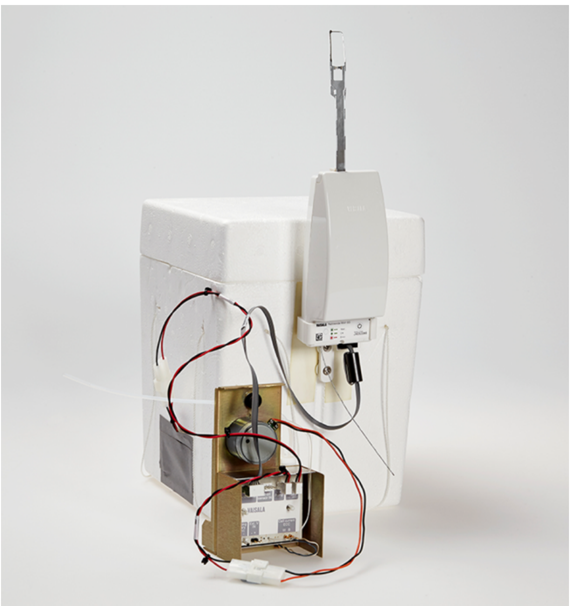
PERFORMANCE OF VAISALA OZONE INTERFACE BOARD OIF411

White Paper



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CHAPTER 1

GENERAL INFORMATION

The purpose of this document is to present the measurements and measurement performance of Vaisala Ozone Interface Board OIF411.

Version Information

Table 1. Manual revisions.

Manual Code	Description
B211385EN-A	May 2014. This manual. First version.

Ozone Sounding with Vaisala Radiosonde RS41

Atmospheric ozone is a significant trace gas. Ozone protects the earth's surface from solar UV radiation. It is also a greenhouse gas, an air pollutant, and has a key role in oxidation reactions. Vaisala Radiosonde RS41 supports measurements of ozone profiles and total ozone column. Ozone sounding with RS41 consists of an ozone sensor unit, Digital Interface Kit RSA411, and RS41 radiosonde.

The RSA411 kit is used with two electrochemical concentration cell (ECC) type sensors: Science Pump Corporation's (SPC) Model ECC6A, or Droplet Measurement Technologies (DMT) Model Z. ECC ozone sensors provide the most accurate ozone profiles for use, for example, in climatological trend analysis and for validating satellite data.

The ozone sensor is connected to RS41 radiosonde via an ozone interface. This combination measures high-resolution profiles of pressure, temperature, humidity, geopotential height, wind, and the vertical distribution of atmospheric ozone up to 3 hPa. Vaisala Sounding System MW41 calculates ozone partial pressure profile and integrated total ozone using raw ozone data and other radiosonde measurements.

Vaisala Ozone Interface Board OIF411

OIF411 provides a robust and convenient interface between the ozone sensor and Vaisala Radiosonde RS41. OIF411 is part of the RSA411 kit. OIF411 is an upgrade to model OIF921 with new supporting measurements and enhanced functionality.

OIF411 measures the ozone sensor current, and the internal temperature of the ozone pump with a cable-attached temperature sensor. OIF411 provides additional measurements of battery and pump performance, as recommended by the Global Atmospheric Watch (GAW) program of the World Meteorological Organization (WMO) [1]. OIF411 also includes a smart heating capability for the ozone sensor, which regulates heating based on temperature. OIF411 can pass data from one or more additional sensors through an XDATA [2] interface. For example, Cryogenic Frostpoint Hygrometer (CFH) and Compact Optical Backscatter Aerosol Detector (COBALD) sensors support XDATA protocol. MW41 makes the data available in a convenient text format.

