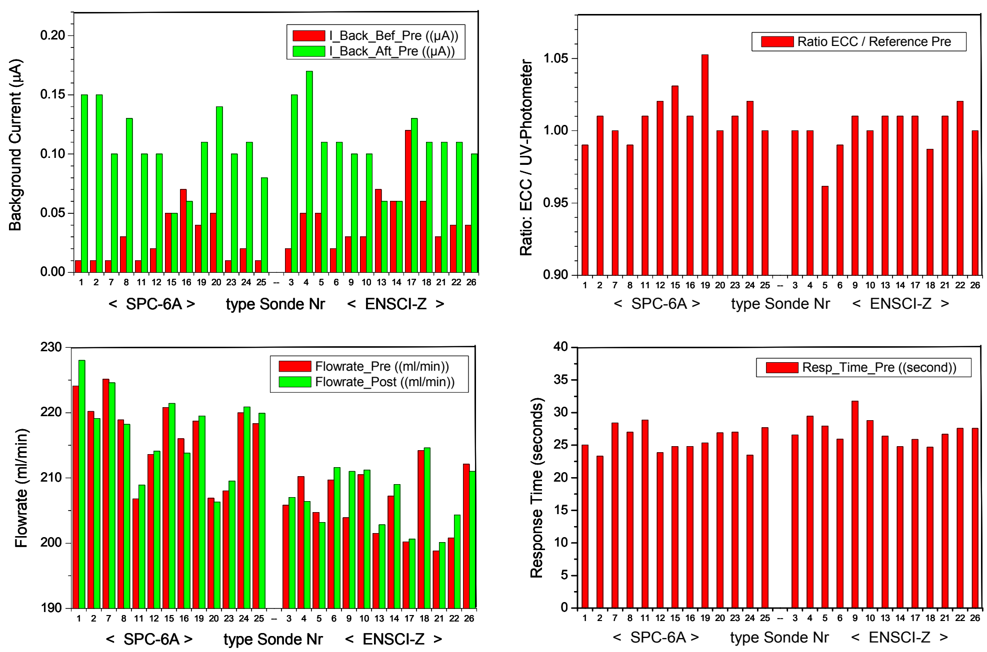

Figure 2: Results from pre-flight tests of the performance of the “flown” ECC-sondes. Left upper diagram: Background current of ECC-sensor before and after exposure with ozone. Right upper diagram: Conversion efficiency of ECC-sensor compared to UV-photometer. Left lower diagram: Flow rate of gas sampling pump at pre-and post- flight simulation. Right lower diagram: Response time of ECC-sensor. For details see text.

Ground Check Parameter	SPC-6A Sonde		ENSCI-Z Sonde	
	Pre-Flight Ground Check Average ± Stand. Deviation	Post-Flight Ground Check Average ± Stand.Deviation	Pre-Flight Ground Check Average ± Stand.Deviation	Post-Flight Ground Check Average ± Stand.Deviation
Background Current Before Ozone Exposure [µA]	0.03 ± 0.02 *{0.10 mPa Ozone}*		0.05 ± 0.03 *{0.19 mPa Ozone}*	
Background Current After Ozone Exposure [µA]	0.11 ± 0.03 *{0.40 mPa Ozone}*		0.11 ± 0.03 *{0.40 mPa Ozone}*	
Ratio of ECC-Sonde to UV-Photometer	1.01 ± 0.02		1.00 ± 0.02	
Response Time [s]	26 ± 2		27 ± 2	
Pump Flow Rate [ml/min]	217 ± 6	217 ± 6	206 ± 5	207 ± 5
Pump Motor Current [mA]	83 ± 7	82 ± 7	76 ± 7	69 ± 5

Table 2: Results from pre–and post-flight tests of the performance of the flown ECC-sondes, obtained during ground checks in the laboratory at ambient pressure and temperature. For details see text.

4. DATA PROCESSING

4.1 Basic Operating Formulas

In the ECC-ozone sensor each molecule of ozone forced through the sensing solution in the electrochemical cell generates an electrical current of approximately two electrons in the external circuit. In other words, the electrical current generated in the electrochemical cell is directly related to the uptake rate of ozone in the sensing solution [*Komhyr*, 1969] and is determined by:

[E-1] $$\mathbf{P_{O3,\,Sonde} = 0.04307 * \frac{T_{Pump}}{\Phi_{V,\,Pump}} * I_{O3,\,Sonde}}$$

$P_{O3,Sonde}$ = Pressure of ozone, [mPa]
T_{Pump} = Temperature of air sampling pump, [K]
$\Phi_{V,Pump}$ = Volumetric flow rate of air sampling pump, [ml/s]
$I_{O3,Sonde}$ = Electrical current due to sampled ozone, [µA]

The overall electrical current, $I_{M,SONDE}$, measured by the sonde may be a superposition of the ozone current, $I_{O3,SONDE}$ and the background current, $I_{B,SONDE}$:

[E-2] $$I_{O_3,Sonde} = I_{M,Sonde} - I_{B,Sonde}$$

$I_{O3,Sonde}$ = Electrical current measured by ozone sensor due to ozone, [μA]

$I_{B,Sonde}$ = Electrical current measured by ozone sensor due to background, [μA]

4.2 Data Correction Methods

All sonde data were processed and corrected according to the operating procedures specified by Komhyr [*1986*], summarized in Table 3.

Background Correction	Temperature Pump	Pump flow Corrections
Before Exposure to Ozone Pressure Dependent	External	Pump Efficiency: Komhyr, 1986 (2.5 cm^3 cathode sensing solution).

Table 3: Corrections used for the standard K86 data processing according Komhyr [1986].

4.2.1 Pump Flow Efficiency Correction

The volumetric flow of the gas sampling pump of each sonde is individually measured before flight as part of the pre-flight preparation procedure. At ambient air pressures below about 200 hPa the efficiency of the gas sampling pump decreases for which is corrected by applying an average pump efficiency correction table as function of ambient pressure reported by *Komhyr* [1986] and listed in Table 4. Also incorporated in Table 4 is the pump flow efficiency corrections recommended by the manufacturer of the ENSCI-sondes [*Komhyr, 1997*]. These corrections are slightly higher above 15 hPa air pressures than the corrections after Komhyr 1986 which are applied in this report.

4.2.2 Background Correction

The background is treated as an offset of the measured signal (see also equation E-3) with a pressure dependent background correction whereby an oxygen dependency is assumed. This means that this offset gradually declines with decreasing pressure and is vanishing small in the upper troposphere and stratosphere [*Komhyr*, 1986].

Pressure (hPa)	Correction after Komhyr, 1986 (SPC-Handbook) (2.5 cm3 cathode solution)	Correction after Komhyr, 1997 (ENSCI-Handbook) (2.5 cm3 cathode solution)
1000	1.000	1.000
200	1.007	1.000
150	1.008	1.002
100	1.010	1.007
70	1.012	1.013
50	1.015	1.018
30	1.024	1.029
20	1.033	1.041
15	1.041	1.048
10	1.054	1.066
7	1.070	1.087
5	1.087	1.124
3	1.124	1.240

Table 4: Pump flow corrections at low pressures according Komhyr, 1986 and 1995/1997.

5. RESULTS AND DISCUSSION

5.1 Introduction

In seven simulation runs a set of 26 ozone sondes (13xSPC-6A and 13xENSCI-Z) were tested (See Table 5). For the simulation runs a typical mid-latitude profile taken from the US Standard Atmosphere (1976) for 40 ^{o}N-50^{o}N with a tropopause height of 12 km similar as the mid-latitude profile type used during JOSIE 1996 [*Smit and Kley*, 1998]. Pressure and temperature in the simulation chamber were regulated to follow an ascent velocity of 5m/s up to an altitude corresponding to about 33-35 km. The pressure inside the test room of the simulation chamber has been measured with three different capacitive manometers: 1-1000 hPa, 0-100 hPa, and 0.1-12.5 hPa (accuracy of each manometer better than +/-0.5 % of their reading). Spatial temperature variations of about 2-5 Kelvin inside the test room depending of the air pressure can be expected. Therefore, two different air temperatures, measured inside the ESC (= Environmental Simulation Chamber), are recorded: temperature inside chamber measured with a Pt100 located at ozone manifold and the actual temperature measured (by Pt-100) at the individual air intake of each sonde, just exterior its Styrofoam box.

Sonde Nr.	Sim Nr.	Sonde Code	Stock Nr.	SondeType
1	51	6A4087	2A	SPC-6A
2	51	6A2069	5A	SPC-6A
3	51	Z02950	4B	ENSCI-Z
4	51	2Z0825	1B	ENSCI-Z
5	52	Z03886	2B	ENSCI-Z
6	52	Z02956	4B	ENSCI-Z
7	52	6A4683	1A	SPC-6A
8	52	6A5969	3A	SPC-6A
9	53	2Z0858	1B	ENSCI-Z
10	53	Z03919	2B	ENSCI-Z
11	53	6A5980	3A	SPC-6A
12	53	6A2111	5A	SPC-6A
13	54	Z03910	2B	ENSCI-Z
14	54	Z02951	4B	ENSCI-Z
15	54	6A4744	1A	SPC-6A
16	54	6A5973	3A	SPC-6A
17	55	Z03916	2B	ENSCI-Z
18	55	Z02954	4B	ENSCI-Z
19	55	6A4088	2A	SPC-6A
20	55	6A5976	3A	SPC-6A
21	56	1Z1666	6B	ENSCI-Z
22	56	2Z0810	6B	ENSCI-Z
23	56	6A5970	3A	SPC-6A
24	56	6A2070	5A	SPC-6A
25	57	6A4086	2A	SPC-6A
26	57	Z03895	2B	ENSCI-Z

Table 5: JOSIE 1998 simulation runs and the individual sondes used.

As independent and common time scale the system time of the data acquisition system (DAS) is used for the processing of the simulation data. The data were made equidistant in time (system time) with a time step of 5 seconds. The presented simulation time is synchronized with the system time but is set to zero at the start of the simulation experiment. The simulated altitude had been calculated step by step as the cumulative sum of the height difference between two successive pressure levels using the hydrostatic equation[(4)].

The results of the 26 tested ECC-sondes during 7 simulation runs are presented in Appendix A of this report in the form of a panel of four diagrams for each sonde. The upper left diagram displays the complete individual vertical profiles of measured ozone by sonde (K86-correction) & UV-Photometer, air temperature and external pump temperature while the upper right diagram presents the tropospheric part of the profile in more detail. The lower left and right diagrams show the corresponding vertical profiles of the absolute deviations and relative deviations of ozone measured by the sonde compared with the UV-Photometer as reference, respectively. Excluded are time response parts (one in troposphere) and (one in stratosphere) which are replaced by linear interpolation between begin and end values of the individual reported parameters. The time response parts are reported separately in section 5.3. The results of the individual profiles show that in general the tested sondes track the simulated ozone profiles very well and are in good agreement with the ozone reference. However, two striking observations were made:

- Occasionally some of the ENSCI-Z sondes showed a narrow, but strong ozone spike at about 30 km altitude (e.g. Sonde Nr. 4, 6, 10, 17). The spikes revealed systematically at a corresponding pressure level of about 13 hPa and were exclusively observed for ENSCI-sondes. After carefully proving the performance of the data acquisition system of the simulation facility it is obvious that the observed ozone spikes are sonde made. Several ozone sounding stations using ENSCI sondes confirmed similar incidental observations of ozone spikes at about 10-15 hPa pressure levels. The origin of these ozone spikes is not understood at all.

- For one stock of SPC-6A sonde (i.e. Stock Nr. 3A) four out of five flown SPC-6A sondes (i.e. 6A5970= Sonde Nr.23, 6A5973= Sonde Nr.16, 6A5976= Sonde Nr.20, and 6A5980= Sonde Nr.11) showed systematically larger (negative) deviations from the UV-Photometer compared with the results obtained from the other tested SPC-6A sondes. However, the identified four sondes did pass all pre-, in-, and post-flight quality screening tests usually applied at the field site in order to check the reliability of the ozone sonde performance and the measured vertical ozone profile. This means that the 4 deviating sondes of Stock Nr.3A will be included in the evaluations of the overall performance of the SPC-6A sondes.

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[4] *Hydrostatic equation is defined as* $\Delta Z = \frac{R}{g} * \frac{T_{i+1} + T_i}{2} * \mathrm{Ln}\left(\frac{P_i}{P_{i+1}}\right)$ *, whereby R= gas constant, g= gravity constant, T= temperature, P= pressure and indices i and i+1 are representing the two succeeding pressure levels*

5.2 Total Ozone Normalization as Screening Test

The total ozone normalization factor is defined as the ratio of the integrated columns of ozone obtained from the UV-photometer and the sonde respectively. Although total ozone normalization factor is not used to correct the sonde profile, it provides an excellent screening test for unreliable soundings using the criterion that in field operation the normalization factor should not deviate more than about 10-20 percent from unity. However, the normalization factor is not a guarantee that the profile is correct. Table 6 shows the total ozone column normalization factor for the K86-corrected ozone sonde data, which is the ratio of the integrated ozone profile measured by the UV-photometer and sonde, for each sonde tested plus the average factor (incl. standard deviation) for each sonde type. All individual normalization factors for the standard corrected data range between 0.92 and 1.01. The average normalization factor obtained for each ECC-sonde type are: 0.973±0.018 for the SPC-6A and 0.933±0.006 for the ENSCI-Z. Although, the normalization factor for ENSCI-Z sondes is about 4 percent lower than for SPC-6A sondes its variability (standard deviation of ±0.006) is significantly smaller than for SPC-6A (standard deviation of ±0.018).

5.3 In-Flight Time Response

To investigate the response time and background characteristics of the different ozone sondes in the troposphere as well as in the stratosphere during each simulation run, ozone was temporarily set to zero level. The individual time response profiles of the four simultaneously tested sondes are for each in-flight response test shown in Appendix-B. From the individual response curves the response time[5] and the observed offset at zero ozone of each sonde has been estimated and listed in Table 7. For the sake of clarity the presented sonde data were already corrected for background according Table 3.

In general, the time response in upward as well as in downward direction is rather good for all tested sondes. The response time of both ECC-sonde types is within 20-30 seconds, which corresponds at an ascent velocity of 5m/s to an altitude resolution of about 100-150 m. The response times of the ENSCI-Z sondes are about 4-6 seconds larger than the SPC-6A sondes response times due to the slightly lower pump flow rates of ENSCI-Z sondes.

During the periods (200-300 s) of zero ozone none of the tested sondes returned to zero. Based on the relative short response time of 20-30 seconds of the ozone sensor it is expected that the sensor signal values would already has been decayed far below the observed offset-values. In the stratospheric part the offsets of each sonde is for both sonde types even substantial larger than in the corresponding tropospheric part of the simulated ozone profile. This may indicate to an offset, which depends on the ozone exposure of the ECC-ozone sensor. However, at present the origin of these offset signal is not understood.

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5 The response time τ_{Res} on a downward response is defined as the time required, that the signal S(t) decayed by a factor 1/e of its initial value S(0) , whereby $S(t) = S(0) * Exp[-t/\tau_{Res}]$

Sonde Nr	Sonde Type	Sonde Code	Stock	Total Ozone Normalization Factor
1	SPC-6A	6A4087	2A	0,966
2	SPC-6A	6A2069	5A	0,954
7	SPC-6A	6A4683	1A	0,963
8	SPC-6A	6A5969	3A	0,972
11	SPC-6A	6A5980	3A	0,969
12	SPC-6A	6A2111	5A	0,942
15	SPC-6A	6A4744	1A	0,955
16	SPC-6A	6A5973	3A	1,002
19	SPC-6A	6A4088	2A	0,967
20	SPC-6A	6A5976	3A	1,001
23	SPC-6A	6A5970	3A	0,997
24	SPC-6A	6A2070	5A	0,974
25	SPC-6A	6A4086	2A	0,981
Average over 13 SPC-6A sondes (±1σ)				**0.973±0.018** *[0.964±0.012]*
3	ENSCI-Z	Z02950	4B	0,927
4	ENSCI-Z	2Z0825	1B	0,926
5	ENSCI-Z	Z03886	2B	0,939
6	ENSCI-Z	Z02956	4B	0,934
9	ENSCI-Z	2Z0858	1B	0,922
10	ENSCI-Z	Z03919	2B	0,933
13	ENSCI-Z	Z03910	2B	0,935
14	ENSCI-Z	Z02951	4B	0,932
17	ENSCI-Z	Z03916	2B	0,933
18	ENSCI-Z	Z02954	4B	0,936
21	ENSCI-Z	1Z1666	6B	0,944
22	ENSCI-Z	2Z0810	6B	0,936
26	ENSCI-Z	Z03895	2B	0,933
Average over 13 ENSCI-Z sondes (±1σ)				**0.933±0.006**

Table 6: Overview of total ozone column normalization factors (RAW-data and K86-corrected data) for the invidual ozone sondes tested. The cursive numbers between brackets are average total ozone normalization factors excluding 6A5970, 6A5973, 6A5976, and 6A5980 for 1A & SPC-6A. The SPC-6A sondes excluded are all from stock 3A, which showed systematically a larger deviation from the UV-Photometer with regard to the other tested SPC-6A sondes.

Sonde Type	Sonde Nr.	Response Time (s)		Offset (mPa)	
		Troposphere	Stratosphere	Troposphere	Stratosphere
SPC-6A	01	-	17	-	0.41
	02	-	17	-	0.41
	07	23	26	0.14	0.41
	08	22	25	0.18	0.61
	11	26	23	0.18	0.48
	12	21	20	0.13	0.40
	15	26	22	0.35	0.97
	16	25	22	0.12	0.53
	19	23	22	0.12	0.5
	20	24	25	0.11	0.59
	23	26	22	0.18	0.55
	24	23	18	0.11	0.43
	25	25	21	0.15	0.52
	Average	**24.0±1.7**	**21.5±2.9**	**0.16±0.07**	**0.52±0.15**
ENSCI-Z	03	-	22	-	0.4
	04	-	25	-	0.5
	05	25	34	0.059	0.7
	06	23	27	0.11	0.71
	09	32	32	0.11	0.5
	10	27	31	0.12	0.51
	13	31	31	0.09	0.56
	14	29	29	0.10	0.51
	17	25.	29	0	0.51
	18	25	29	0.05	0.43
	21	26	27	0.16	0.63
	22	31	30	0.07	0.42
	26	29	29	0.1	0.51
	27	29	25	0.18	0.37
	Average	**27.7±2.9**	**28.6±3.2**	**0.10±0.05**	**0.52±0.10**

Table 7: Response time and offset of individual sondes obtained from in-flight response characteristics during simulation runs in which ozone was temporarily set to zero (see text). It is to be noted that the sonde data were already corrected for the background (see table 2).

5.4 Comparison Sondes with UV-Photometer

5.4.1 Introduction

An overview of the quantitative results of the sonde comparison with the UV-photometer for each sonde type is shown in Figure 3 for SPC-6A- and ENSCI-Z-sondes in the upper and lower diagrams, respectively. For each type of all tested sondes the comparison is presented as averages (± one standard deviation) of the ozone pressure deviations (left diagram) and as averages (± one standard deviation) of the relative deviations (right diagram) of the individual sonde readings from the UV-photometer, respectively.

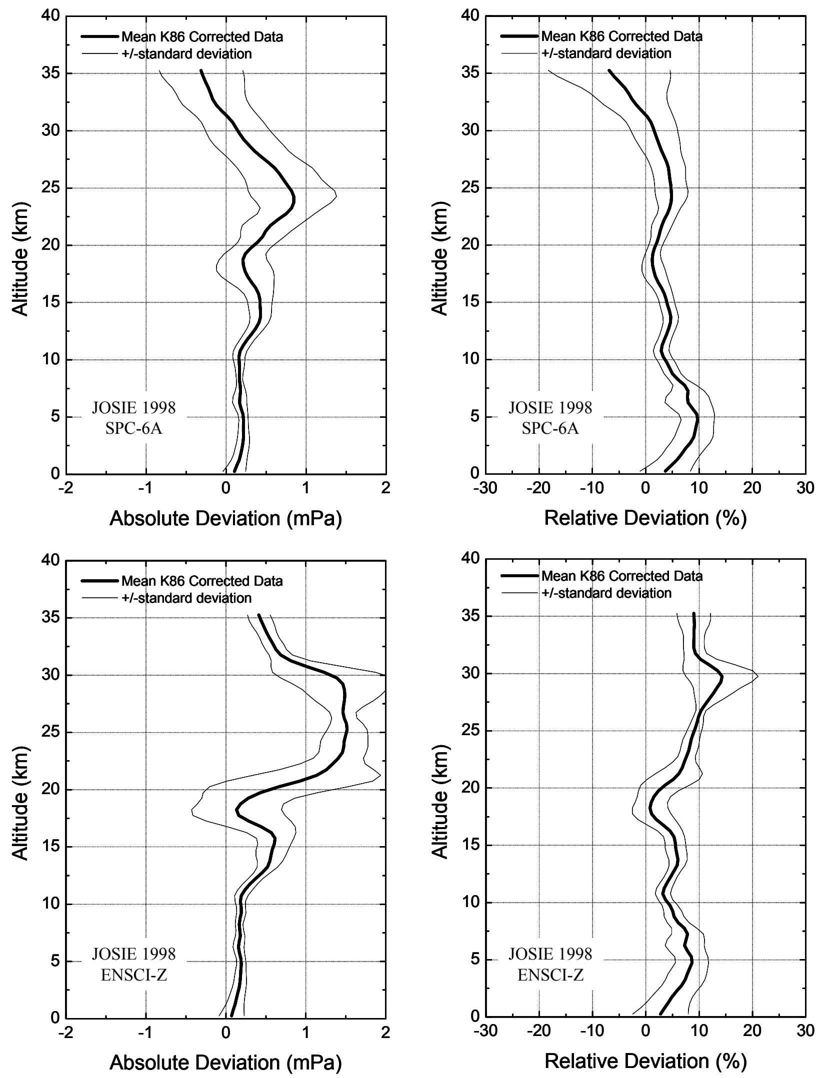

Figure 3: JOSIE-1998 comparison of all (13) tested SPC-6A (upper diagrams) and all (13) tested ENSCI-Z ozone sondes (lower diagrams). Results presented as averages (± one standard deviation) of the ozone pressure deviations (left diagrams) and as averages (± one standard deviation) of relative deviations (lower left and right diagram) of the individual sonde readings from the UV-photometer, respectively.

