FORSCHUNGSZENTRUM JÜLICH GmbH

Institut für Chemie 2:
Chemie der Belasteten Atmosphäre

OZONE PROFILES AT JÜLICH, FRG DURING 1988 AND 1989

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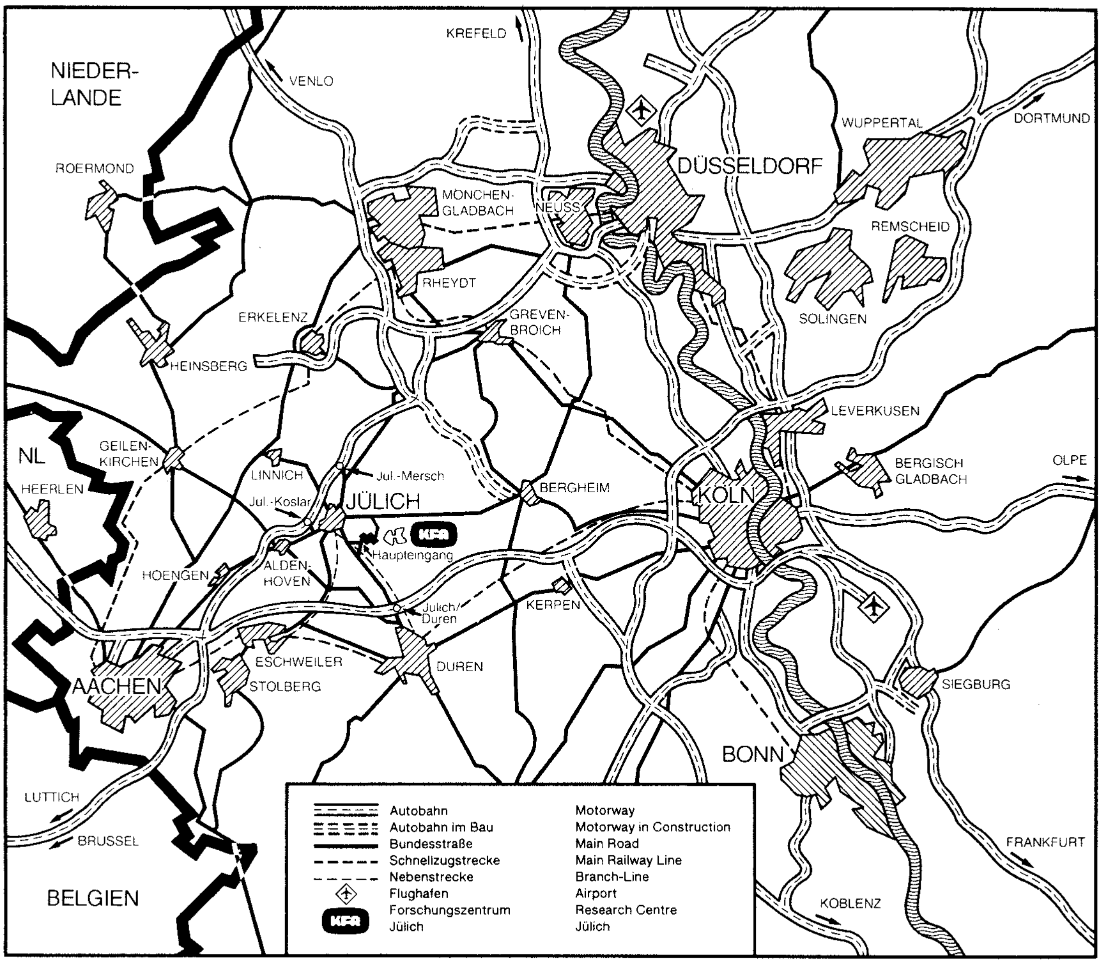

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Summary

Ozone soundings were performed regular at Jülich , FRG (50° 41' N, 6° 24' E). This report, the first one of an intended series, contains information on technical aspects and presents vertical profiles obtained during 1988 and 1989.

Introduction

Tropospheric ozone is of crucial importance as a precursor of reactive radicals. Through absorption of infrared radiation it contributes to the greenhouse effect. At higher concentrations, ozone is toxic for humans, animal– and plant–life. At lower concentrations, it reduces the net photochemical production of plants. Ozone is also thought to play a role in the syndrome of forest damage.

Measurements of ozone made during the last thirty years and in the last century have shown that ozone concentrations near ground and in the free troposphere are increasing at a rate of approximately 1% per year (Attmanspacher [1984], Feister [1987], Volz [1988]).

The chemistry, transport and budget of tropospheric ozone and other photooxidants is investigated in a major component of the EUROTRAC project TOR (Tropospheric ozone research). Within TOR, a network of stations (figure 1) performs regular vertical soundings of ozone and meteorological parameters, including relative humidity.

The sounding program at Jülich was begun in 1988. Regular flights, with a frequency of currently one per week were started in Juli 1989.