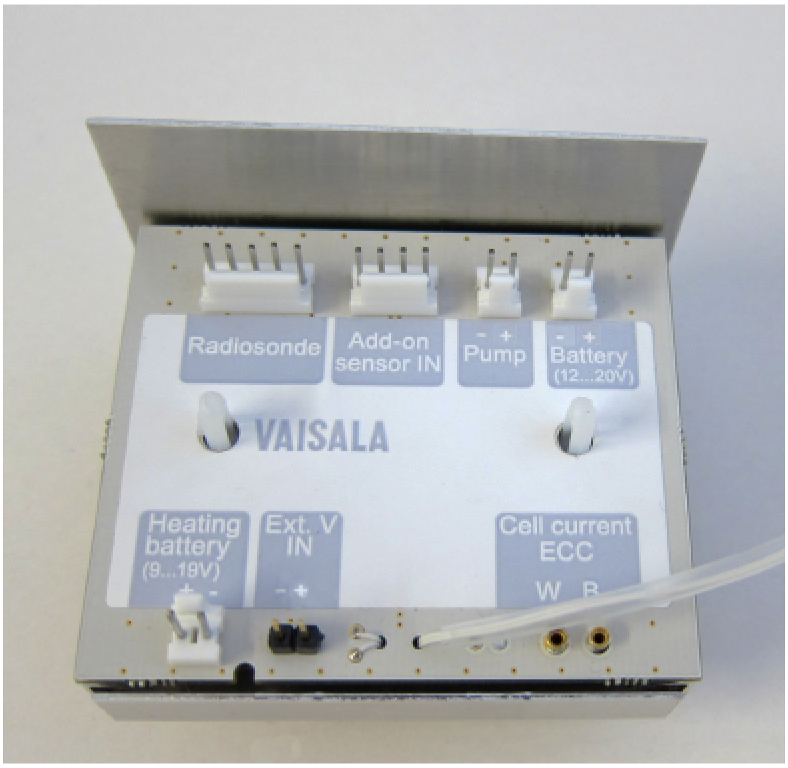

Figure 1. Ozone Interface Board OIF411. Clockwise from the top: radiosonde interface, add-on sensor interface, ozone pump current, ozone pump battery voltage, ozone sensor current, wire for pump temperature measurement, external voltage measurement, and connector for heating battery.

CHAPTER 2
EXECUTIVE SUMMARY

OIF411 provides accurate and stable measurements over the whole measurement range. **Table 2** presents a summary of the key parameters provided by OIF411. Measurement accuracy was estimated with an uncertainty analysis, based on the recommended evaluation of measurement data described in JCGM 100:2008 [3]. The specifications are expressed using expanded uncertainty (k=2), encompassing approximately 95% of the dispersion of results.

Ozone sensor current measurement and pump temperature measurement contribute directly to the accuracy of the ozone measurement. Instructions for calculating combined uncertainty for ozone partial pressure for a given ozone sensor model are given in GAW publication [1]. Proper ground preparations and the type of solution used in the ECC sensor are critical for the accuracy of the measurement.

Table 2. Key performance figures of Ozone Interface Board OIF411.

Ozone Interface Board OIF411	
Accuracy of ozone sensor current measurement Measurement range Resolution Combined uncertainty (*	 0…14 µA 0.1 nA 0.2 %, minimum 3 nA
Accuracy of pump temperature measurement Measurement range Resolution Measurement uncertainty (**	 -5… +60 °C 0.01 °C 0.2 °C
Accuracy of pump voltage measurement Measurement range Resolution Measurement uncertainty (***	 0… 19.7 V 0.1 V 1.5 %, minimum 0.1 V
Accuracy of pump current measurement Measurement range Resolution Measurement uncertainty (***	 0… 300 mA 1 mA 2.5 %, minimum 3 mA
Accuracy of external voltage measurement Measurement range Resolution Input resistance Measurement uncertainty (***	 0… 12 V 0.1 V 111 kΩ 0.1 %, minimum 2 mV

(* Includes uncertainties of calibration and electrical components.

(** Based on sensor specifications.

(*** Includes uncertainties of the electrical components.

Resolution refers to the reported resolution in MW41 output.

CHAPTER 3

OZONE SENSOR CURRENT MEASUREMENT

During the flight, the ozone sensor samples air with a small gas sampling pump. The ozone in the air reacts with the potassium iodide in the sensing solution in the ECC cells. The resulting electrical current is measured by OIF411 with very high accuracy. The measured current is directly proportional to ozone concentration.

This chapter describes the factors affecting the accuracy of the ozone current measurement in OIF411, and included in the measurement uncertainty analysis. The instrument specifications are an outcome of this analysis and they are presented in Table 2 and Figure 4.

Measurement Electronics

OIF411 electronics uses OIF921 design as a basis. The new design includes enhancements utilizing technological advancements in high-quality components.

Calibration with Temperature Dependence

The sensor current measurement of each OIF411 board is individually calibrated with a reference current source which is traceable to international standards. Uncertainty analysis for the calibration includes linearity, repeatability, and long-term and short-term stability of the calibration reference, and short-term stability and resolution of the unit in calibration.

The temperature dependence was estimated theoretically and verified in laboratory tests. The theoretical evaluation used the specified temperature dependence values for each electronic component. The results indicate that the maximum specified temperature change (from +25 °C calibration temperature to +65 °C) causes a 0.2 nA uncertainty (k=2) at zero current. The uncertainty increases by 0.05% of the measured current. In practice the impact of the temperature dependence is small. **Figure 2** shows the combined effect of calibration uncertainty and temperature dependence.