In the troposphere and lower stratosphere up to 20 km altitude both sonde types show a rather similar performance. In the lower and middle troposphere the sondes overestimate ozone on about 5-10 % compared to the UV-photometer. Between 10 and 20 km altitude the agreement of both sonde types with the UV-photometer is very good. Above 20 km altitude the ENSCI-Z sondes tends to overestimate ozone while the SPC-6A sondes underestimate ozone compared to the UV-photometer readings. However, the low readings of the SPC-6A sondes above 20 km altitude is mainly caused by the four sondes from Stock 3A (See Section 5.1) which showed systematically larger (negative) deviations from the UV-Photometer compared with the results obtained from the other tested SPC-6A sondes. Figure 4 show, similar to upper diagrams of Figure 4 (upper diagrams), the comparison of SPC-6A sondes, however, yet by excluding the four marked sondes of Stock Nr.3A (i.e. 6A5970= Sonde Nr.23, 6A5973= Sonde Nr.16, 6A5976= Sonde Nr.20, and 6A5980= Sonde Nr.11), which showed significant lower readings above 25 km altitude (see section 5.1).

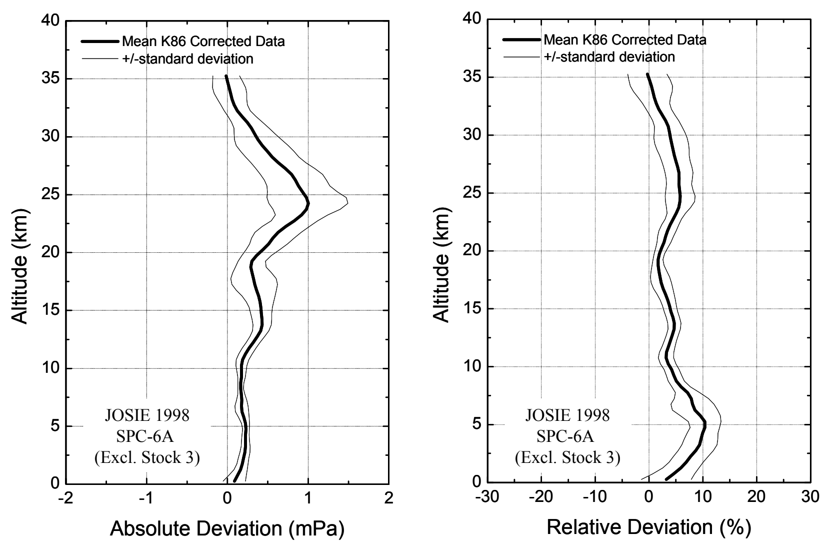

Figure 4:JOSIE-1998 comparison of 9 tested SPC-6A ozone sondes presented as average (± one standard deviation) of the ozone pressure deviations (left diagram) and as average (± one standard deviation) of relative deviations (right diagram) of the individual SPC-6A sonde readings from the UV-photometer, respectively. Excluded are the sondes 6A5970= Sonde Nr.23, 6A5973= Sonde Nr.16, 6A5976= Sonde Nr.20, and 6A5980= Sonde Nr.11 which showed significant lower readings above 25 km altitude (see section 5.1).

5.4.2 Precision, Bias and Accuracy

The precision is determined by the standard deviation of the average of the sonde deviations (= bias) with the UV-Photometer, while the accuracy is determined as the sum of sonde precision and the absolute value of its bias with the UV-Photometer. A survey of the SPC6A-sonde bias, its precision and accuracy are listed in Table 8 and 9 in altitude bins of 5 km on ozone pressure scale and on relative scale with regard to UV-Photometer, respectively.

Up to 20 km altitude both types of sondes show a very good precision better than ±(2-4)%, however, both sonde types show a positive bias of about 5-10 %, particularly in the troposphere. In the middle stratosphere (above 25 km) the performance of both sonde types starts to deviate from each other quite significantly. The precision of the SPC-6A sonde decreases with altitude to about ±(5-10)% while the observed bias changes sign with altitude from about +5% at 25 km into -8% at 35 km. This in contrast to the ENSCI-sonde type, which exhibits a precision of ±(4-5)% and a rather large positive bias of about 10% up to 35 km altitude. The lower precision and negative bias of the SPC6A sondes above 25 km altitude is mainly caused by the four sondes from Stock 3A (See previous section and also Section 6.1). The accuracy of the SPC6A and ENSCI-Z sondes is majorly determined by the contribution of the bias, which is mostly positive of sign.

A direct comparison between the performance of the tested SPC-6A and ENSCI-Z sondes are displayed in Figure 5, which shows the absolute and relative differences between the SPC-6A and ENSCI-Z sondes while Table 10 gives an overview of these differences in altitude bins of 5 km.

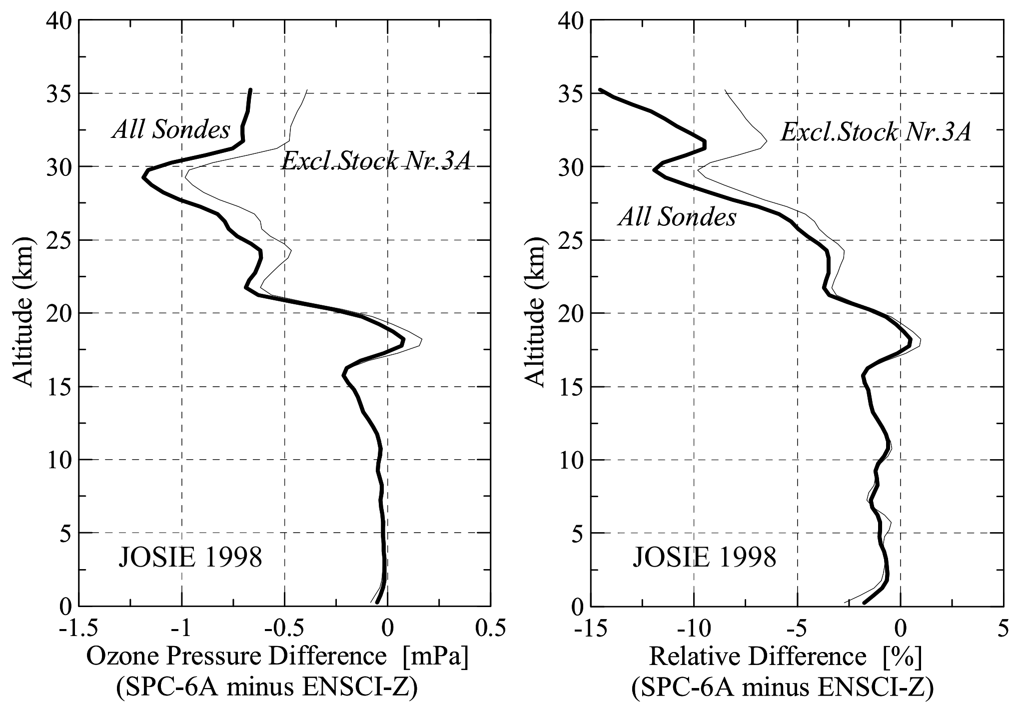

Figure 5: JOSIE-1998 comparison of the absolute (left diagram) and relative (right diagram) differences between SPC-6A and ENSCI-Z sondes derived from the differences of the average deviations of the SPC-6A and ENSCI-Z sondes with the UV-Photometer as presented in the Figures 4 and 5 for all tested SPC-6A sondes (fat line) and excluding the sondes of stock nr. 3A (thin line), respectively.

Altitude Range (Km)	Mean Absolute Deviation ± Standard Deviation = Bias±Precision Note: Between brackets is the accuracy which is defined as ±(Bias + Precision)		
	SPC-6A **(mPa)**	**SPC-6A: Excluded Stock 3A** **(mPa)**	**ENSCI-Z** **(mPa)**
30-35	-0.1 ± 0.5 (± 0.6)	0.1 ± 0.2 (± 0.3)	0.7 ± 0.3 (± 1.0)
25-30	0.5 ± 0.5 (± 1.0)	0.7 ± 0.4 (± 1.1)	1.5 ± 0.6 (± 2.1)
20-25	0.7 ± 0.5 (± 1.2)	0.8 ± 0.3 (± 1.1)	1.3 ± 0.7 (± 2.0)
15-20	0.3 ± 0.3 (± 0.6)	0.4 ± 0.2 (± 0.6)	0.4 ± 0.5 (± 0.9)
10-15	0.3 ± 0.1 (± 0.4)	0.3 ± 0.1 (± 0.4)	0.4 ± 0.2 (± 0.6)
5-10	0.2 ± 0.1 (± 0.3)	0.2 ± 0.1 (± 0.3)	0.2 ± 0.1 (± 0.3)
0-5	0.2 ± 0.1 (± 0.3)	0.2 ± 0.1 (± 0.3)	0.2 ± 0.1 (± 0.3)

Table 8: Bias (systematic deviation) and precision of the SPC-6A (incl. And excl. stock 3A) and ENSCI-Z ozone sondes. The accuracy (between brackets) is determined by the sum of the precision and the absolute value of the bias. For details see text.

Altitude Range (Km)	Mean Relative Deviation±Standard Deviation = Relative Bias±Relative Precision Note: Between brackets is the accuracy which is defined as ±(Rel.Bias+Rel.Precision)		
	SPC-6A **(%)**	**SPC-6A: Excl. Stock 3A** **(%)**	**ENSCI-Z** **(%)**
30-35	-2.0 ± 7.1 (± 9.1)	1.8 ± 3.0 (± 4.8)	9.9 ± 4.1 (± 13.9)
25-30	3.5 ± 3.9 (± 7.4)	5.0 ± 2.7 (± 7.7)	12.0 ± 4.7 (± 16.7)
20-25	4.0 ± 2.8 (± 6.8)	4.2 ± 1.8 (± 6.0)	7.3 ± 3.7 (± 11.0)
15-20	2.2 ± 2.0 (± 4.2)	2.4 ± 1.4 (± 3.8)	2.9 ± 3.4 (± 6.2)
10-15	3.9 ± 1.8 (± 5.7)	4.0 ± 1.3 (± 5.3)	4.8 ± 2.0 (± 6.8)
5-10	6.8 ± 3.3 (± 10.1)	7.1 ± 2.7 (± 9.8)	6.9 ± 3.2 (± 10.2)
0-5	7.8 ± 4.0 (± 11.8)	7.6 ± 3.4 (± 11.0)	6.2 ± 4.1 (± 10.4)

Table 9: Relative bias (systematic deviation) and relative precision of the SPC-6A (incl. And excl. stock 3A) and ENSCI-Z ozone sondes. The relative accuracy (between brackets) is determined by the sum of the precision and the absolute value of the bias. For details see text.

Altitude Range (Km)	Difference SPC-6A minus ENSCI-Z			
	Difference SPC-6A – ENSCI-Z (mPa)		Relative Difference SPC-6A – ENSCI-Z (%)	
	All Sondes	Excluded Stock Nr.3A	All Sondes	Excluded Stock Nr.3A
30-35	-0.75	-0.52	-11.2	-7.6
25-30	-0.96	-0.78	-7.9	-6.4
20-25	-0.59	-0.50	-3.3	-2.8
15-20	-0.076	-0.03	-0.6	-0.2
10-15	-0.090	-0.09	-1.1	-1.0
5-10	-0.033	-0.03	-1.2	-1.1
0-5	-0.024	-0.03	-1.0	-1.2

Table 10: JOSIE-1998 comparison of the absolute and relative differences between SPC-6A and ENSCI-Z sondes derived from the differences of the average deviations of the SPC-6A and ENSCI-Z sondes with the UV-Photometer as presented in the Tables 8 and 9 for all tested SPC-6A sondes) and excluding the sondes of stock nr.3, respectively.

7. SUMMARY AND CONCLUSIONS

Performance experiments of ECC-ozone sondes of two different model types (SPC-6A and ENSCI-Z) were conducted in the environmental simulation chamber at the Research Centre Juelich (Germany) in the scope of JOSIE. JOSIE-1998 primarily focused on the quality check of the instrumental performance over a sample of 26 randomly selected ECC-sondes (13 SPC-6a and 13 ENSCI-1Z), which were provided by the different ECC-sonde users in the GAW/GLONET-sounding network. All tested ECC-sondes were subject to the same preparing (cathode sensing solution: 1% KI, full buffered), operating, and data correcting procedures described by *Komhyr* [1986] while the simulation profile of pressure, temperature and ozone concentration were at typical mid-latitude conditions according the profile also used during JOSIE-1996 [*Smit and Kley*, 1998]. In order to determine precision, accuracy and response of both sonde types the individual sondes were tested under a variety of conditions and compared with an accurate UV-photometer.

All sondes tracked the simulated ozone profiles very well within scale lengths better than 150 m. In the troposphere and lower stratosphere up to 20 km altitude both sonde types show a rather similar performance. The precision of $\pm$(3-4)% yielded is comparable to the precision obtained during JOSIE 1996. However, in the altitude region below 20 km both sonde types tend to overestimate ozone by about 5-10 %, particularly in the troposphere. This in contrast to the smaller bias observed in the troposphere during JOSIE 1996 which may be due to a change of the magnitude of background current. In the middle stratosphere, particularly above 25 km altitude, the performance of both sonde types starts to deviate from each other quite significantly. The precision of the SPC-6A sonde decreases with altitude to about $\pm$(5-10)% while the observed bias changes sign with altitude from about +5% at 25 km into -8% at 35 km. This in contrast to the ENSCI-sonde type that exhibits a precision of $\pm$(4-5)% and a rather large positive bias of about 10% up to 35 km altitude. It has to be noted that

the ENSCI-manufacturer recommends using a 0.5% KI, half buffered sensing solution for the cathode cell which will lower the ozone sonde readings by about 5% [*Johnson et al*., 2002]
A key conclusion from the observed JOSIE-1998 results is that the performance characteristics of the two ECC-sonde types are significantly different in the middle stratosphere above 25 km. It is reminded that both sonde types were prepared and operated according exactly the same procedures [*Komhyr,* 1986]. The cause of the observed differences is not fully understood. Still a large source of uncertainty is the correction table for the pump flow efficiency at lower pressures, which is based on averages obtained from rather old pump efficiency measurements made in the past. However, ozone sonde pump efficiency corrections determined by various experimental methods reveal substantial differences, which become of increasing significance at decreasing pressures below 30 hPa [*Johnson et al.,* 2002]. In addition, the pump flow efficiency of individual sonde pumps can vary substantially. Therefore, it is strongly recommended to intercompare and evaluate the existing experimental methods for the determination of the pump flow efficiency. Further, a second source of uncertainty is the concentration of the KI in combination with the concentration of the buffer used in the sensing solution of the cathode cell that can have a significant impact on the performance of the ECC-sonde [*Johnson et al*., 2002].

However, the results clearly demonstrate that already small differences of instrumental lay out of the different sonde types can have significant influences on the performance of the different model types. Therefore, it is strongly recommended that caution has to be taken to any general conclusions about the performance characteristics of ECC-sondes in the middle stratosphere between 25 and 35 km altitude. This caution is particularly addressed to the recent controversial issue of the change of the chemical composition of sensing solution. Therefore, in the scope of the JOSIE-2000 simulation experiments, testing the performance of both ECC-types under different sensing solutions (1%KI full-buffered, 0.5%KI half-buffered, and 2%KI unbuffered), were conducted at the WCCOS. In preparation of the establishment of SOP's for the different ozone sonde types operational in GAW, JOSIE 2000 was dedicated to support the assessment of standard operating procedure for ozone sondes (ASOPOS).

Acknowledgements

We want to thank Dr Volker Mohnen (University of Albany, USA) and Dr Mike Proffitt (WMO, Switzerland) for their personal engagements and arranging financial support to conduct JOSIE 1998. Many thanks to Dr Karin Thomas (KT-Consulting, Germany) for data processing and preparation of most of the figures. Further, we are very grateful to the people of the AW-ozone sounding stations who provided us with ECC-sondes to conduct JOSIE 1998: Dr Bryan Johnson (NOAA/CMDL, USA), Dr Frank Schmidlin (NASA/GSFC, USA), Dr Jonathan Davies (AES, Canada), Dr Hugo DeBacker (KMI, Belgium), Dr Bojan Bojkov (NILU, Norway), and Dr Bruno Hoegger (ASP, Switzerland). JOSIE 1998 was sponsored by WMO/GAW and Forschungszentrum Jülich.

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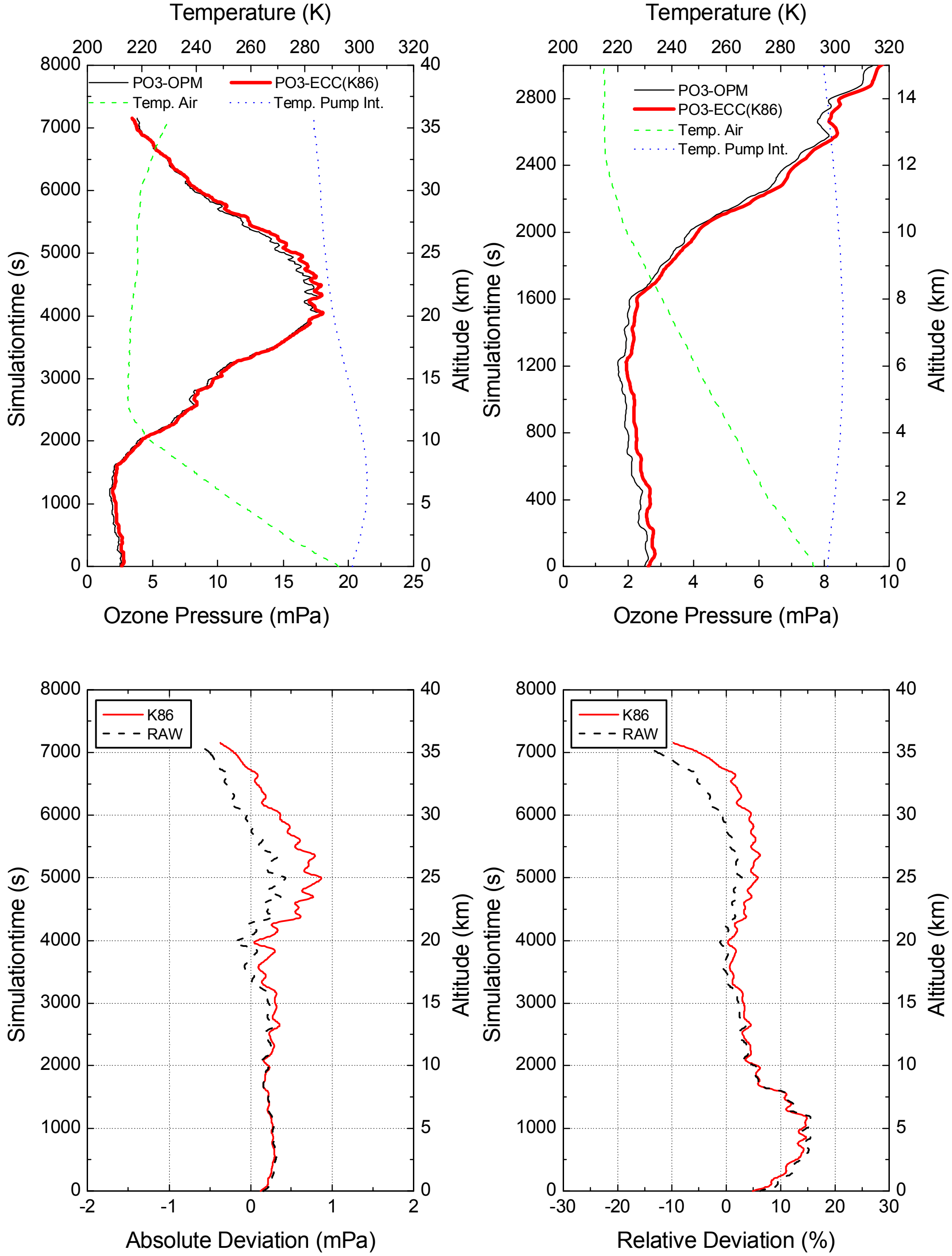
Results