In the first part of this report we present a short description of our ozone sounding system. The second part contains all results obtained at Jülich up to December 1989.

2. Ozone Sounding System

2.1 Introduction to instrumentation

The equipment described serves to measure the concentration of atmospheric ozone from ground–level up to 25 km and above.
The ozone/radiosonde is a balloon–borne instrument which consists of the following components, as illustrated in figure 2:

1. Ozone sonde of ECC–type (= Electrochemical Concentration Cell).
2. Standard meteorological radio sonde for measuring pressure, temperature and relative humidity.
3. Interface board which converts the analog signals measured by the sondes (Ozone concentration, pressure, temperature and relative humidity) into a digitally coded data stream which is modulated into a two tone signal and telemetered to the ground station, using the 403 MHz–FM–transmitter of the radio sonde.
4. A hydrogen filled weather balloon.
5. A small parachute to slow the descent rate of the package after burst of the weather balloon.

The ground station, also indicated in figure 2, consists of

1. Conventional FM–receiver (400–406 MHz) for the demodulation of the received FM–signal into a two tone signal.
2. Modem to convert the signal into a hexadecimal coded data frame of ASCII–characters.
3. Personal computer for further processing and reduction of the sonde data.

2.2 Ozone Sonde: ECC–Type

The ozone sonde is shown in figure 3A. It consists mainly of the following components:

An ozone sensor of EEC–type (Komhyr,1969,1971), based on an electrochemical method, generates an electrical current proportional to the flow rate of ozone through the solution. A small electrically driven gas sampling pump forces ambient air through the ozone sensor. By knowing the gas flow rate, its temperature and pressure, the measured electrical current can be converted to the ozone concentration.

The ECC–ozone sensor is based on the iodine/iodide redox reaction by ozone which is performed in an electrochemical concentration cell of the type:

$$Pt, I_2; I^- \;\; || \;\; I^-; I_2, Pt$$

A cross–sectional view of the cell is shown in figure 3B. The cell consists of two half cells, made of Teflon, which serve as the cathode and anode chamber, resp.. Both half–cells contain a platinium mesh, serving as electrodes. They are immersed in a KI–solution of different concentrations. The two chambers are linked together by an ion–bridge in order to provide an ion–pathway and to prevent mixing of the cathode– and anode electrolytes.

The ECC does not require an external electrical potential; this is in contrast to the Brewer–Mast Type. The ECC gets its driving e.m.f. from a difference in the concentration of the KI–solution in the cathode– and anode–chamber, 0.1 and 8.0 mol respectively. The ozone in the cathode chamber reacts with the iodide in the solution according to the redox reaction

$$2\,KI + O_3 + H_2O \longrightarrow I_2 + 2\,KOH + 2\,O_2$$

The electric current is direct proportional to the mass flow of ozone into the cathode chamber.
For a given pumpflow the partial pressure of ozone is calculated by using the formula

$$P(O_3) = \frac{0.407 \cdot T_{ecc}}{\phi_V} \cdot I, \text{ whereby}$$

P = pressure in nbar
I = electrical current ozone, in micro amperes
T_{ECC} = air pump temperature of air sampling, in degrees Kelvin
ϕ_V = volumetric flowrate of air, in milli–liters per second.

The electrical current is fed into an I/V–converter on the interface board. The temperature of the air sampling pump is measured by a thermistor.

The observed cell output current, i_{obs}, is in practice a superposition of the ozone current I, and a background current, i_a. The background–current which differs somewhat for individual sondes is determined at ground before launching the sonde.

Typical values for the ozone sensor are:

i_{obs}: 0–6 μA (equivalent to 0 – 200 nbar ozone)
i_a : 0.1 μA
ϕ_V : 3.5 ml/sec

The power supply for the electrical motor of the air sampling pump is a battery pack of seven serially connected Lithium dry cells (Panasonic BR2/3A), with a +12V voltage regulator which has the advantage of having a high power (1000 m Ah) and no emission of SO_2 in contrast to wet–batteries.

2.3 Meteorological radiosonde RS 80 of Vaisala

The RS 80 radiosonde has 3 sensors, one each for pressure (P), temperature (T) and relative humidity (U). All are capacitive devices. The PTU sensors are multiplexed to frequencies between 7 and 10 KHz and transmitted by a FM modulated quartz stabilized 403 MHz transmitter.