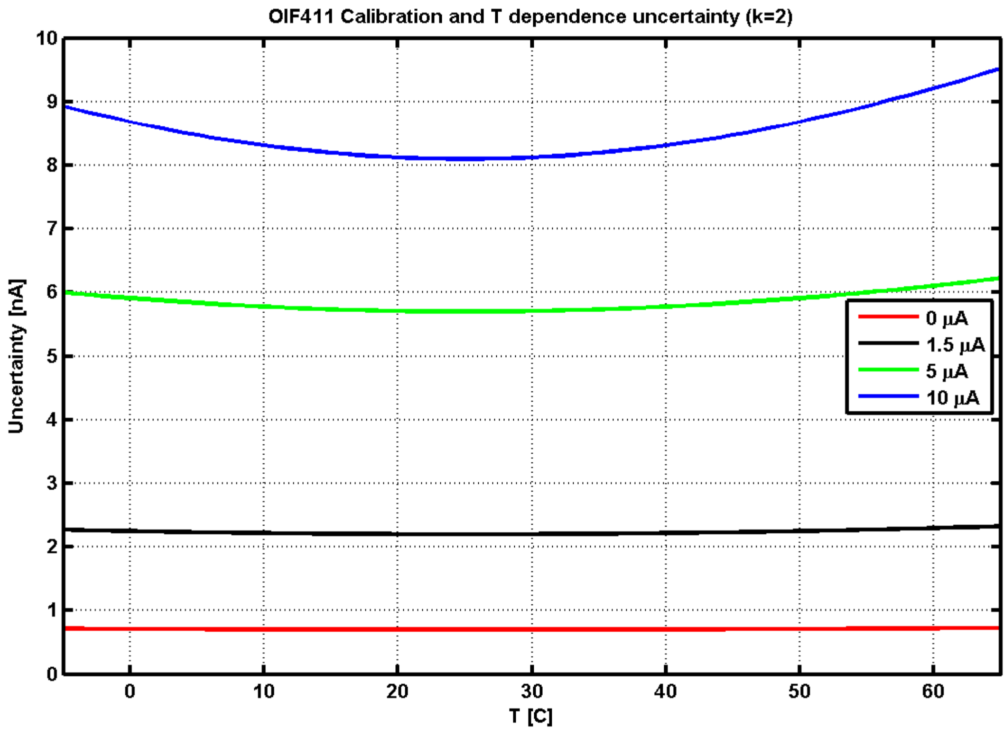

Figure 2. Uncertainty (k=2) related to calibration process and temperature dependence of the measurement electronics, shown as a function of temperature for different current levels.

A set of OIF411 units were tested in laboratory tests which covered temperature range from -5 to +65 °C. All tested units showed temperature dependence that was smaller than the theoretically estimated dependence. The results for one unit are shown in **Figure 3**.