of

Individual Tested ECC-Ozone Sondes

JOSIE-98

Sonde No.=01 Sonde Type=SPC-6A Sol. Type=1A Sim. No.=51



JOSIE-98

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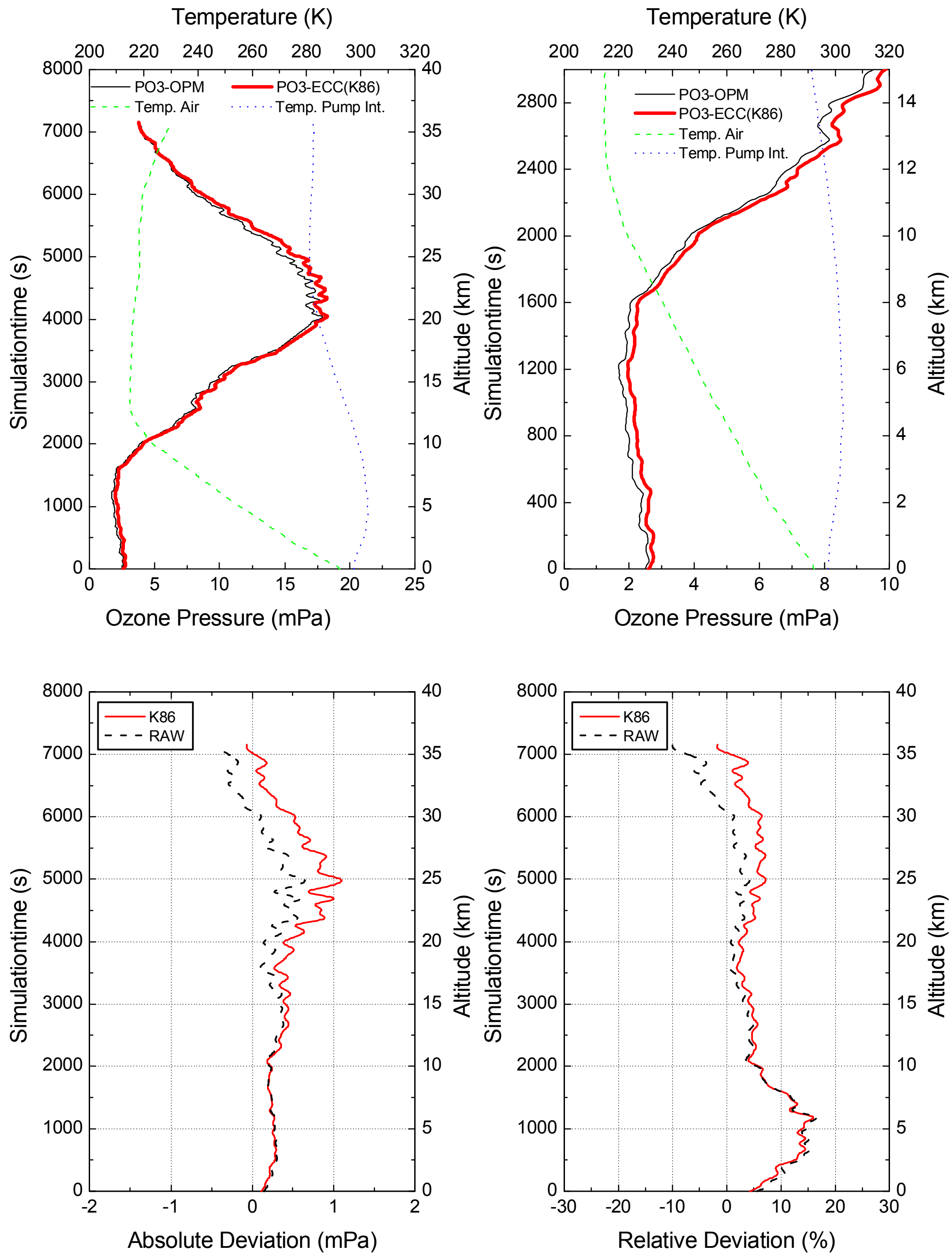

JOSIE-98

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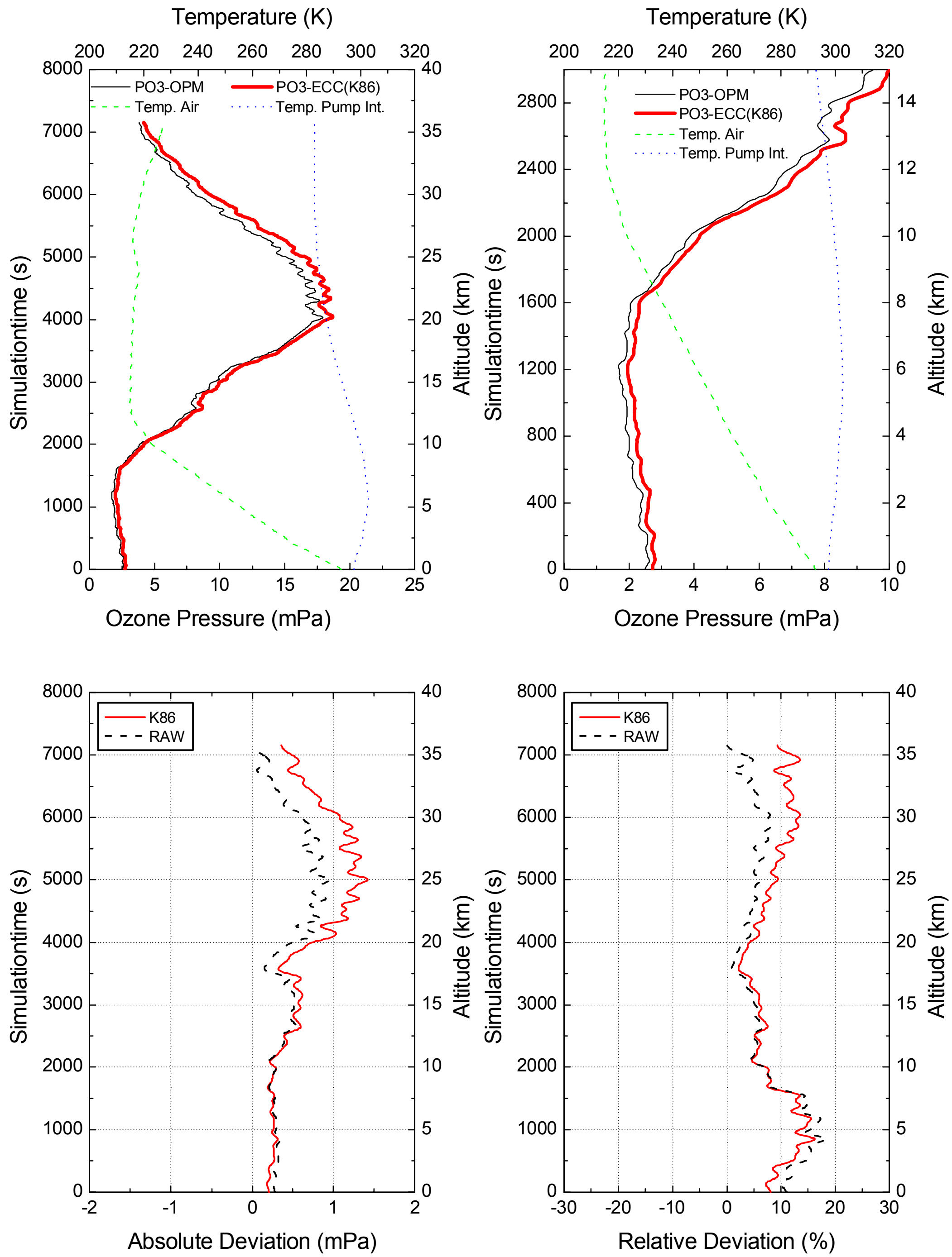

JOSIE-98

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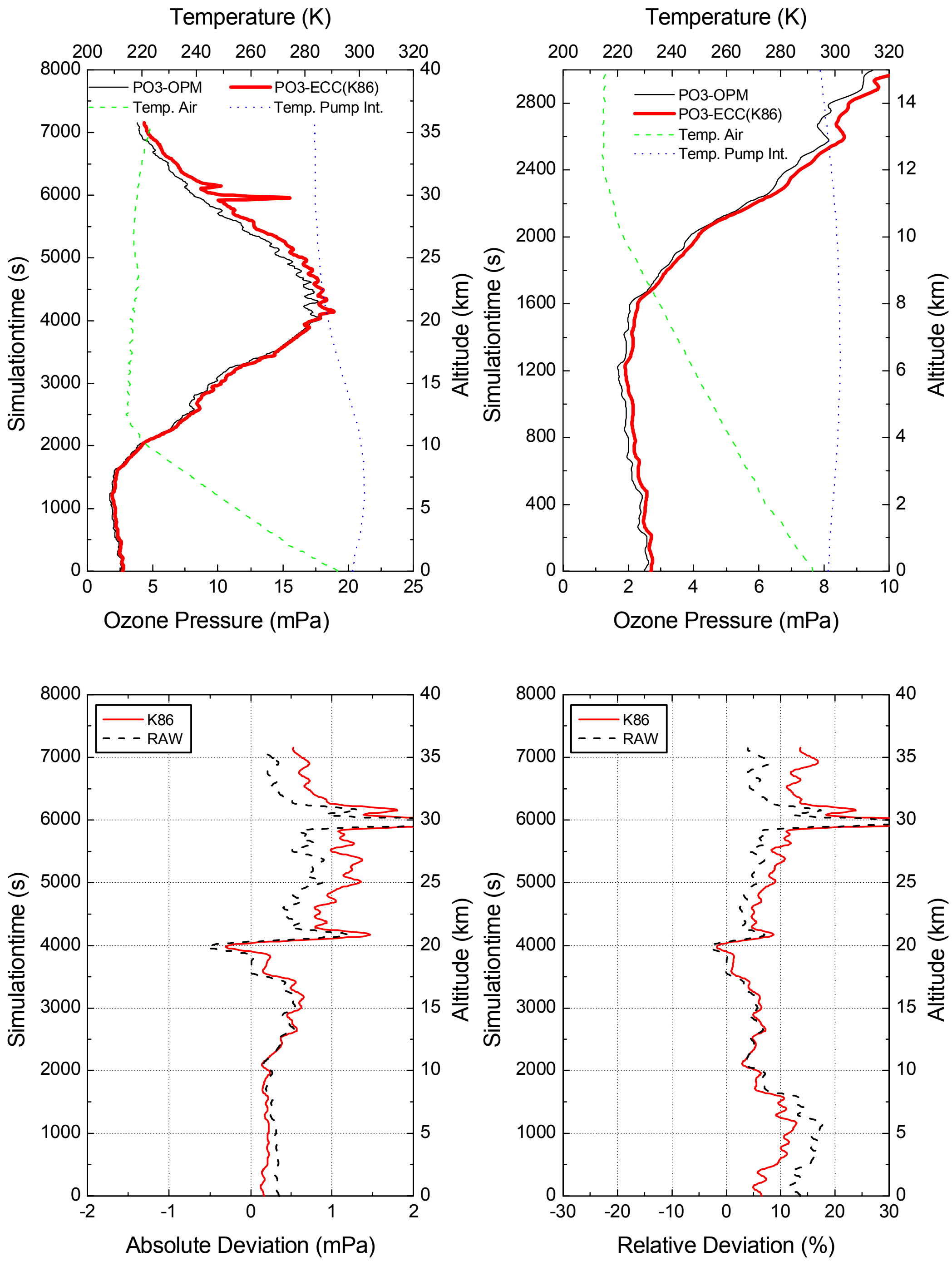

JOSIE-98

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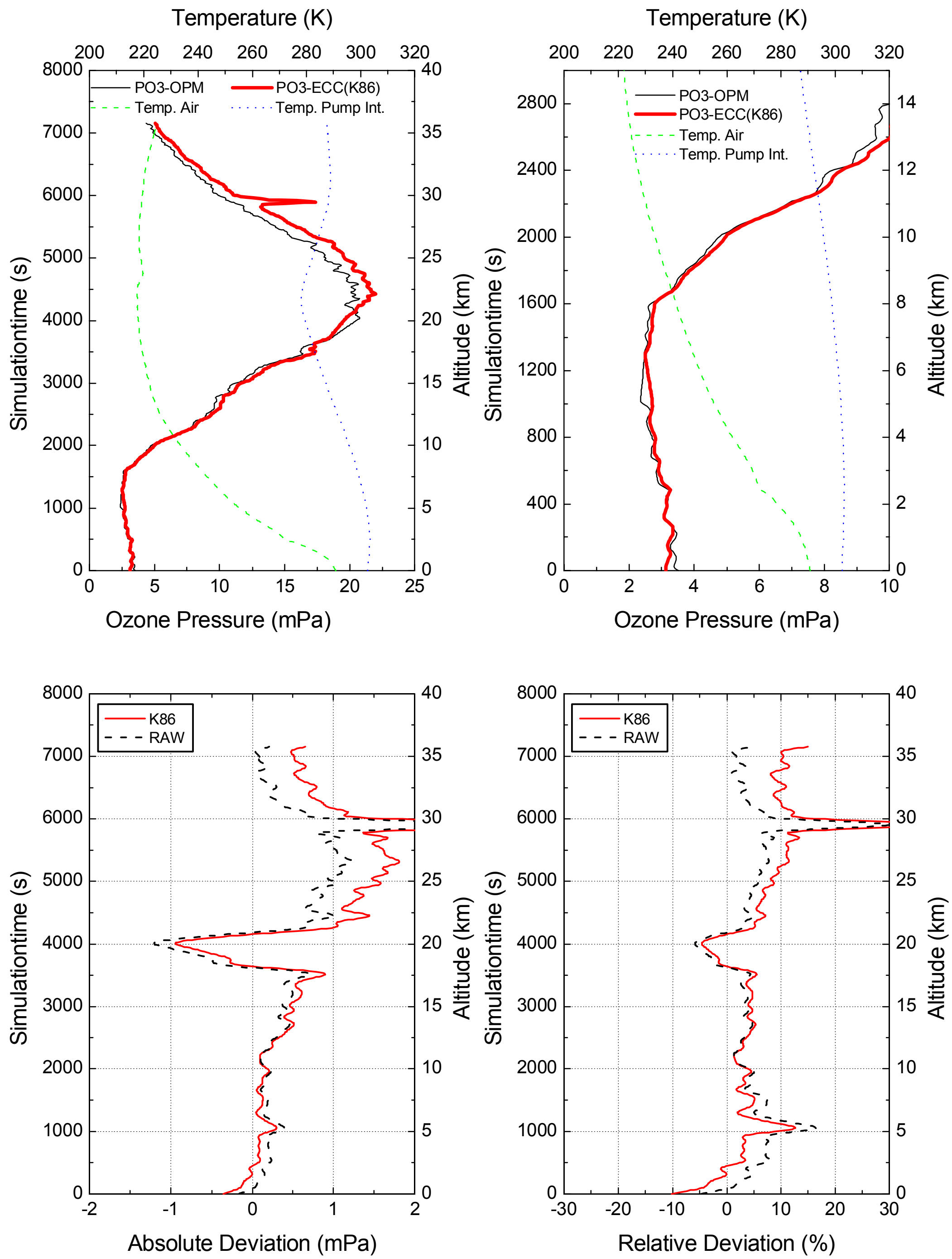

JOSIE-98

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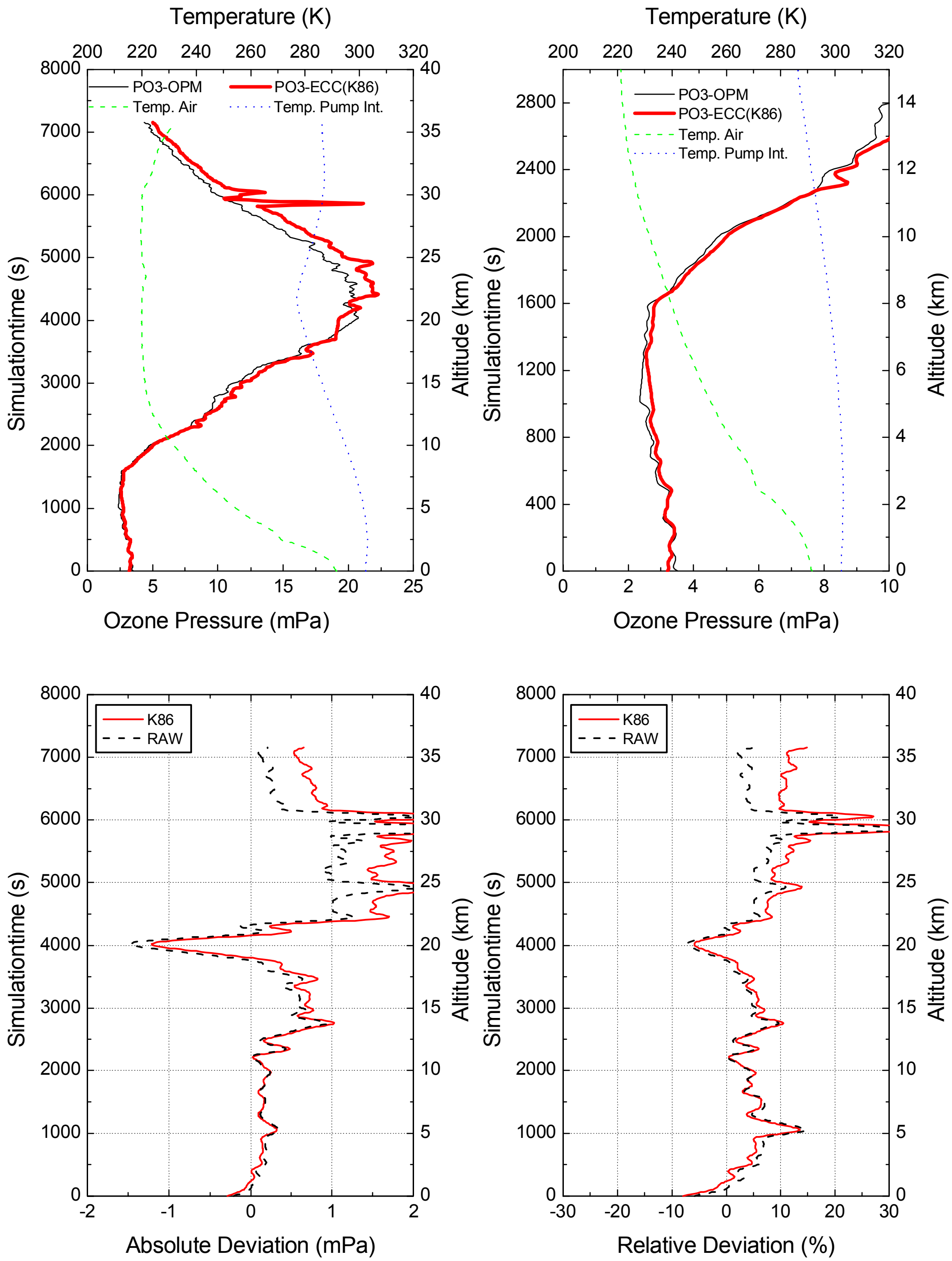
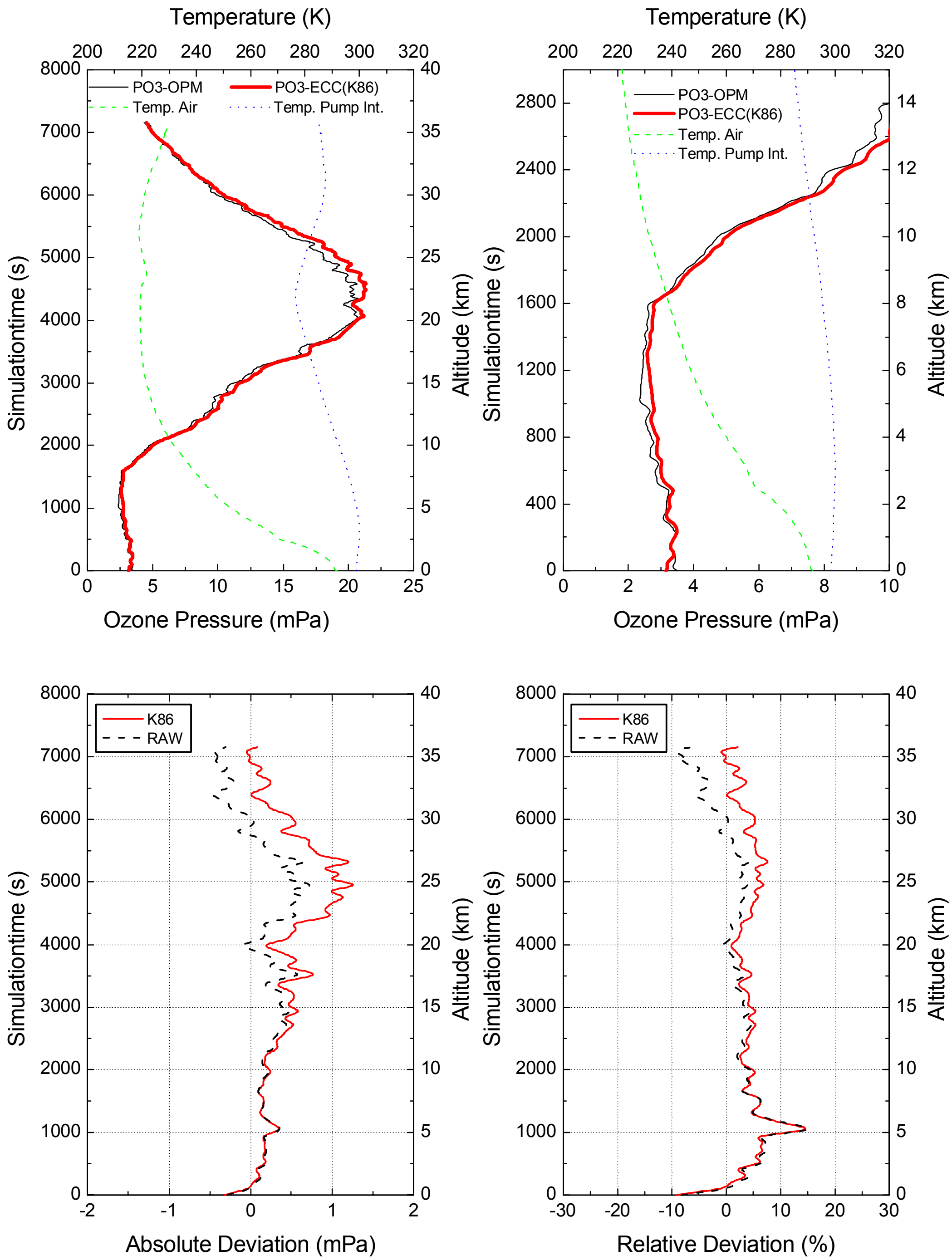


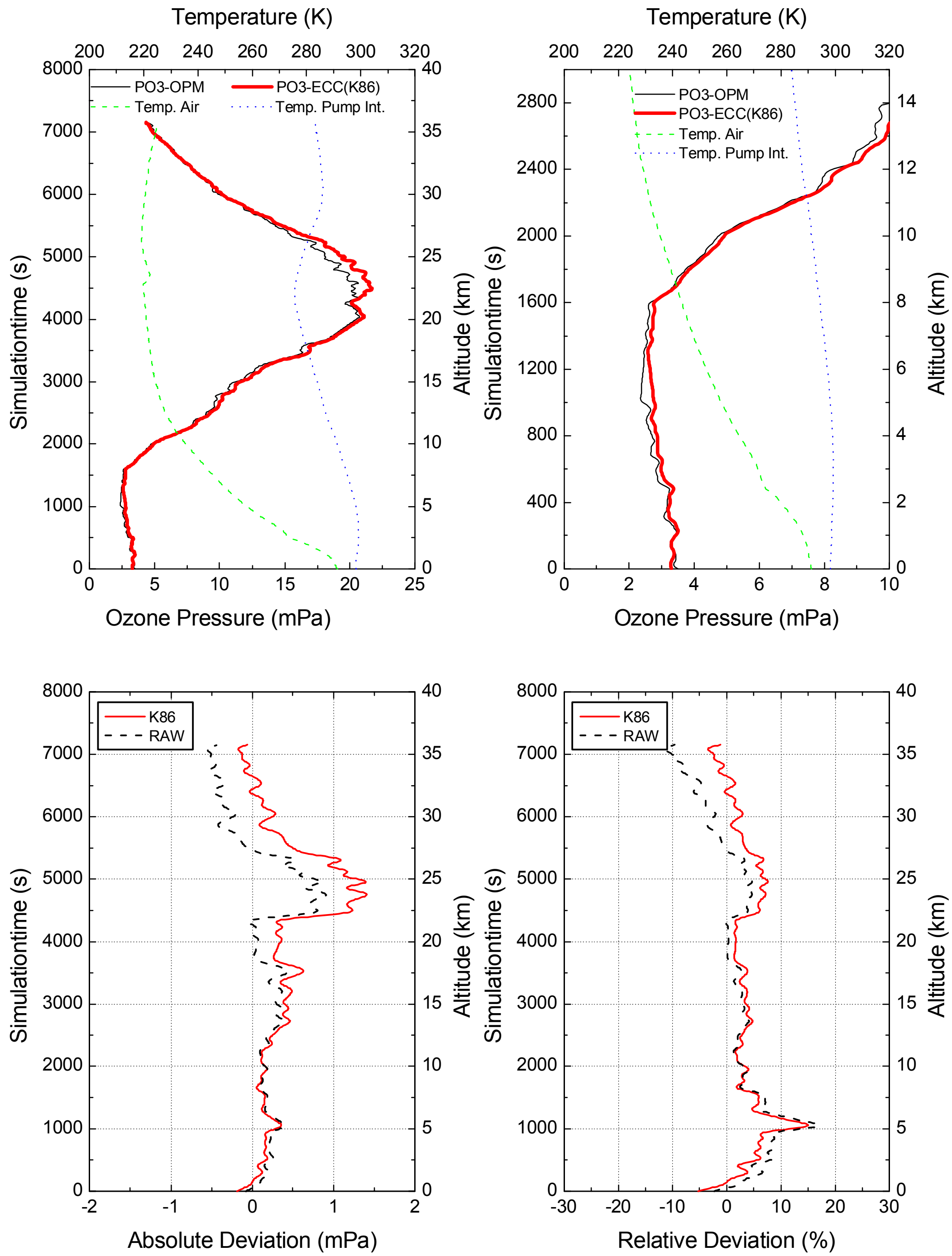
JOSIE-98

Sonde No.=07   Sonde Type=SPC-6A   Sol. Type=1A   Sim. No.=52



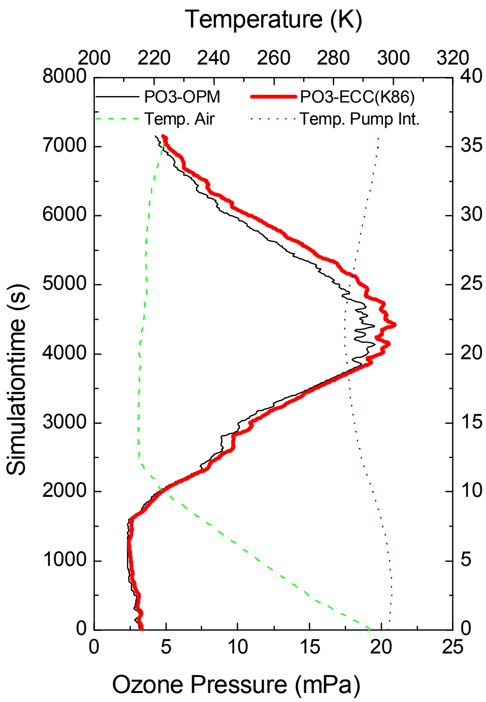
JOSIE-98

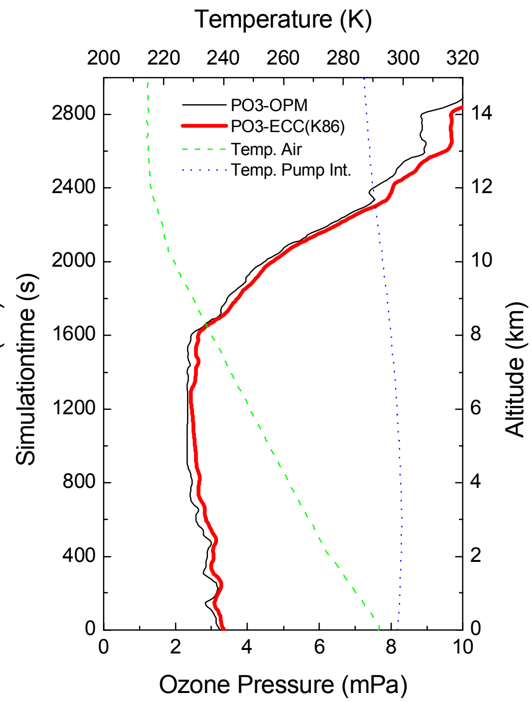
Sonde No.=08 Sonde Type=SPC-6A Sol. Type=1A Sim. No.=52

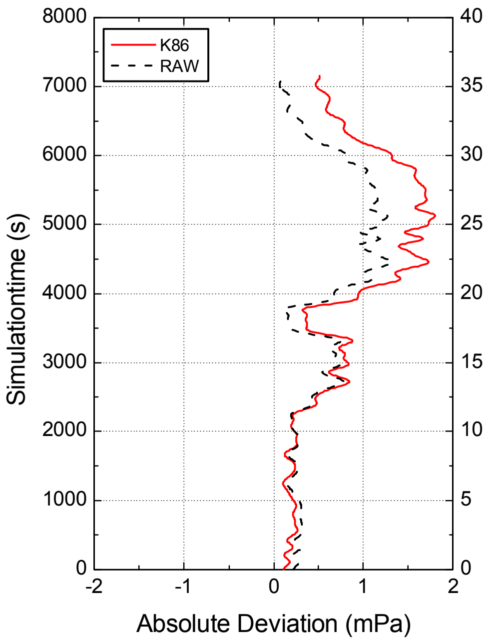


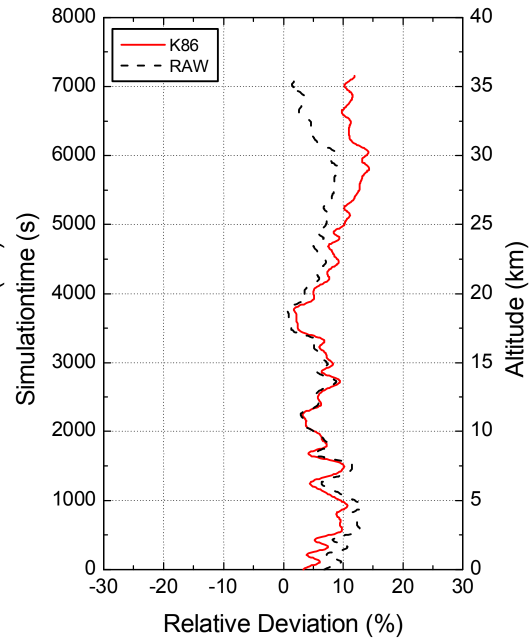
JOSIE-98

Sonde No.=09 Sonde Type=ENSCI-Z Sol. Type=1A Sim. No.=53









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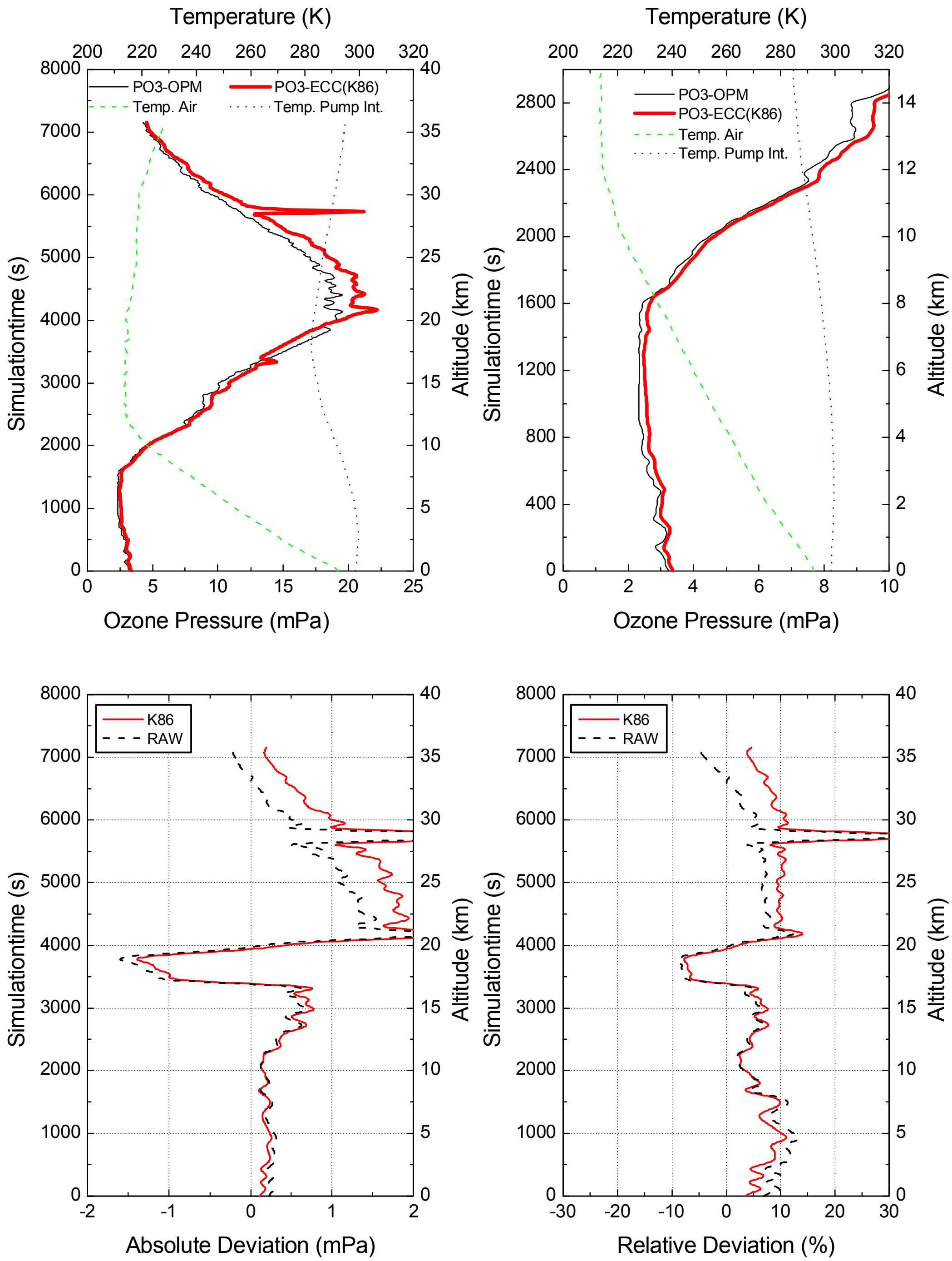

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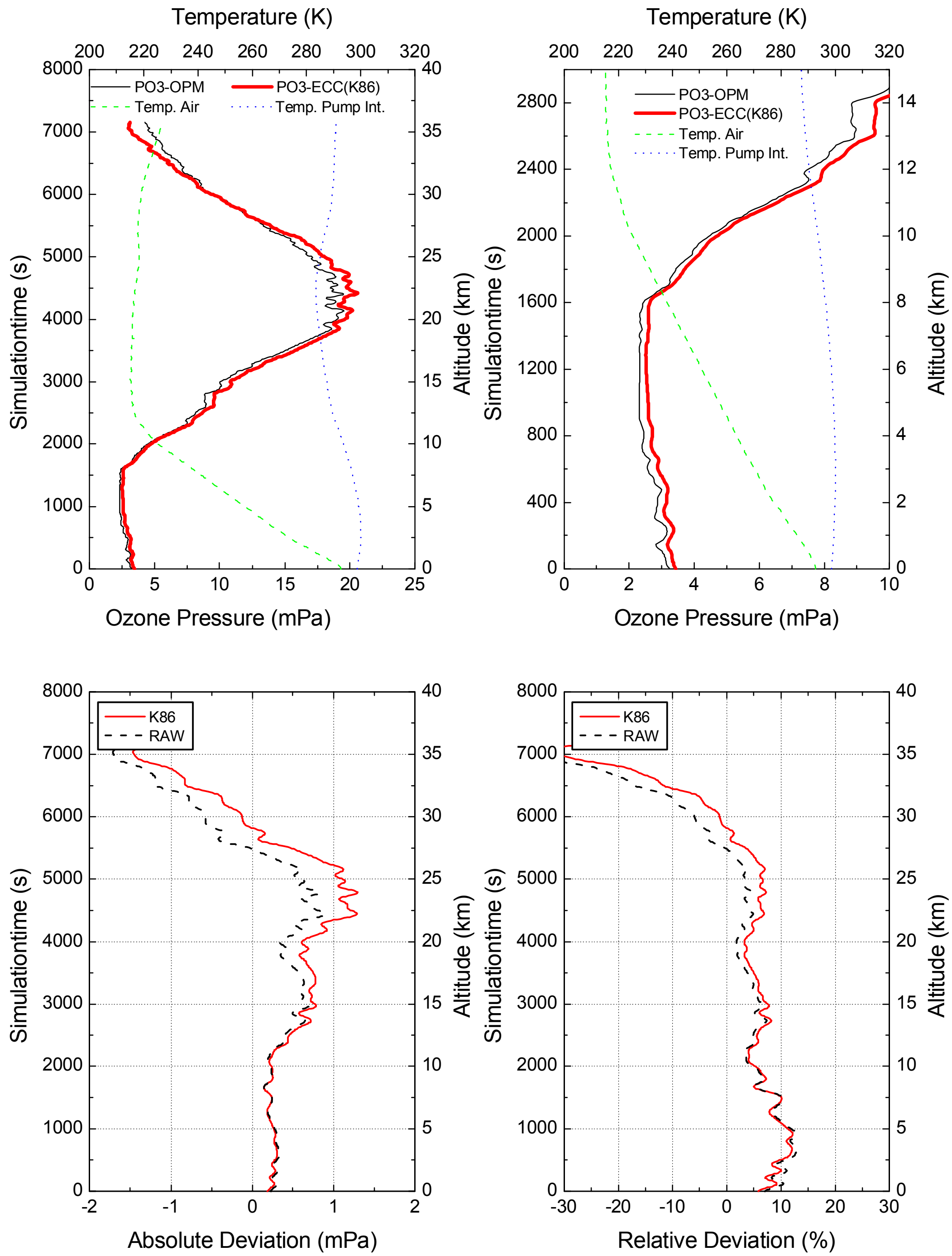

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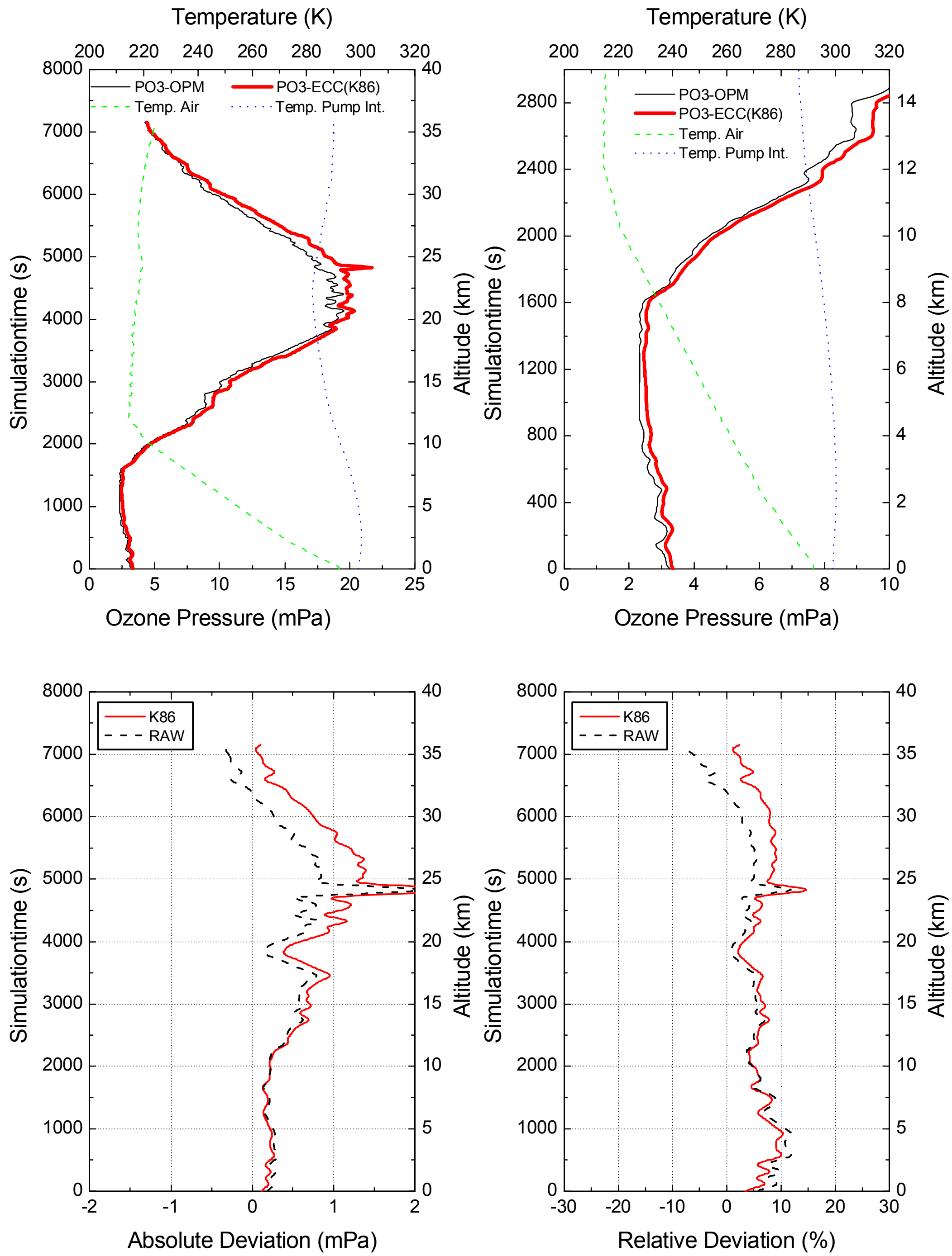