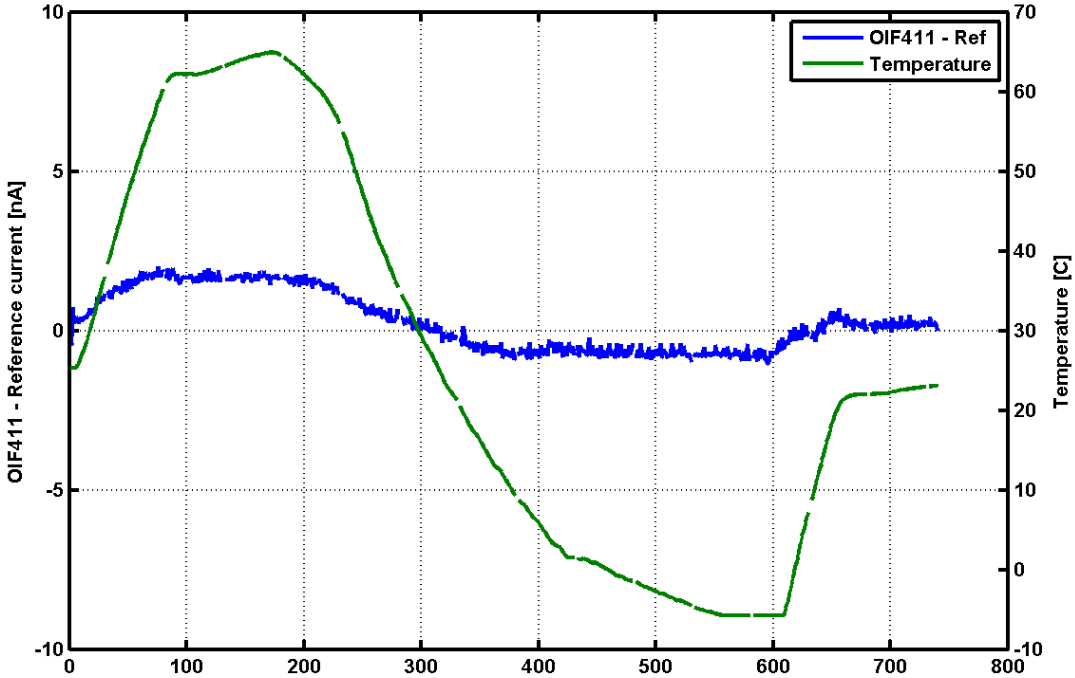

Figure 3. Temperature dependence of the measured ozone current for one OIF411 unit, for a reference current of 10 µA. The figure shows the difference of OIF411 current from the reference (green) and OIF411 temperature (blue) during the test.

Humidity Dependence

The humidity dependence of the ozone current measurement was evaluated in a 20-hour test where the temperature and humidity conditions varied from +22 °C / 55 % RH to +40 °C / 95 % RH. The observed difference to a reference measurement varied by 0.01 % during the measurement. The humidity dependence is thus negligible.

Noise Level

Noise level was estimated in unit tests in laboratory conditions using a stable current source. The noise level is defined by the standard deviation of the measured current. It was estimated 0.1 nA over the range of the measurement conditions.

Linearity

Linearity was estimated by comparing measurements against a calibrated current source using a current level that was not included in the calibration process. The tests indicated a minor 1 nA non-linearity over the range of the measurement conditions.

Combined Uncertainty

Figure 4 presents the specifications for the combined uncertainty of OIF411 current measurement over the measurement range. The specification is based on the analysis of calibration and measurement electronics uncertainty. The OIF411 specifications are not comparable with the previous model OIF921. To give a more accurate estimate of the performance during the flight, the OIF411 analysis takes into account more uncertainty components.

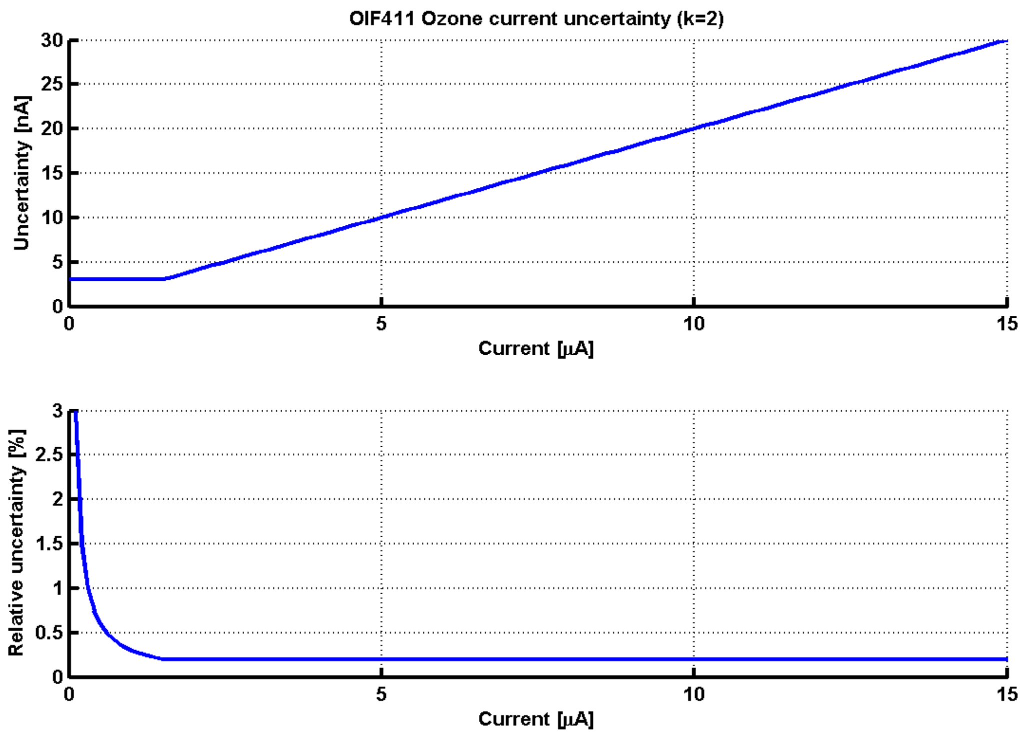

Figure 4. Combined uncertainty (k=2) of OIF411 ozone sensor current measurement as a function of the electric current. The top graph shows the uncertainty in units of nA and the bottom graph in terms of relative uncertainty.