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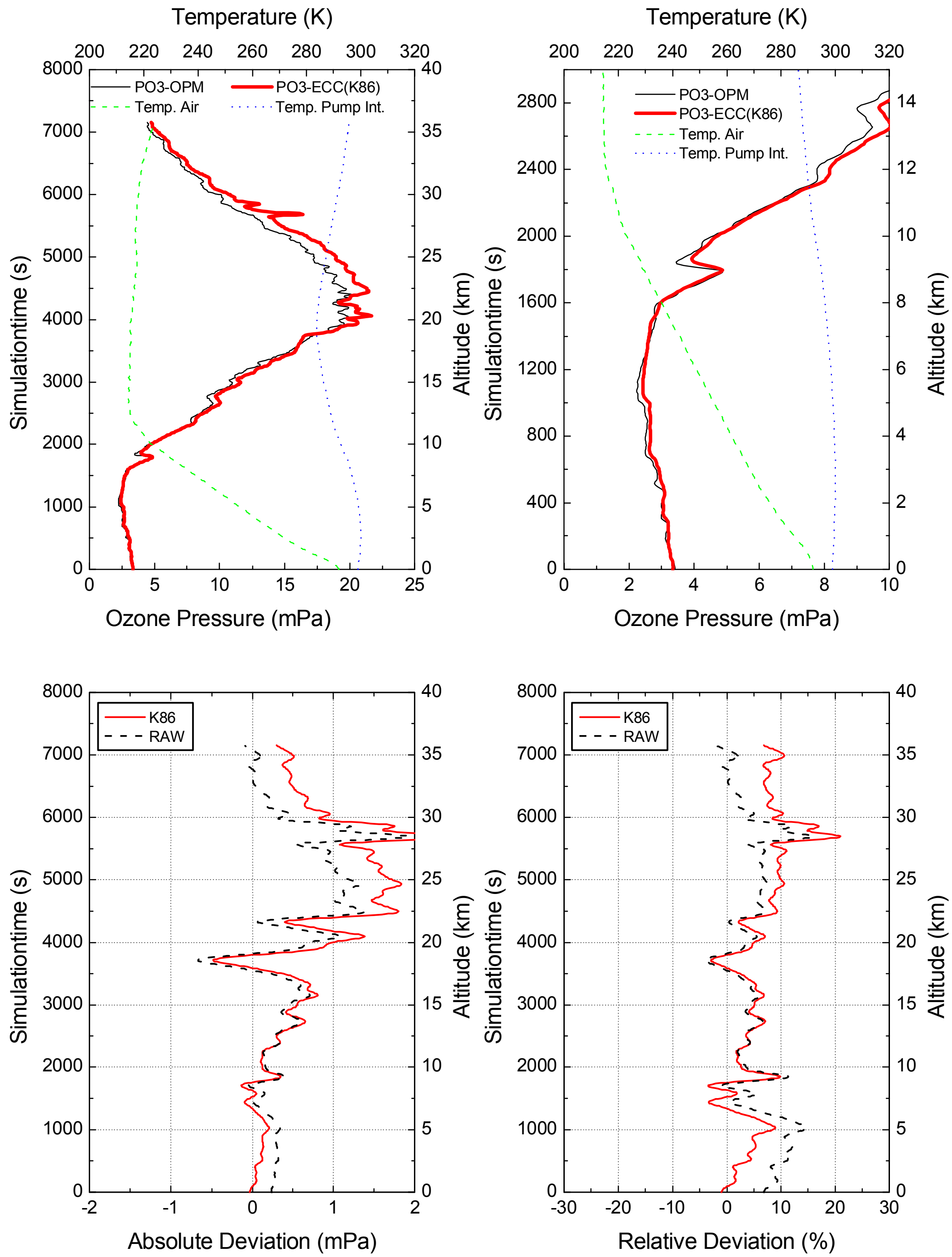

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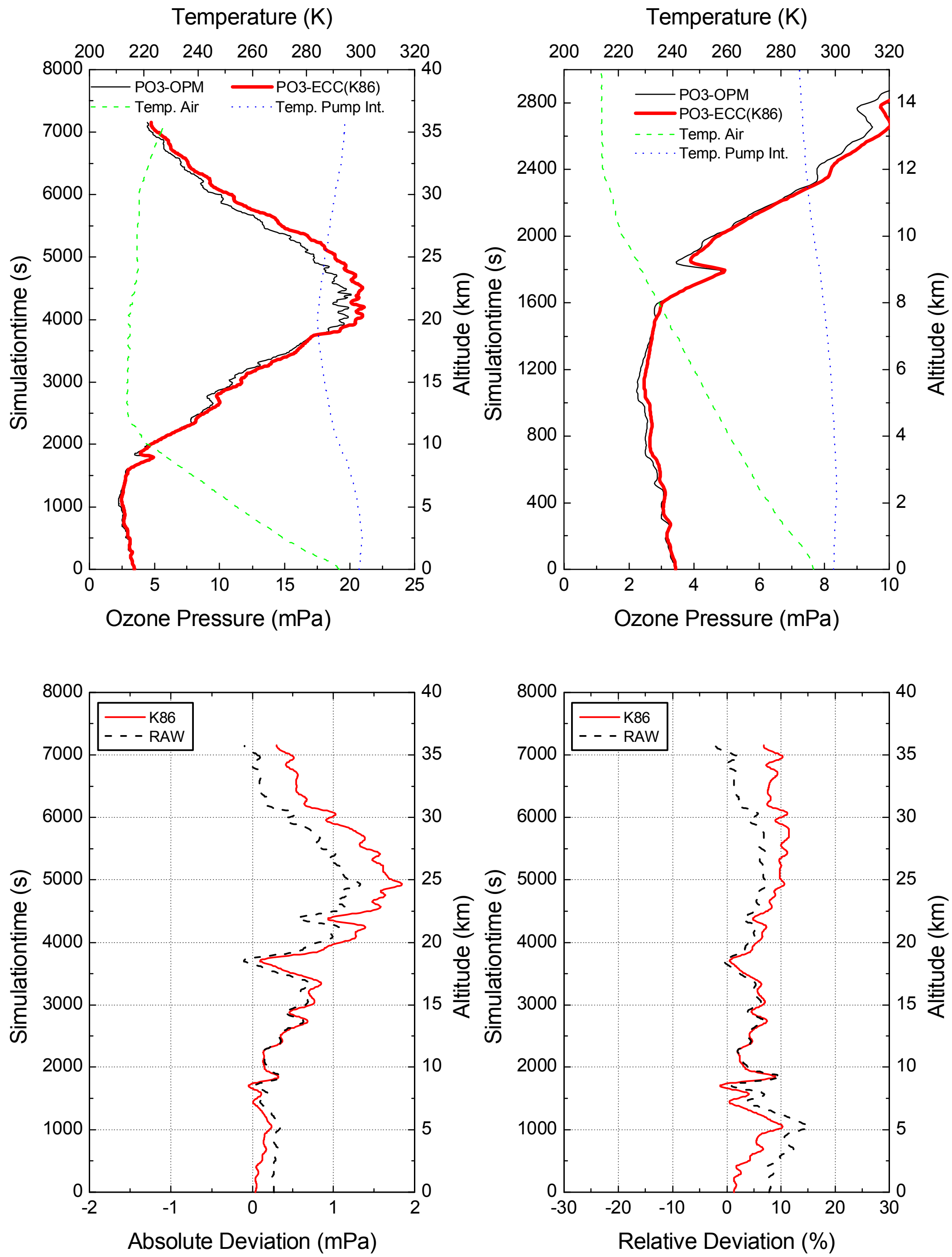

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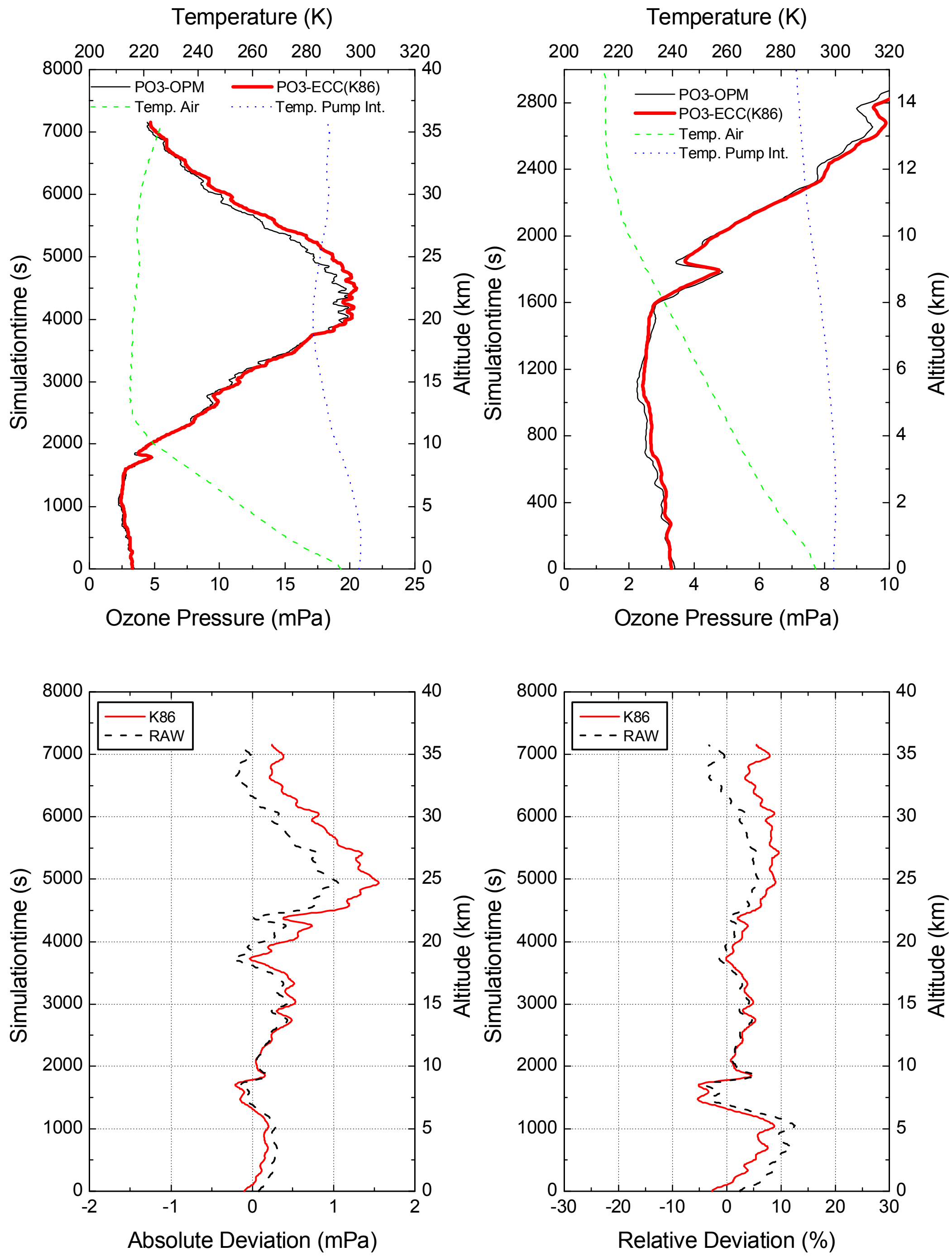

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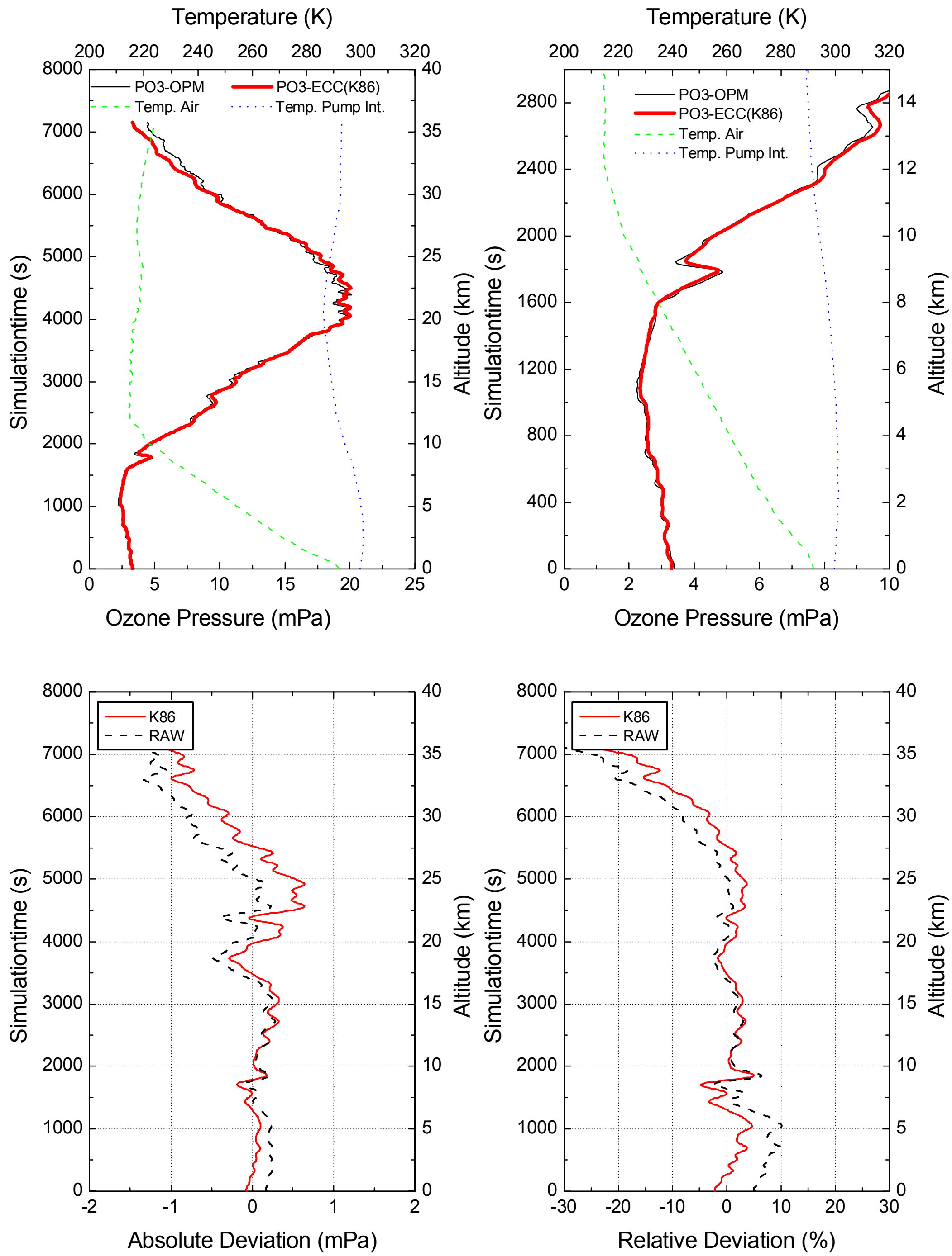

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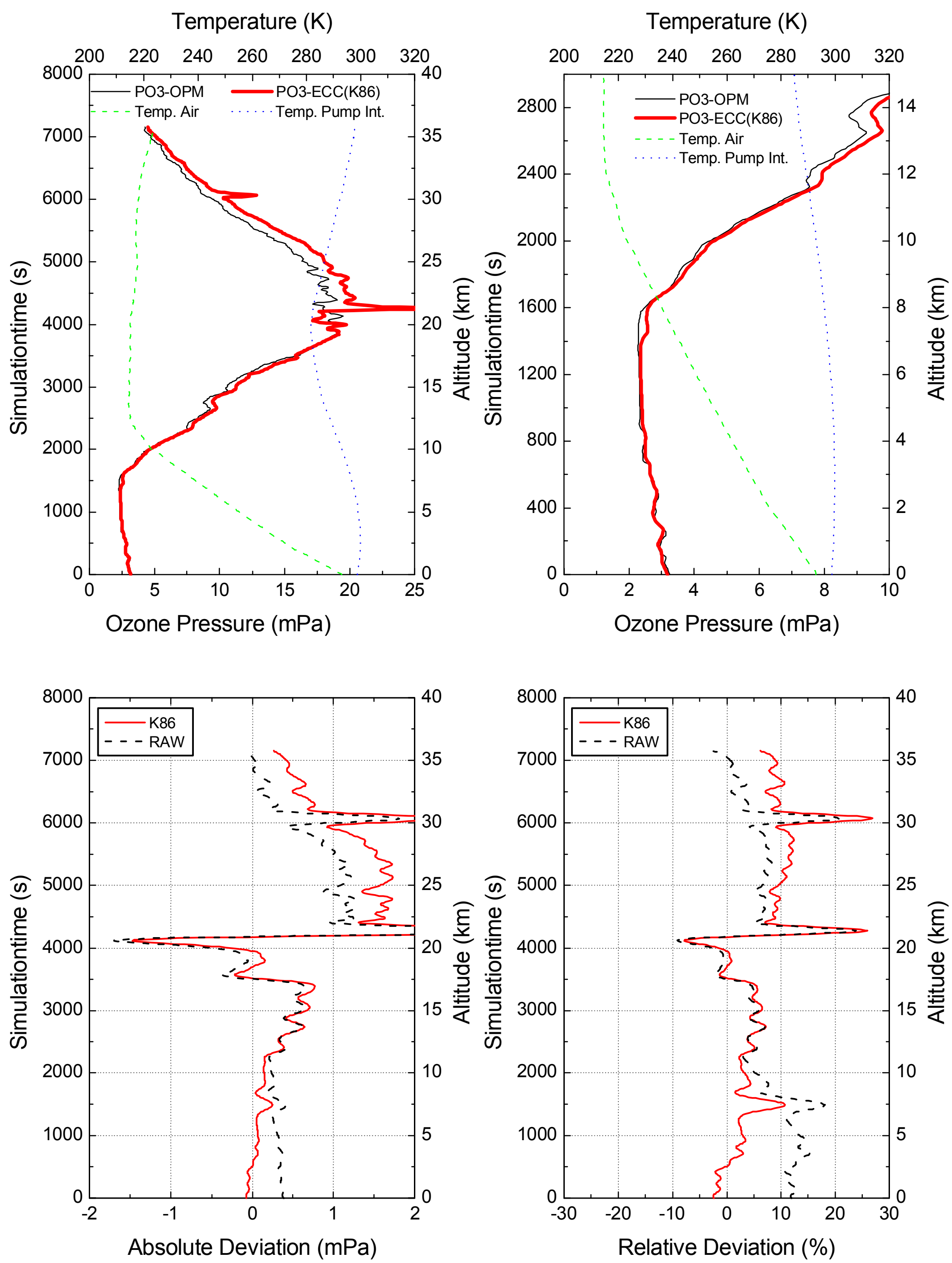