CHAPTER 4
PUMP TEMPERATURE MEASUREMENT

Temperature Sensor

The temperature of the gas sampling pump is measured to estimate changes in the air mass flow rate. Together with ozone current measurement, pump temperature measurement is an essential component of the ozone sounding. The temperature is measured with an accurate negative temperature coefficient (NTC) resistor. The sensor accuracy is 0.2 °C. The temperature measurement follows the procedure recommended by GAW [1], where the sensor is placed inside the pump enclosure.

Measurement Electronics

The impact of the OIF411 measurement electronics on the temperature measurement was evaluated throughout the measurement range. The temperature dependence of the measurement electronics was estimated to have a negligible effect of less than 0.01 °C in the temperature measurement over the operating range of -5 °C to +65 °C. Humidity dependence was also negligible within the resolution of the measurement.

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CHAPTER 5
TEST RESULTS

The ozone current measurement results were evaluated in performance tests in laboratory conditions and during radiosonde soundings. The tests verify that OIF411 measurements are within the specifications compared with a reference instrument. Radiosonde soundings demonstrate the performance of the whole ozone measurement setup including the radiosonde, RSA411 and the ozone sensor.

Performance in Laboratory Tests

Comparison with a Reference

In this test, OIF411 was connected to a precision current source (Agilent B2902A). OIF411 was also connected to a radiosonde and the measurement data was collected with MW41. Five pairs of units were tested in room temperature, covering the full measurement range. **Table 3** shows the comparison results from one tested OIF411 unit using seven current levels. Differences between OIF411 and the reference instrument were small and remained within OIF411 accuracy specifications. Variations between the tested OIF411 units were within 0.001 µA.

Table 3. Comparison of current measurements with OIF411 and Agilent B2902A reference multimeter. The column on the right shows the OIF411 accuracy specification.

Current Source [µA]	OIF411 – Reference Average Differences [µA]	OIF411 Accuracy Specification (k=2) [µA]
0.0	0.000	0.003
0.5	-0.001	0.003
1.0	-0.001	0.003
3.0	-0.002	0.006
6.0	-0.004	0.012
10.0	-0.006	0.020
14.0	-0.009	0.028

Comparison of OIF411 and OIF921

In this test, first OIF411 and then OIF921 were connected to the same precision current source. Five pairs of units were tested in room temperature. **Table 4** shows the comparison results from one pair of tested OIF411 and OIF921 units using five current levels. In the tests, OIF921 boards measured higher current levels. OIF411 showed consistently a better match with calibrated reference instrument, as shown in the example in Table 3.

Table 4. Comparison of current measurements with OIF411 and OIF921.

Current Source [µA]	OIF411 – OIF921 Average Differences [µA]
0.0	-0.005
0.5	-0.007
3.0	-0.010
6.0	-0.012
10.0	-0.021

Performance in Flight Tests

Several flight tests were conducted during OIF411 development to verify OIF411 performance, and to compare OIF921 and OIF411 models. Test sites were at the Vaisala factory site and in Sodankylä (WMO #02836) at customer premises. This section shows ozone partial pressure profiles from three flight setups.

Instrument Setup During Ozone Sounding

When a radiosonde is attached to a large body, such as the ozone sensor box or the CFH instrument, the air flow pattern changes near the radiosonde. The air flow is also altered by the attenuated motion of the radiosonde in flight. Sounding tests were conducted in various climates and weather conditions to find the optimum setup for RS41 radiosonde and the ozone sensor box combination. Based on these tests, the optimum attachment for the radiosonde is near the top of the box, with the boom pointing upwards [4]. **Figure 5** shows the configuration for an ozone sounding. In a standard RS41 sounding, the optimal boom angle is 45°. These boom positions were found to give the most consistent measurement results for RS41.

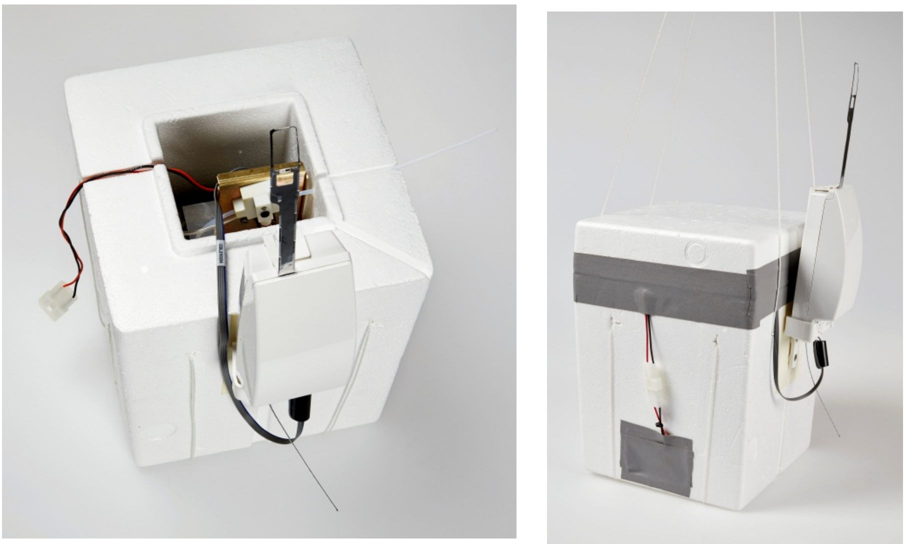

Figure 5. Instrument setup for ozone sounding: on the left with the cover of the flight box removed, on the right ready for release.

Comparison of Two OIF411 Boards Using Same Ozone Sensor

In this test sounding, two OIF411 interface boards were attached to the same ozone sensor (SPC-6A). The OIF411 boards were connected to two RS41-SG radiosondes, attached to the opposite sides of the ozone box. The test was used to evaluate measurement reproducibility. **Figure 6** shows ozone partial pressure profiles from the two OIF411 measurements during the test flight. The average difference was 0.016 mPa and the standard deviation of differences 0.029 mPa. The noise in the measurement comes mostly from the test setup, for example, timing differences in reading the two OIF411 boards. The differences are small compared with a 5% fraction of the ozone profile, shown with a dashed line. The 5% profile presents an approximation for typical uncertainty of measurements for ozone soundings [1].

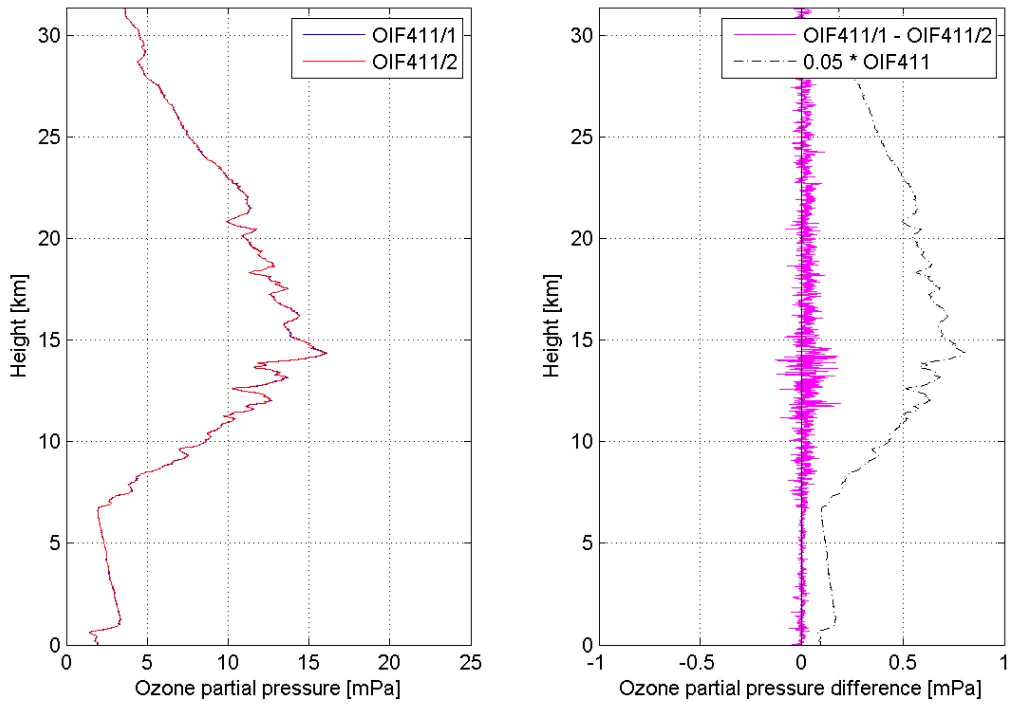

Figure 6. Comparison of ozone vertical profiles from two OIF411 boards measuring the same ozone sensor during a sounding on March 18, 2014 in Vantaa, Finland. Measured total ozone was 335.0 DU for OIF411/1 and 334.4 DU for OIF411/2.