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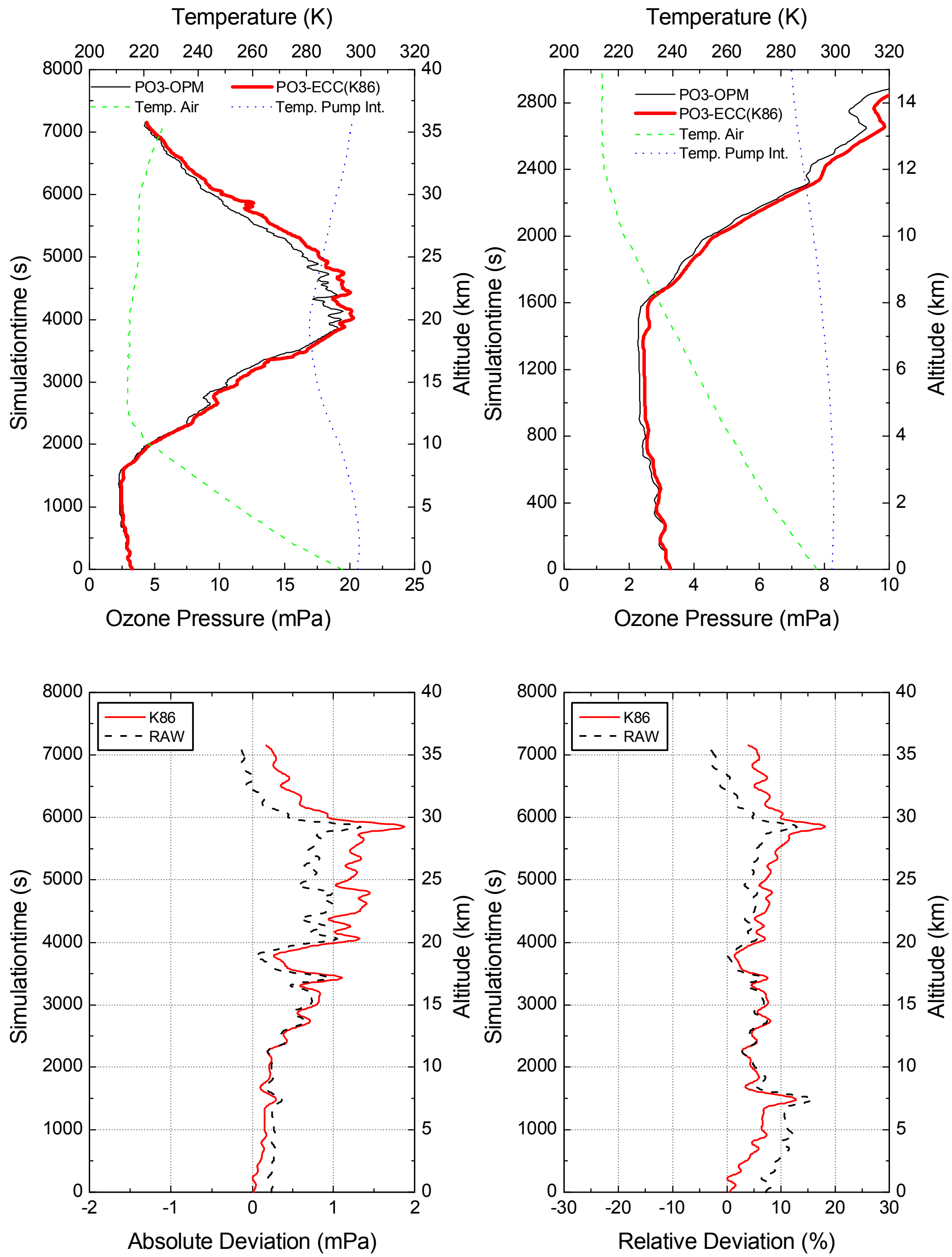

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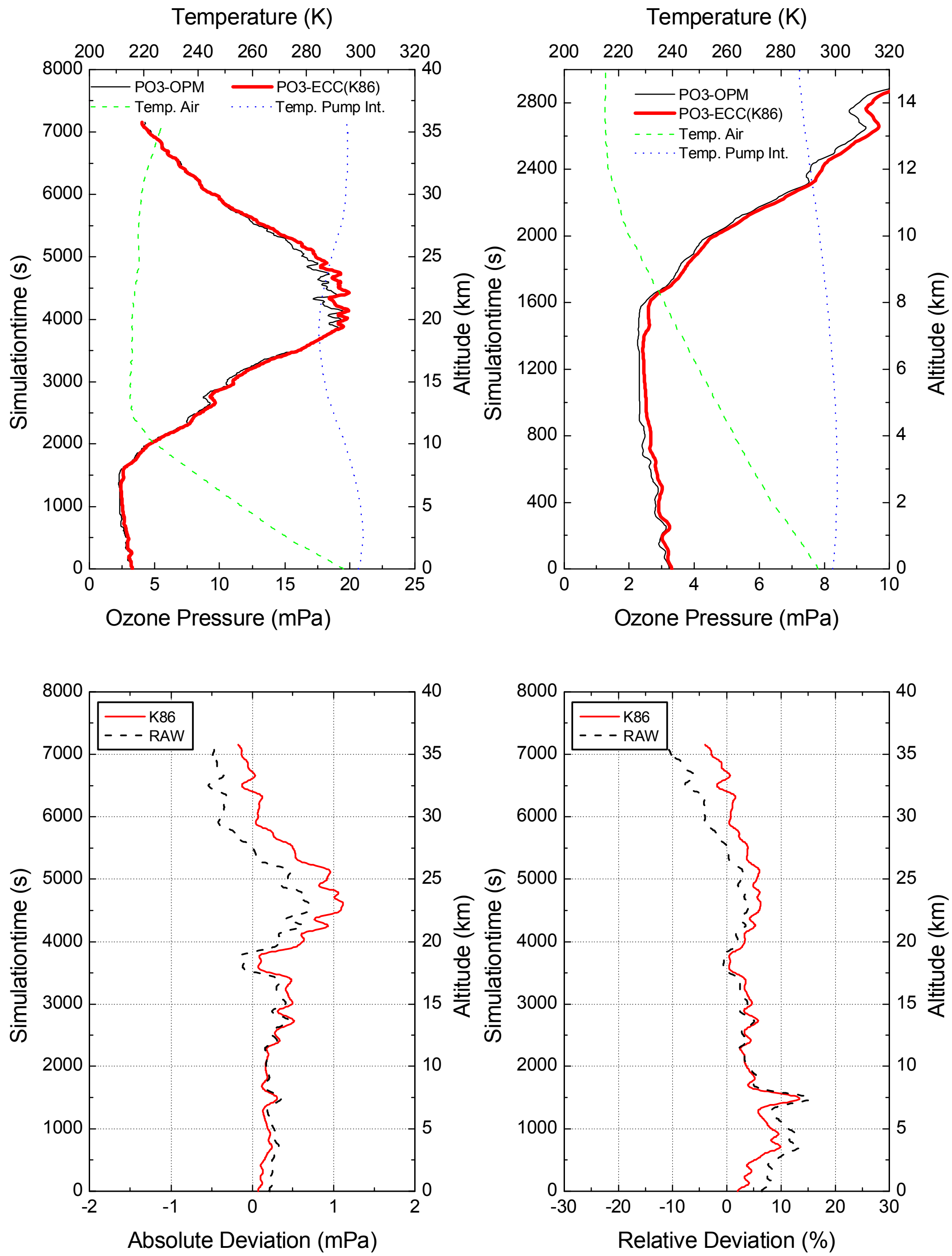

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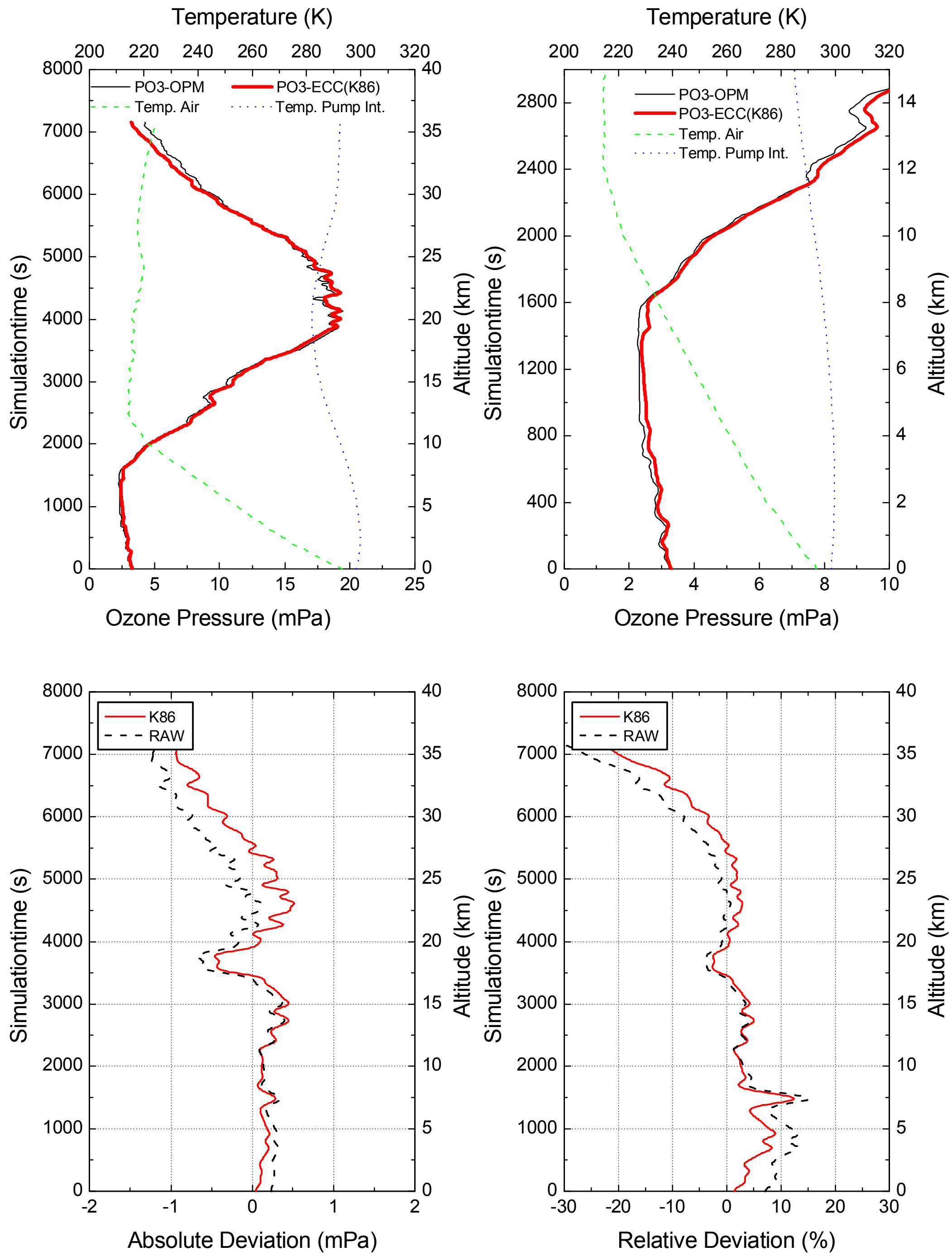

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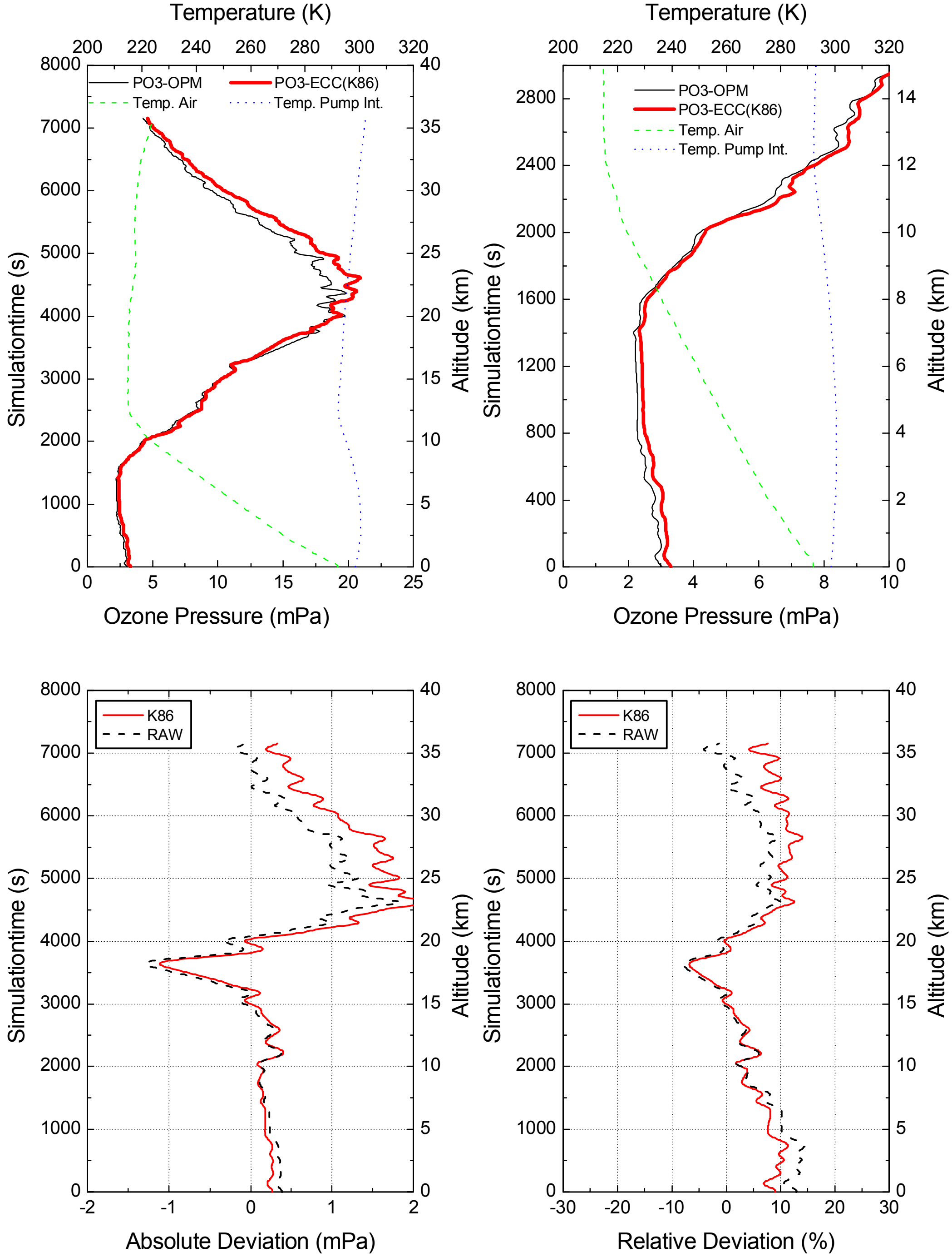

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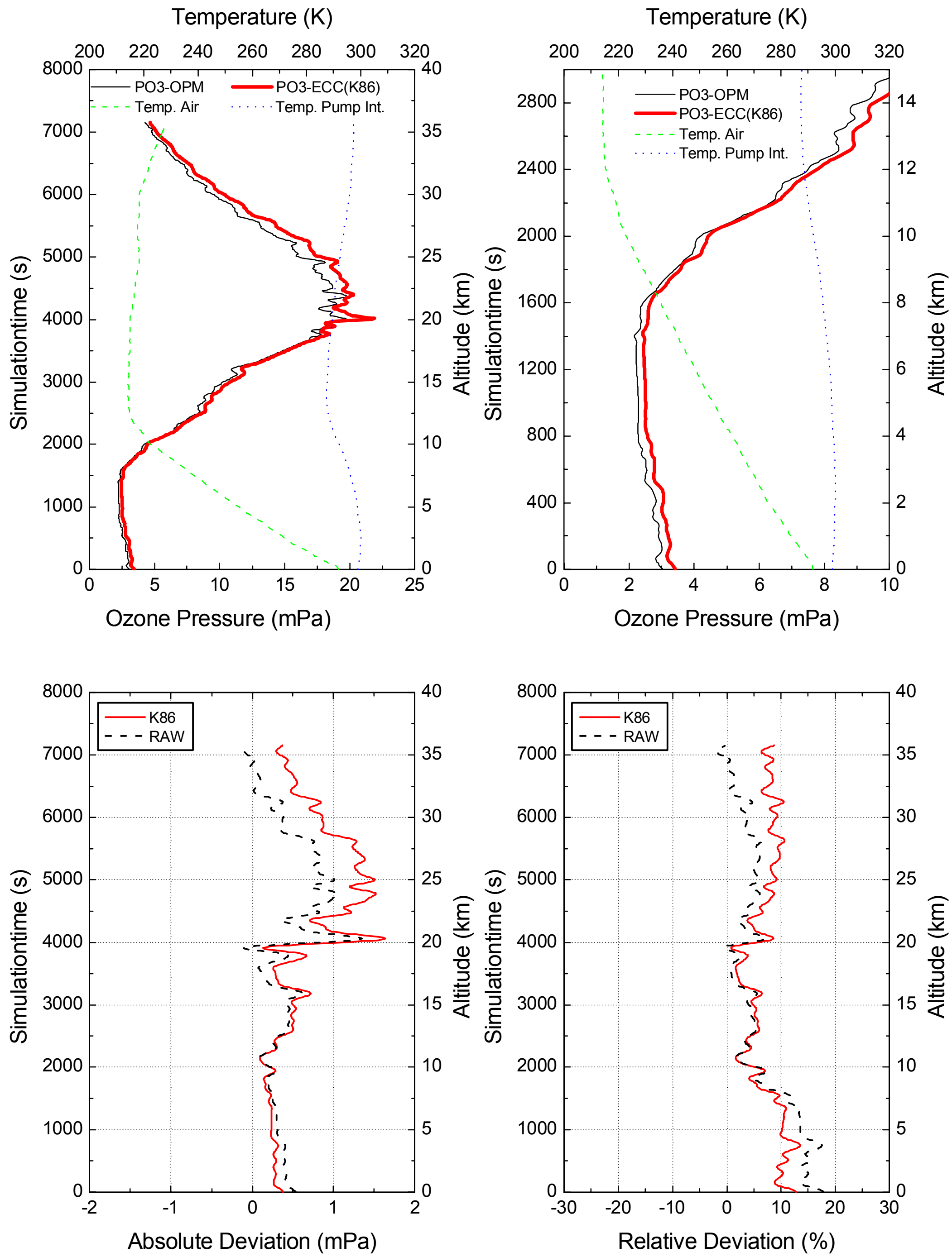

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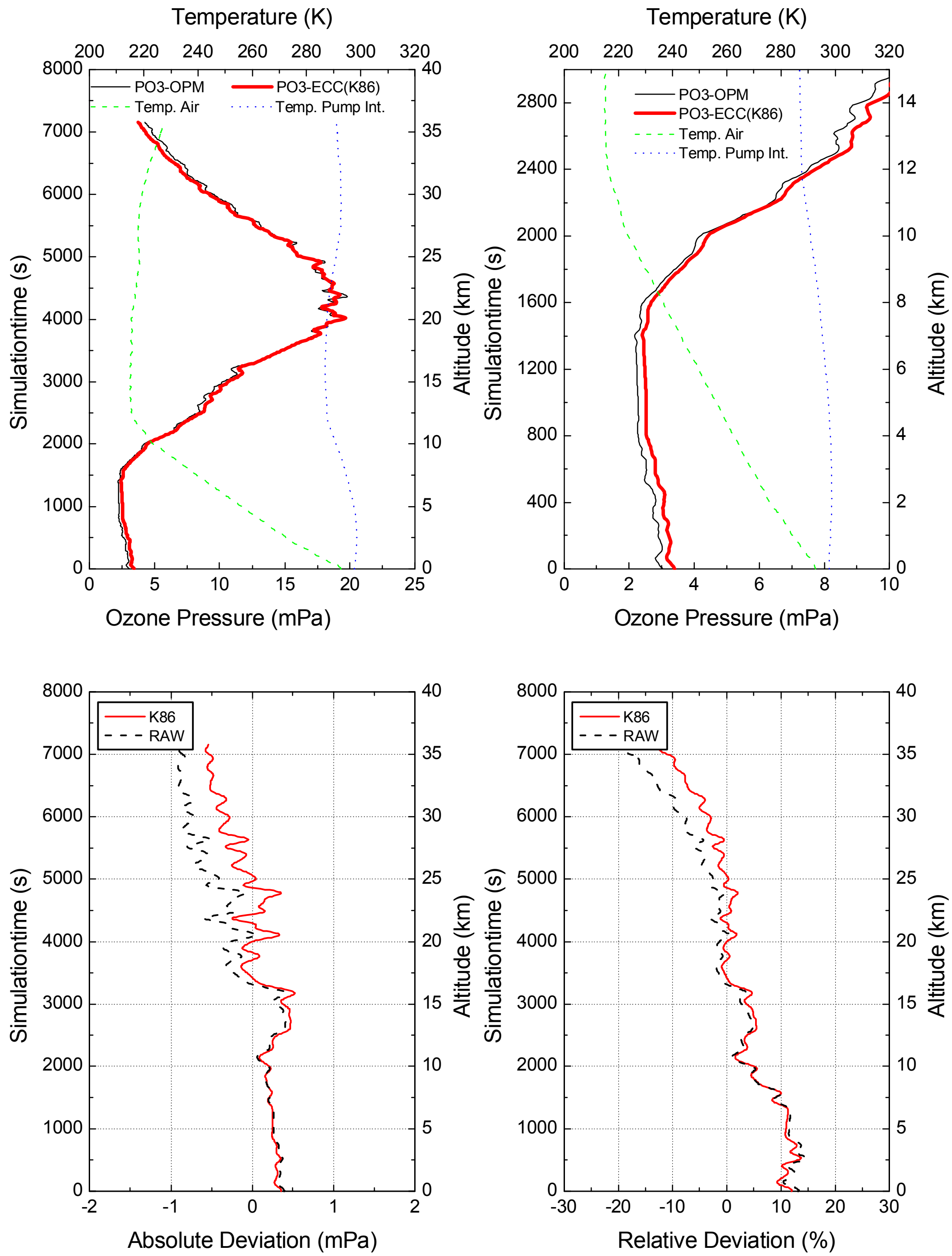

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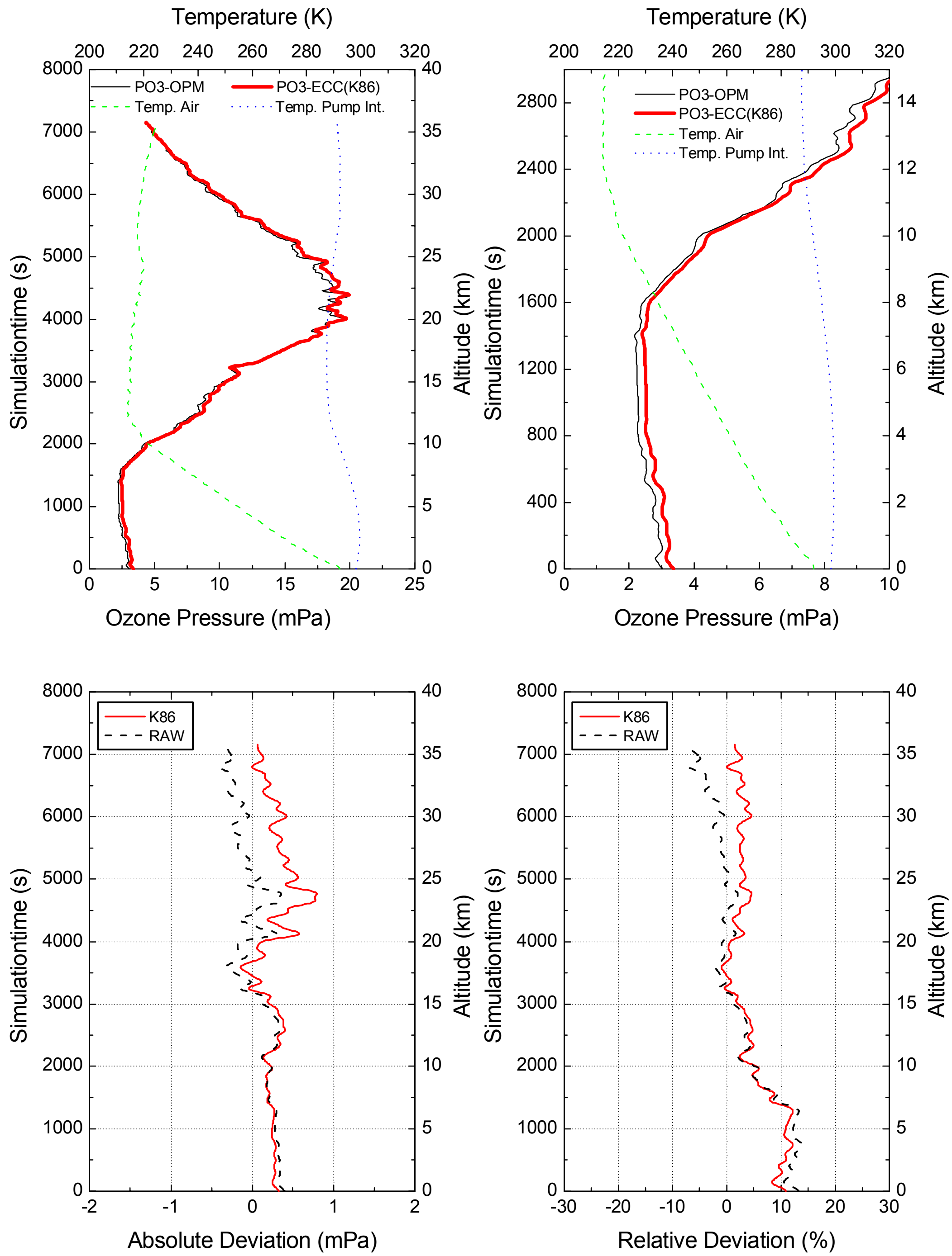

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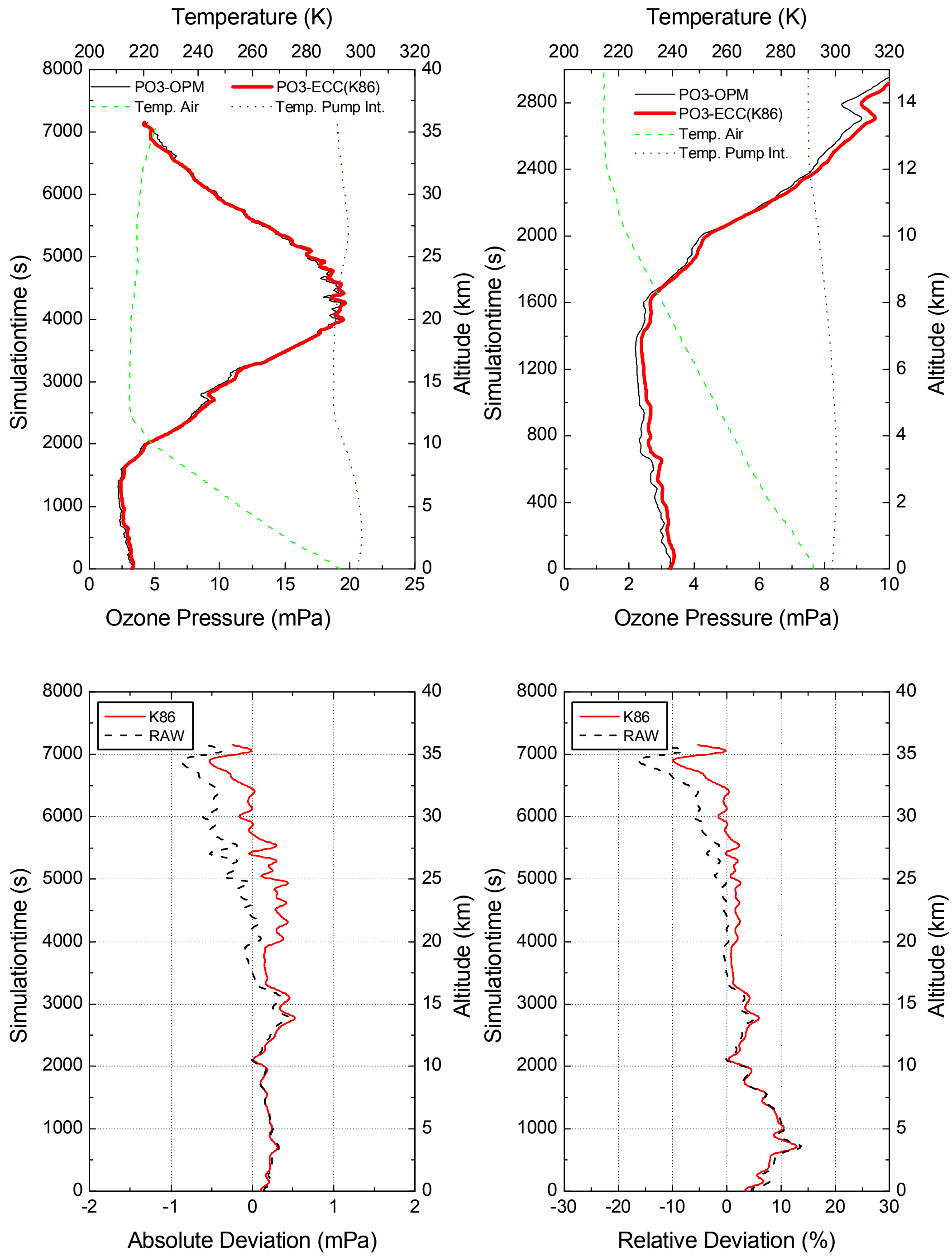

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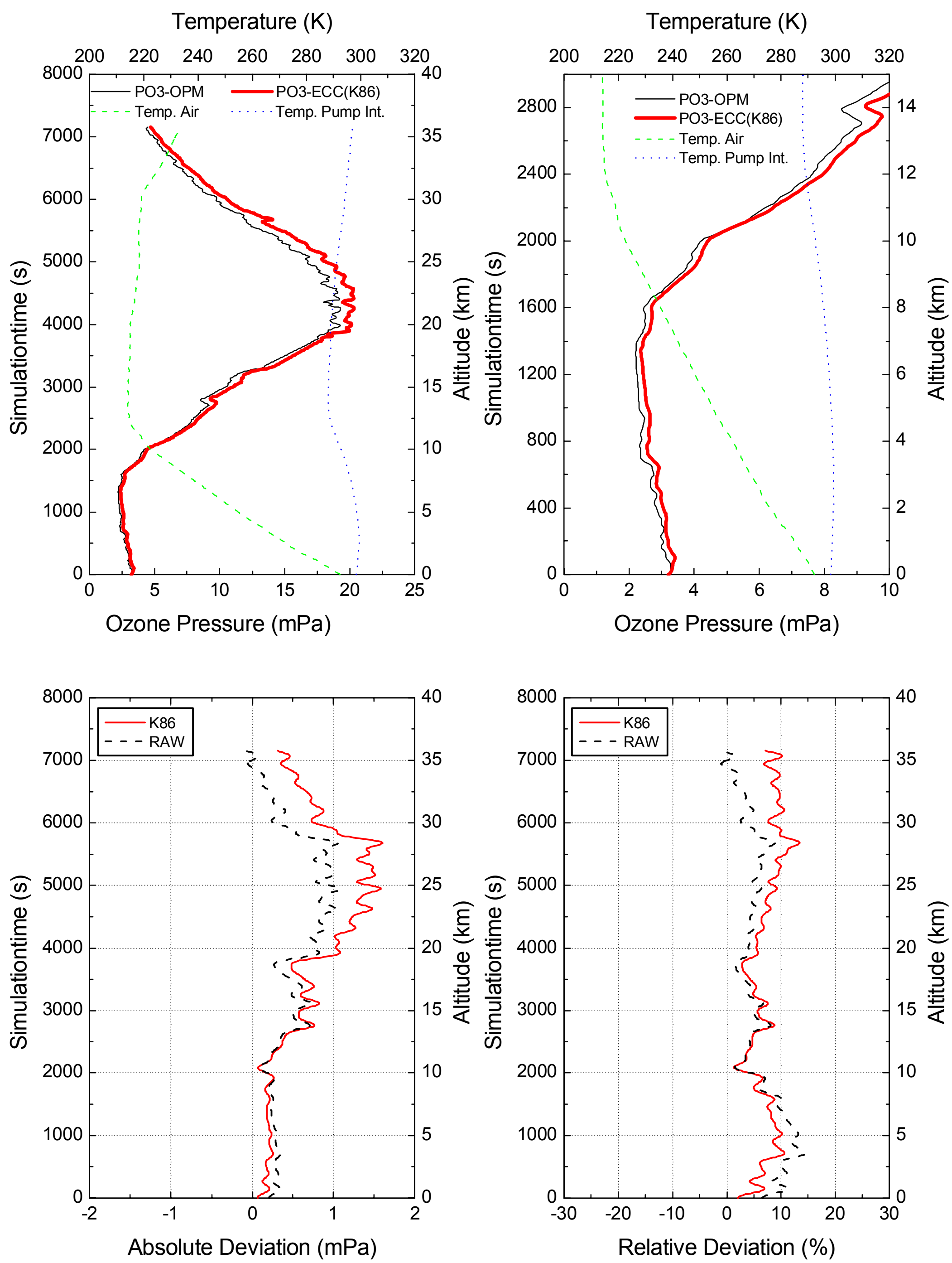
Sonde No.=26 Sonde Type=ENSCI-Z Sol. Type=1A Sim. No.=57

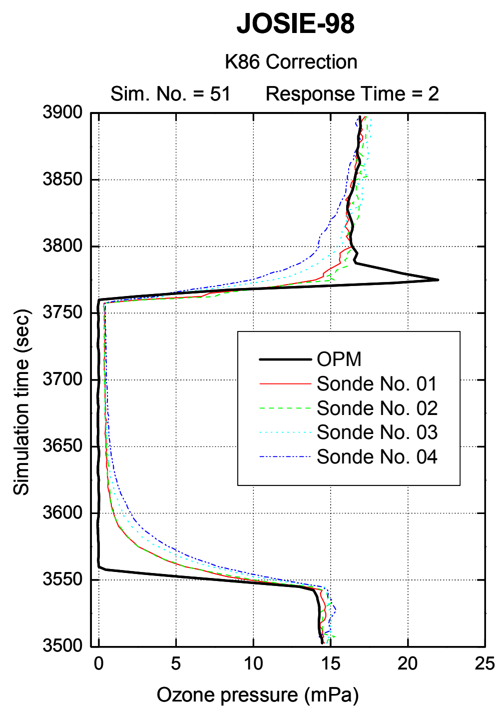


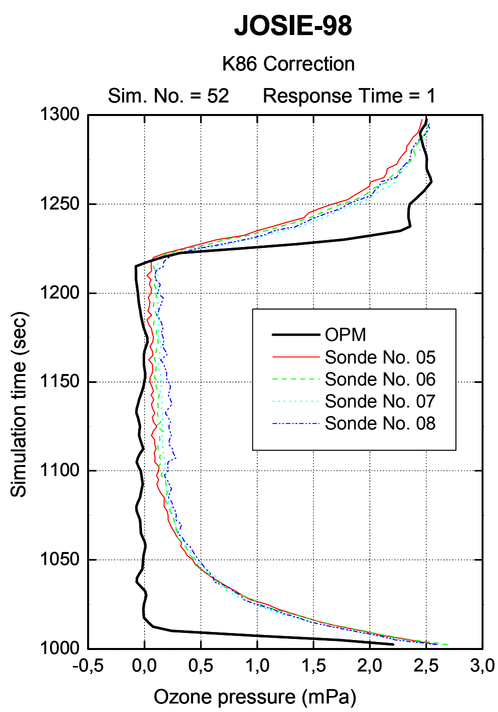
ANNEX B

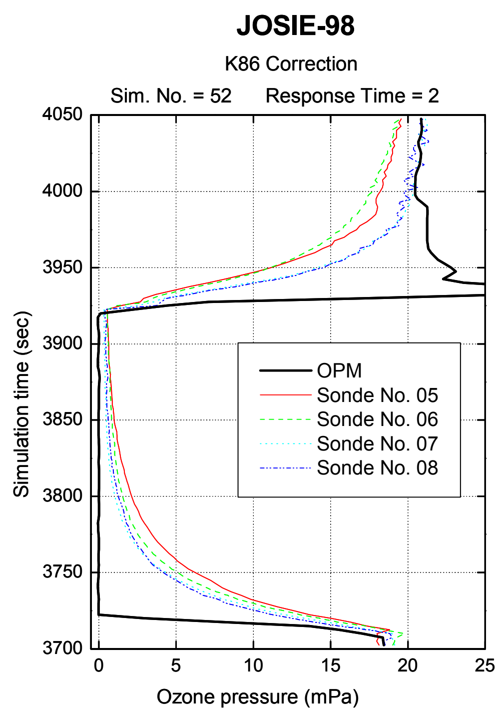
Results

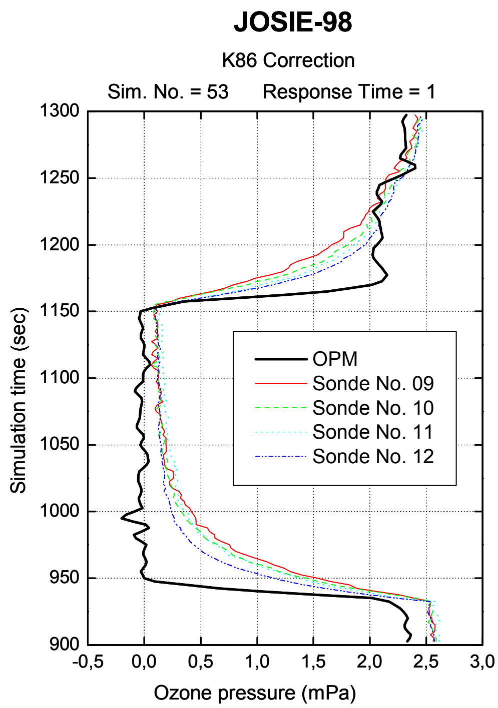
of

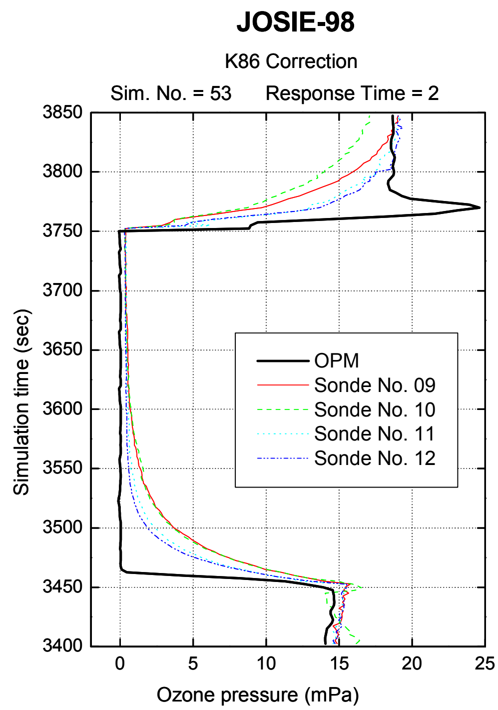
Individual Response Time Tests


JOSIE-98
K86 Correction
Sim. No. = 51 Response Time = 2
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 01
Sonde No. 02
Sonde No. 03
Sonde No. 04


JOSIE-98
K86 Correction
Sim. No. = 52 Response Time = 1
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 05
Sonde No. 06
Sonde No. 07
Sonde No. 08


JOSIE-98
K86 Correction
Sim. No. = 52 Response Time = 2
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 05
Sonde No. 06
Sonde No. 07
Sonde No. 08


JOSIE-98
K86 Correction
Sim. No. = 53 Response Time = 1
OPM
Sonde No. 09
Sonde No. 10
Sonde No. 11
Sonde No. 12
Simulation time (sec)
Ozone pressure (mPa)


JOSIE-98
K86 Correction
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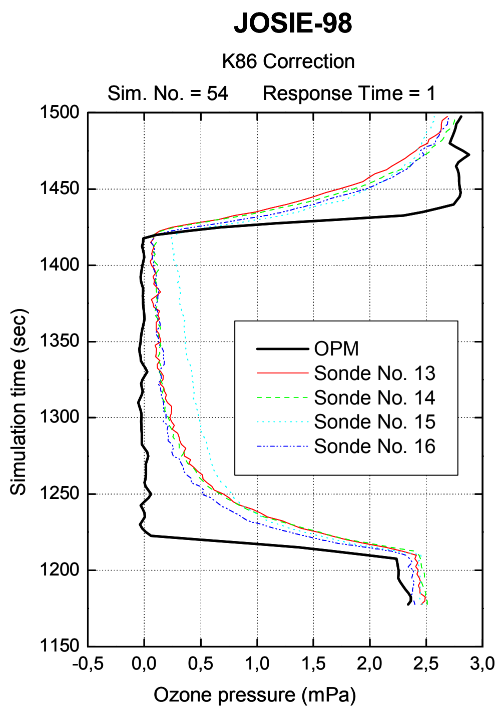
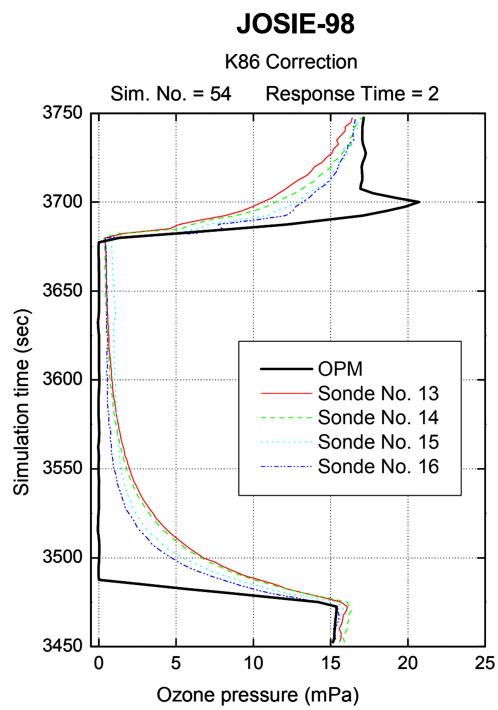
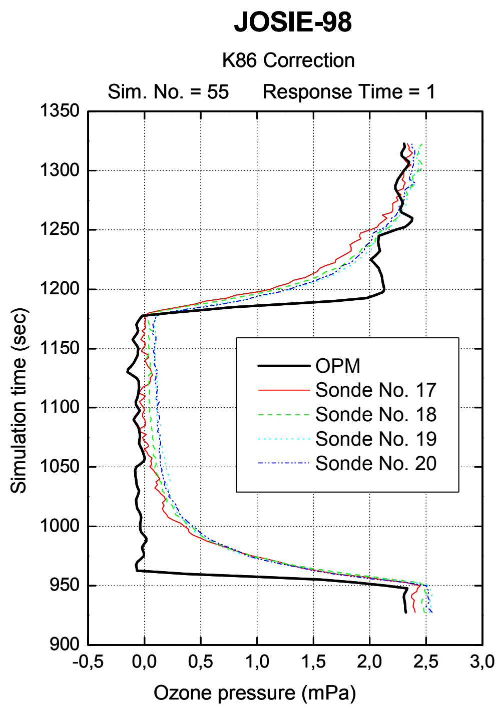
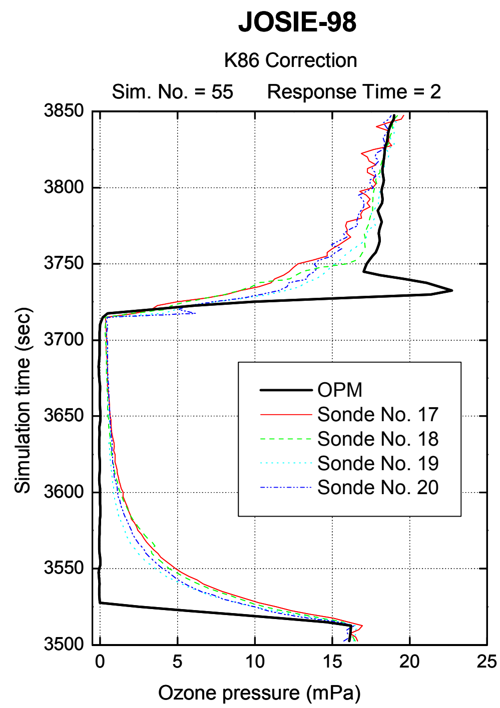
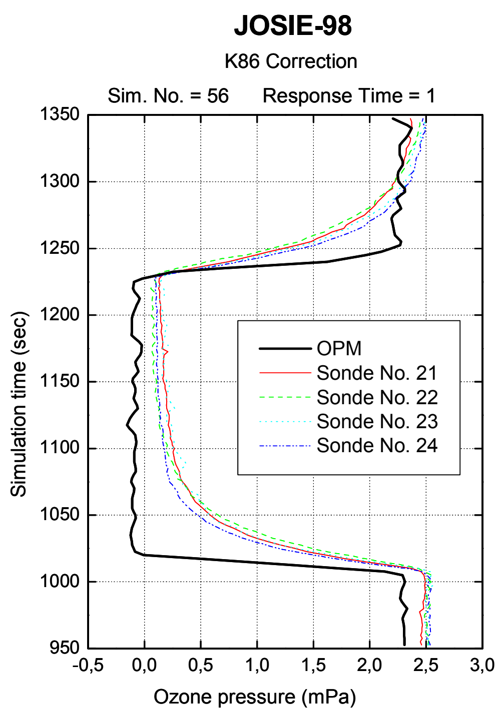
OPM
Sonde No. 09
Sonde No. 10
Sonde No. 11
Sonde No. 12
Simulation time (sec)
Ozone pressure (mPa)