Comparison of OIF411 and OIF921 Using Same Ozone Sensor

In this flight setup, OIF411 and OIF921 were attached to the same ozone sensor (DMT-Z). In this way, the comparison concentrated on the actual differences between the two interface boards, eliminating ozone sensor-related uncertainty. The ozone data measured from OIF411 was received with MW41 via an RS41-SG radiosonde. The ozone data measured from OIF921 was received with MW31 via an RS92-SGP radiosonde. **Figure 7** from an example flight shows a comparison of ozone partial pressure profiles between OIF411 and OIF921. The average difference was -0.046 mPa. OIF921 measured slightly higher current levels compared with OIF411. This result agrees with the observations made in laboratory conditions. The differences are small compared with the 5% fraction of the ozone profile, shown with a dashed line.

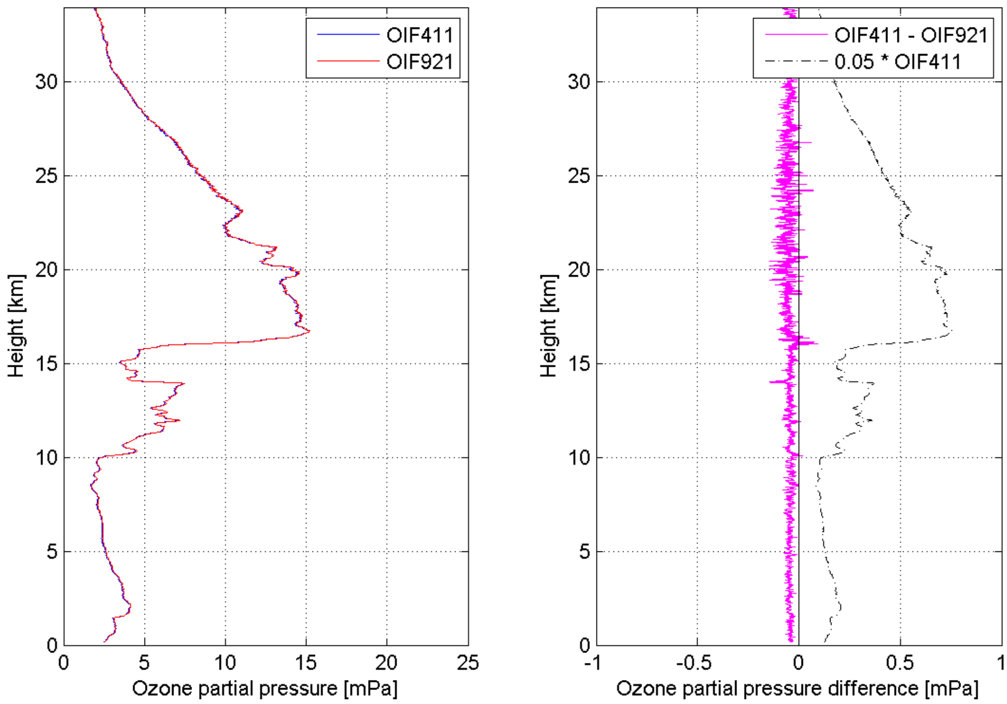

Figure 7. Comparison of ozone vertical profiles from OIF411 and OIF921 during a sounding on February 6, 2014 in Sodankylä, Finland. OIF411 and OIF921 were connected to the same ozone sensor. Measured total ozone was 282.5 DU for OIF411 and 284.0 DU for OIF921.

Comparison of OIF411 and OIF921 Using Separate Ozone Sensors

In this flight setup, OIF411 and OIF921 were connected to two separate ozone sensors (DMT-Z), attached to a rig. The ozone data measured from OIF411 was received with MW41 via an RS41-SG radiosonde. The ozone data measured from OIF921 was received with MW31 via an RS92-SGP radiosonde. **Figure 8** from an example flight shows a comparison of ozone partial pressure profiles between OIF411 and OIF921. The results demonstrate differences between the two systems, including the impact of ozone sensor measurement uncertainty.

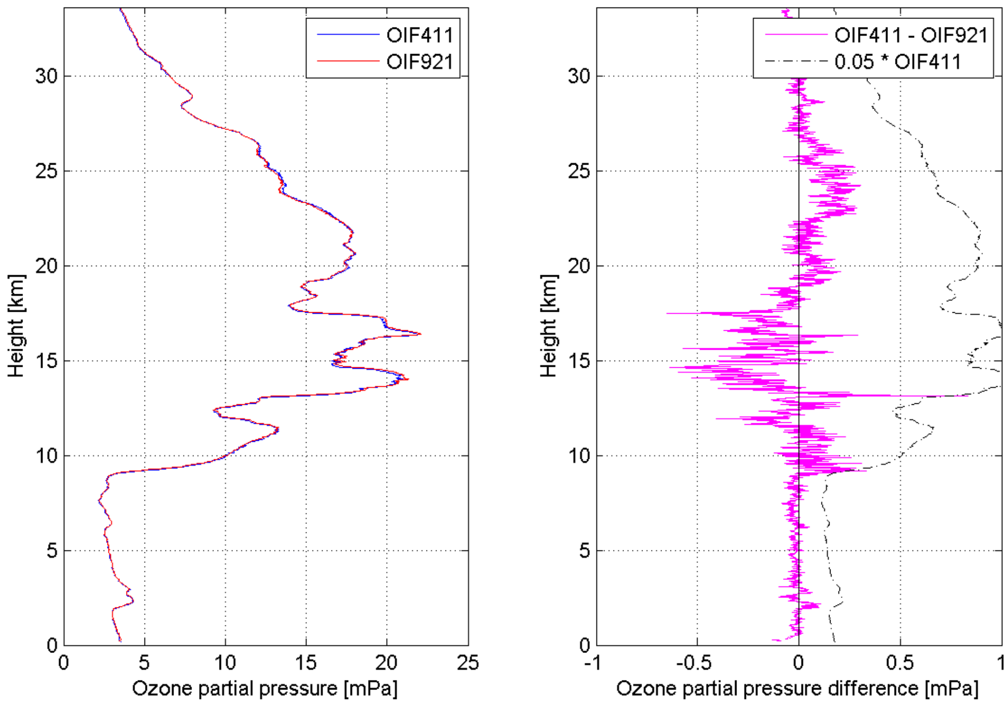

Figure 8. Comparison of ozone vertical profiles from OIF411 and OIF921 during a sounding on April 8, 2014 in Sodankylä, Finland. OIF411 and OIF921 were connected to separate ozone sensors in a rig sounding. Measured total ozone was 427.4 DU for OIF411 and 429.3 DU for OIF921.

CHAPTER 6
ADDITIONAL FEATURES

The OIF411 design includes new features that ensure high-quality and availability of ozone measurements, and allow cost-efficient inclusion of other measurement instruments in experiments.

Ozone Pump Diagnostic Measurements

OIF411 provides two diagnostics for the ozone pump: battery performance can be monitored with the pump battery voltage measurement, and pump performance with the pump motor current. These measurements are useful in verifying that the ozone sensor functions properly and that the ozone measurement is valid. Large currents may indicate excessive friction in the moving parts, while low currents can be symptomatic of pump leakage. These diagnostics are recommended by GAW [1].

Add-on Sensors

Users can combine additional sensors to the OIF411 interface, and then use a single RS41 radiosonde to transmit measurement data from several instruments to the ground system. OIF411 provides an XDATA interface which is compatible, for example, with CFH and COBALD instruments. XDATA is collected and distributed in a text format that allows users to provide their custom post-processing to the data.

Heating Capability

In very low ambient temperatures, the liquid in the ECC cells may freeze during the flight, ending the ozone sounding before the ozone sensor and radiosonde reach the important ozone layers in the stratosphere. Various heating systems have been utilized in the past, but administering the proper heating amount has required an experienced operator and improvised techniques, such as stabilizing water bags. One challenge is that at low pressures, the liquid starts boiling at very low temperatures. The obvious risk is the generation of over-heating and stopping the measurement as a consequence.

OIF411 provides controlled heating for the ozone sensor compartment powered by an additional battery. The heating turns on automatically when the measured ozone pump temperature drops below +5 °C, and turns off when the temperature rises above +7 °C. The ECC cell solution is typically a few degrees colder than the pump temperature, and thus the heating algorithm has been designed to keep the cells at just above the freezing point.

Test simulations with heating in an atmospheric chamber showed that the system prevents the solution from both freezing and boiling in low pressures. The heating functionality was also verified in flight tests, and no premature stops due to cell solution freezing or boiling were noticed.

Voltage Measurement

OIF411 provides a spare voltage measurement channel for additional measurements. The combined uncertainty of the measurement is 0.1 %, minimum 2 mV. The estimated temperature dependence of the voltage measurement is 40 mV within a temperature range of -5 °C to +65 °C and 12 V input voltage. The humidity dependence is negligible compared with the resolution of the measurement. The noise level remains below 5 mV at 12 V input voltage.

References

[1] Quality Assurance and Quality Control for Ozonesonde Measurements in GAW. GAW Report No. 201

[2] Vaisala Radiosonde RS41 Additional Sensor Interface User's Guide

[3] JCGM 100:2008. Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement

[4] Ozone Sounding with Vaisala Radiosonde RS41 User's Guide

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