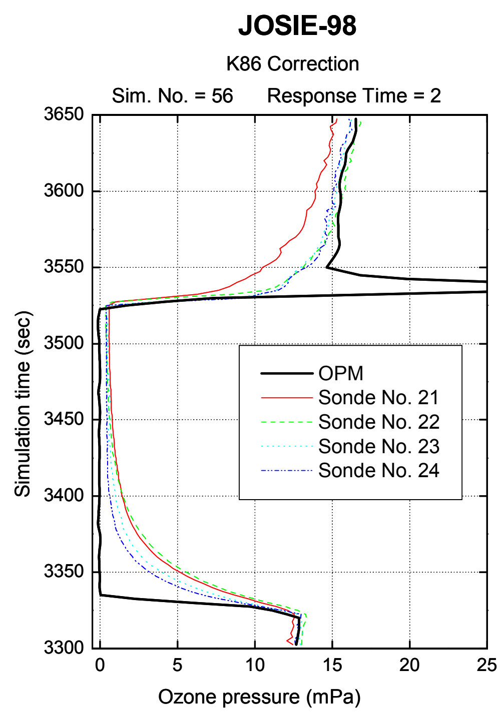

JOSIE-98
K86 Correction
Sim. No. = 54 Response Time = 1
OPM
Sonde No. 13
Sonde No. 14
Sonde No. 15
Sonde No. 16
Simulation time (sec)
Ozone pressure (mPa)

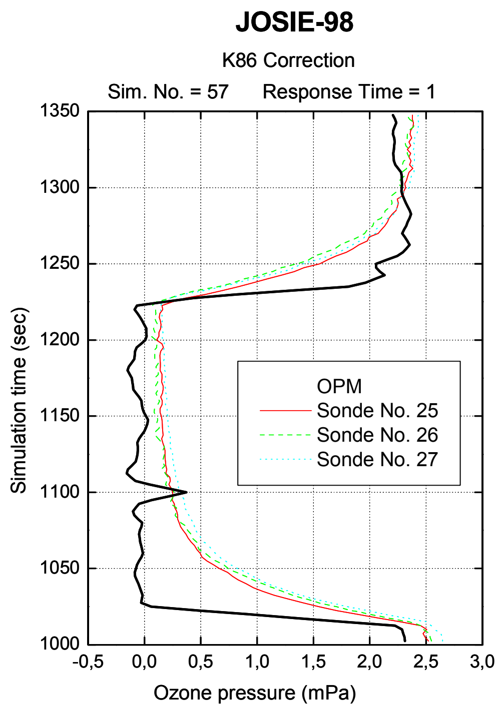

JOSIE-98
K86 Correction
Sim. No. = 54 Response Time = 2
OPM
Sonde No. 13
Sonde No. 14
Sonde No. 15
Sonde No. 16
Simulation time (sec)
Ozone pressure (mPa)

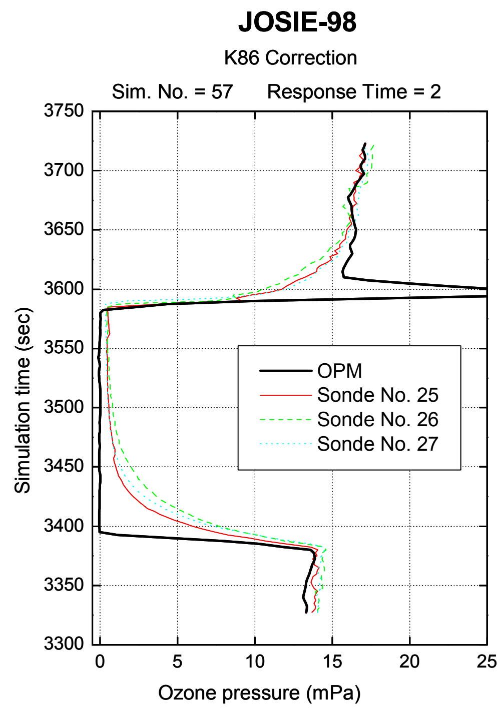

JOSIE-98
K86 Correction
Sim. No. = 55 Response Time = 1
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 17
Sonde No. 18
Sonde No. 19
Sonde No. 20


JOSIE-98
K86 Correction
Sim. No. = 55 Response Time = 2
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 17
Sonde No. 18
Sonde No. 19
Sonde No. 20


JOSIE-98
K86 Correction
Sim. No. = 56 Response Time = 1
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 21
Sonde No. 22
Sonde No. 23
Sonde No. 24


JOSIE-98
K86 Correction
Sim. No. = 56 Response Time = 2
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 21
Sonde No. 22
Sonde No. 23
Sonde No. 24


JOSIE-98
K86 Correction
Sim. No. = 57
Response Time = 1
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 25
Sonde No. 26
Sonde No. 27
1000
1050
1100
1150
1200
1250
1300
1350
-0,5
0,0
0,5
1,0
1,5
2,0
2,5
3,0


JOSIE-98
K86 Correction
Sim. No. = 57
Response Time = 2
Simulation time (sec)
Ozone pressure (mPa)
OPM
Sonde No. 25
Sonde No. 26
Sonde No. 27
3300
3350
3400
3450
3500
3550
3600
3650
3700
3750
0
5
10
15
20
25

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50. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1985. December 1987 (WMO TD No. 198).

51. Report of the NBS/WMO Expert Meeting on Atmospheric CO_2 Measurement Techniques, Gaithersburg, USA, 15-17 June 1987. December 1987.

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53. WMO Meeting of Experts on Strategy for the Monitoring of Suspended Particulate Matter in BAPMoN - Reports and papers presented at the meeting, Xiamen, China, 13-17 October 1986. October 1988.

54. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1983, Volume II: Precipitation chemistry, continuous atmospheric carbon dioxide and suspended particulate matter (WMO TD No. 283).

55. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at 31 December 1987 (WMO TD No. 284).

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57. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1986, Volume I: Atmospheric Aerosol Optical Depth. July 1988.

58. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at BAPMoN sites for the years 1986 and 1987 (WMO TD No. 306).

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72. Integrated Background Monitoring of Environmental Pollution in Mid-Latitude Eurasia by Yu.A. Izrael and F.Ya. Rovinsky, USSR (WMO TD No. 434).

73. Report of the Experts Meeting on Global Aerosol Data System (GADS), Hampton, Virginia, 11 to 12 September 1990 (WMO TD No. 438).

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75. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at Global Atmosphere Watch (GAW)-BAPMoN sites for the year 1990 (WMO TD No. 447).

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80. Report of the WMO Meeting of Experts on the Quality Assurance Plan for the GAW, Garmisch-Partenkirchen, Germany, 26-30 March 1992 (WMO TD No. 513).

81. Report of the Second Meeting of Experts to Assess the Response to and Atmospheric Effects of the Kuwait Oil Fires, Geneva, Switzerland, 25-29 May 1992 (WMO TD No. 512).

82. Global Atmospheric Background Monitoring for Selected Environmental Parameters BAPMoN Data for 1991, Volume I: Atmospheric Aerosol Optical Depth (WMO TD No. 518).

83. Report on the Global Precipitation Chemistry Programme of BAPMoN (WMO TD No. 526).

84. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at GAW-BAPMoN sites for the year 1991 (WMO TD No. 543).

85. Chemical Analysis of Precipitation for GAW: Laboratory Analytical Methods and Sample Collection Standards by Dr Jaroslav Santroch (WMO TD No. 550).

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87. Report of the Third Session of EC Panel/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, Geneva, 8-11 March 1993 (WMO TD No. 555).

88. Report of the Seventh WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques, Rome, Italy, 7 - 10 September 1993, (edited by Graeme I. Pearman and James T. Peterson) (WMO TD No. 669).

89. 4th International Conference on CO_2 (Carqueiranne, France, 13-17 September 1993) (WMO TD No. 561).

90. Global Atmospheric Background Monitoring for Selected Environmental Parameters GAW Data for 1992, Volume I: Atmospheric Aerosol Optical Depth (WMO TD No. 562).

91. Extended Abstracts of Papers Presented at the WMO Region VI Conference on the Measurement and Modelling of Atmospheric Composition Changes Including Pollution Transport, Sofia, 4 to 8 October 1993 (WMO TD No. 563).

92. Report of the Second WMO Meeting of Experts on the Quality Assurance/Science Activity Centres of the Global Atmosphere Watch, Garmisch-Partenkirchen, 7-11 December 1992 (WMO TD No. 580).

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94. Report on the Measurements of Atmospheric Turbidity in BAPMoN (WMO TD No. 603).

95. Report of the WMO Meeting of Experts on UV-B Measurements, Data Quality and Standardization of UV Indices, Les Diablerets, Switzerland, 25-28 July 1994 (WMO TD No. 625).

96. Global Atmospheric Background Monitoring for Selected Environmental Parameters WMO GAW Data for 1993, Volume I: Atmospheric Aerosol Optical Depth.

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98. Report of the WMO Meeting of Experts on Global Carbon Monoxide Measurements, Boulder, USA, 7-11 February 1994 (WMO TD No. 645).

99. Status of the WMO Global Atmosphere Watch Programme as at 31 December 1993 (WMO TD No. 636).

100. Report of the Workshop on UV-B for the Americas, Buenos Aires, Argentina, 22-26 August 1994.

101. Report of the WMO Workshop on the Measurement of Atmospheric Optical Depth and Turbidity, Silver Spring, USA, 6-10 December 1993, (edited by Bruce Hicks) (WMO TD No. 659).

102. Report of the Workshop on Precipitation Chemistry Laboratory Techniques, Hradec Kralove, Czech Republic, 17-21 October 1994 (WMO TD No. 658).

103. Report of the Meeting of Experts on the WMO World Data Centres, Toronto, Canada, 17-18 February 1995, (prepared by Edward Hare) (WMO TD No. 679).

104. Report of the Fourth WMO Meeting of Experts on the Quality Assurance/Science Activity Centres (QA/SACs) of the Global Atmosphere Watch, jointly held with the First Meeting of the Coordinating Committees of IGAC-GLONET and IGAC-ACE, Garmisch-Partenkirchen, Germany, 13 to 17 March 1995 (WMO TD No. 689).

105. Report of the Fourth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Garmisch, Germany, 6-11 March 1995) (WMO TD No. 718).

106. Report of the Global Acid Deposition Assessment (edited by D.M. Whelpdale and M-S. Kaiser) (WMO TD No. 777).

107. Extended Abstracts of Papers Presented at the WMO-IGAC Conference on the Measurement and Assessment of Atmospheric Composition Change (Beijing, China, 9-14 October 1995) (WMO TD No. 710).

108. Report of the Tenth WMO International Comparison of Dobson Spectrophotometers (Arosa, Switzerland, 24 July - 4 August 1995).

109. Report of an Expert Consultation on 85Kr and 222Rn: Measurements, Effects and Applications (Freiburg, Germany, 28-31 March 1995) (WMO TD No. 733).

110. Report of the WMO-NOAA Expert Meeting on GAW Data Acquisition and Archiving (Asheville, NC, USA, 4-8 November 1995) (WMO TD No. 755).

111. Report of the WMO-BMBF Workshop on VOC Establishment of a "World Calibration/Instrument Intercomparison Facility for VOC" to Serve the WMO Global Atmosphere Watch (GAW) Programme (Garmisch-Partenkirchen, Germany, 17-21 December 1995) (WMO TD No. 756).

112. Report of the WMO/STUK Intercomparison of Erythemally-Weighted Solar UV Radiometers, Spring/Summer 1995, Helsinki, Finland (WMO TD No. 781).

113. The Strategic Plan of the Global Atmosphere Watch (GAW) (WMO TD No. 802).

114. Report of the Fifth WMO Meeting of Experts on the Quality Assurance/Science Activity Centres (QA/SACs) of the Global Atmosphere Watch, jointly held with the Second Meeting of the Coordinating Committees of IGAC-GLONET and IGAC-ACE[Ed], Garmisch-Partenkirchen, Germany, 15-19 July 1996 (WMO TD No. 787).

115. Report of the Meeting of Experts on Atmospheric Urban Pollution and the Role of NMSs (Geneva, 7-11 October 1996) (WMO TD No. 801).

116. Expert Meeting on Chemistry of Aerosols, Clouds and Atmospheric Precipitation in the Former USSR (Saint Petersburg, Russian Federation, 13-15 November 1995).

117. Report and Proceedings of the Workshop on the Assessment of EMEP Activities Concerning Heavy Metals and Persistent Organic Pollutants and their Further Development (Moscow, Russian Federation, 24-26 September 1996) (Volumes I and II) (WMO TD No. 806).

118. Report of the International Workshops on Ozone Observation in Asia and the Pacific Region (IWOAP, IWOAP-II), (IWOAP, 27 February-26 March 1996 and IWOAP-II, 20 August-18 September 1996) (WMO TD No. 827).

119. Report on BoM/NOAA/WMO International Comparison of the Dobson Spectrophotometers (Perth Airport, Perth, Australia, 3-14 February 1997), (prepared by Robert Evans and James Easson) (WMO TD No. 828).

120. WMO-UMAP Workshop on Broad-Band UV Radiometers (Garmisch-Partenkirchen, Germany, 22 to 23 April 1996) (WMO TD No. 894).

121. Report of the Eighth WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques (prepared by Thomas Conway) (Boulder, CO, 6-11 July 1995) (WMO TD No. 821).

122. Report of Passive Samplers for Atmospheric Chemistry Measurements and their Role in GAW (prepared by Greg Carmichael) (WMO TD No. 829).

123. Report of WMO Meeting of Experts on GAW Regional Network in RA VI, Budapest, Hungary, 5 to 9 May 1997.

124. Fifth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, (Geneva, Switzerland, 7-10 April 1997) (WMO TD No. 898)

125. Instruments to Measure Solar Ultraviolet Radiation, Part 1: Spectral Instruments (lead author G. Seckmeyer) (WMO TD No. 1066)

126. Guidelines for Site Quality Control of UV Monitoring (lead author A.R. Webb) (WMO TD No. 884).

127. Report of the WMO-WHO Meeting of Experts on Standardization of UV Indices and their Dissemination to the Public (Les Diablerets, Switzerland, 21-25 July 1997) (WMO TD No. 921).

128. The Fourth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting, (Rome, Italy, 22-25 September 1996) (WMO TD No. 918).

129. Guidelines for Atmospheric Trace Gas Data Management (Ken Masarie and Pieter Tans), 1998 (WMO TD No. 907).

130. Jülich Ozone Sonde Intercomparison Experiment (JOSIE, 5 February to 8 March 1996), (H.G.J. Smit and D. Kley) (WMO TD No. 926).

131. WMO Workshop on Regional Transboundary Smoke and Haze in Southeast Asia (Singapore, 2 to 5 June 1998) (Gregory R. Carmichael). Two volumes.

132. Report of the Ninth WMO Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques (Edited by Roger Francey), (Aspendale, Vic., Australia).

133. Workshop on Advanced Statistical Methods and their Application to Air Quality Data Sets (Helsinki, 14-18 September 1998) (WMO TD No. 956).

134. Guide on Sampling and Analysis Techniques for Chemical Constituents and Physical Properties in Air and Precipitation as Applied at Stations of the Global Atmosphere Watch. Carbon Dioxide (WMO TD No. 980).

135. Sixth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Zurich, Switzerland, 8-11 March 1999) (WMO TD No.1002).

136. WMO/EMEP/UNEP Workshop on Modelling of Atmospheric Transport and Deposition of Persistent Organic Pollutants and Heavy Metals (Geneva, Switzerland, 16-19 November 1999) (Volumes I and II) (WMO TD No. 1008).

137. Report and Proceedings of the WMO RA II/RA V GAW Workshop on Urban Environment (Beijing, China, 1-4 November 1999) (WMO-TD. 1014) (Prepared by Greg Carmichael).

138. Reports on WMO International Comparisons of Dobson Spectrophotometers, Parts I – Arosa, Switzerland, 19-31 July 1999, Part II – Buenos Aires, Argentina (29 Nov. – 12 Dec. 1999 and Part III – Pretoria, South Africa (18 March – 10 April 2000) (WMO TD No. 1016).

139. The Fifth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting (Halkidiki, Greece, September 1998)(WMO TD No. 1019).

140. WMO/CEOS Report on a Strategy for Integrating Satellite and Ground-based Observations of Ozone (WMO TD No. 1046).

141. Report of the LAP/COST/WMO Intercomparison of Erythemal Radiometers (Thessaloniki, Greece, 13-23 September 1999) (WMO TD No. 1051).

142. Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), A Contribution to the Implementation of the Long-Term Plan (WMO TD No.1077).

143. Global Atmosphere Watch Measurements Guide (WMO TD No. 1073).

144. Report of the Seventh Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry and the GAW 2001 Workshop (Geneva, Switzerland, 2 to 5 April 2001) (WMO TD No. 1104).

145. WMO GAW International Comparisons of Dobson Spectrophotometers at the Meteorological Observatory Hohenpeissenberg, Germany (21 May – 10 June 2000, MOHp2000-1), 23 July – 5 August 2000, MOHp2000-2), (10 – 23 June 2001, MOHp2001-1) and (8 to 21 July 2001, MOHp2001-2). Prepared by Ulf Köhler (WMO TD No. 1114).

146. Quality Assurance in monitoring solar ultraviolet radiation: the state of the art. (WMO TD No. 1180).

147. Workshop on GAW in RA VI (Europe), Riga, Latvia, 27-30 May 2002 (WMO TD No. 1206).

148. Report of the Eleventh WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques (Tokyo, Japan, 25-28 September 2001) (WMO TD No 1138).

149. Comparison of Total Ozone Measurements of Dobson and Brewer Spectrophotometers and Recommended Transfer Functions (prepared by J. Staehelin, J. Kerr, R. Evans and K. Vanicek) (WMO TD No. 1147).

150. Updated Guidelines for Atmospheric Trace Gas Data Management (Prepared by Ken Maserie and Pieter Tans (WMO TD No. 1149).

151. Report of the First CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Geneva, Switzerland, 18-19 March 2003) (WMO TD No. 1181).

152. Current Activities of the Global Atmosphere Watch Programme (as presented at the 14th World Meteorological Congress, May 2003). (WMO TD No. 1168).

153. WMO/GAW Aerosol Measurement Procedures: Guidelines and Recommendations. (WMO TD No. 1178).

154. WMO/IMEP-15 Trace Elements in Water Laboratory Intercomparison. (WMO TD No. 1195).

155. 1st International Expert Meeting on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies (Gif sur Yvette, France, 3-5 June 2003) (WMO TD No. 1201).

156. Addendum for the Period 2005-2007 to the Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), GAW Report No. 142 (WMO TD No. 1209).