2.4 Ozone data interface and theory of operation

The electronic interface was developed for TOR by TMAX, Boulder, Colorado (USA). The basis of the interface is to convert all signals such as the ozone–current, the temperature of the gas–sampling and six frequencies of the RS 80 radio sonde, into a digitally coded data stream. This data stream is then modulated as a two tone signal on the 403 MHz, FM–transmitter of the RS 80–sonde and telemetered to ground.
As figure 4 shows the ozone current (0–10 μA) of the ECC, I_{ecc}, is converted to voltage by an I/V–converter and fed into the ADC of the MCU (Micro computer unit).
The temperature of the ozone–sensor, T_{ecc}, measured by a thermistor, is also fed into the ADC of the MCU. (The ADC has still two free input–channels which could be used in the future for other supporting measurements). The six PTU–frequency–signals of the RS 80–sonde are fed into a programmable timer, whereby the period is measured over a fixed number of N–cycles (this is equivalent to frequency counting).
Next the MCU collects 4 input multiplexed ADC (I_{ecc}, T_{ecc} plus the two auxiliary channels) and the six PTU–frequencies of the RS 80, all of which are formatted into a digital ASCII, 11 bit–NRZ data stream and put on the output line of the MCU.

The digital NRZ–datastream is converted into a FSK–tone signal (FSK = Frequency shifted key) of 2025 and 2225 HZ respectively which is then used to frequency modulate the 403 MHz transmitter of the RS 80.

The data are transmitted to the ground in hexadecimal format of ASCII–characters.
The use of this interface electronics allows the simultaneous measurement of the concentrations of ozone and water vapor, so that its relationship enables us to investigate the O_3 variations in terms of transport of sources and sinks. In the more conventional ozone sounding one rely on the humidity signal of the radio sonde in order to use this channel for the transmission of the ozone signal. Additionaly, this interface has the advantage that the actual temperature of the air sampling is measured for a more accurate determination of the ozone concentration.

2.5 Ground station

At the ground the 403 MHz telemetry signal is received by a conventional FM–receiver (UR15, Vaisala, Finnland). The signal is demodulated back to the data stream of FSK–tone signals and then converted to the ASCII hexadecimal data format by a modem (UTU/XT, Kantronics, USA) and fed via a RS232–serial port into a personal computer for further data processing.

2.6 Balloon and parachute

The used balloon is a TA600 (Totex–Japan) with the following specifications:

weight	600 gramm
payload	1000 gramm
freelift	1190 gramm
at launch	diameter 1.7 m
	volume 2.4 m^3
gasfilling	H_2 or He
material	latex
burst altitude	≈25 km

With a payload of about 1000 gramm and a free lift of 1300 gramm an ascent rate of typically 5 m/sec and a burst altitude of about 25–30 km is achieved.

3. Flight operation

3.1 Pre–flight preparation of ozone sonde, radiosonde and data interface board

Before each flight the sonde is carefully prepared and checked following the guidelines after Komhyr (1986) for the ozone sensor and of Vaisala, respectively, for radio sonde.

Ozone sonde:

Performance of the ozone sensor is checked for:

- –the response time of the cell
- –the accuracy, through comparison of the sensor output with a reference UV–photometer (Dasibi 1008 RS)
- –background current of the cell and air flow through the sensor.

Radiosonde:

The performance of the radiosonde at ground is checked in the laboratory at ambient pressure, temperature and zero relative humidity.

Data interface board:

The current–voltage converter is compared to a calibrated current source.
The output of the temperature measurement of the pump (Thermistor) is also checked.
These calibrations are incorporated in post flight data processing.

4. Data processing

About every 7s a complete dataframe is received such that for an ascent rate of about 5m/s the height resolution of the data transmission of a complete cycle of all parameters is equivalent to a 35 m height resolution. The response time of the ozone sensor itself was around 20 s at an in–flight temperature of the sensor of about 30 °C such that at an average ascent rate of 5m/s the effective height resolution for ozone measurement was about 100 m.
For all ozone sensors flown the accuracy was better than ±5%.

The logistics of the data processing are schematically shown in figure 5.
Received data during the flights are stored online as frames of ASCII–characters (raw flight data). The raw data are decoded back to the analog signals of the different sensors of the ECC and radiosonde respectively which are then converted to ozone concentration and meteorological parameters.
Eventual erratic data from telemetry noise are eliminated. Also, corrections resulting from the ground check procedure are incorporated.

5. Vertical Ozone profiles

Prior to the start of TOR project some ozone soundings were started in June and July 1988 (flight numbers 35 to 40).
In July 1989 the ozone sounding program within the TOR project was started on a regular base of one flight per week.
Normally the sounding are performed every wednesday at a time of around 10–11 (UT) from the roof of our institute at an altitude of 80 m above sea level.
The results of these flights are presented in the form of individual vertical profiles of ozone and meteorological parameters.
Two plots are presented for every flight. The first one shows the complete profile during ascent until burst of the balloone. This plot gives a standard ozonogram with the partial pressure of ozone (mPa), temperature (degrees celsius) and relative humidity (%) on the abscissa as a function of pressure (hPa) on a logarithmic scale.
The second plot presents the tropospheric part of the individual soundings in greater detail. Here, we use units of mixing ratio (ppbv) for ozone on the abscissa as a function of geometric altitude (km) where the altitude was computed step by step as a cumulative sum of the height difference between two successive pressure levels using the hydrostatic equation.

Acknowledgement

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We thank O. Heißenbütttel for writing the graphics program.

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Figures

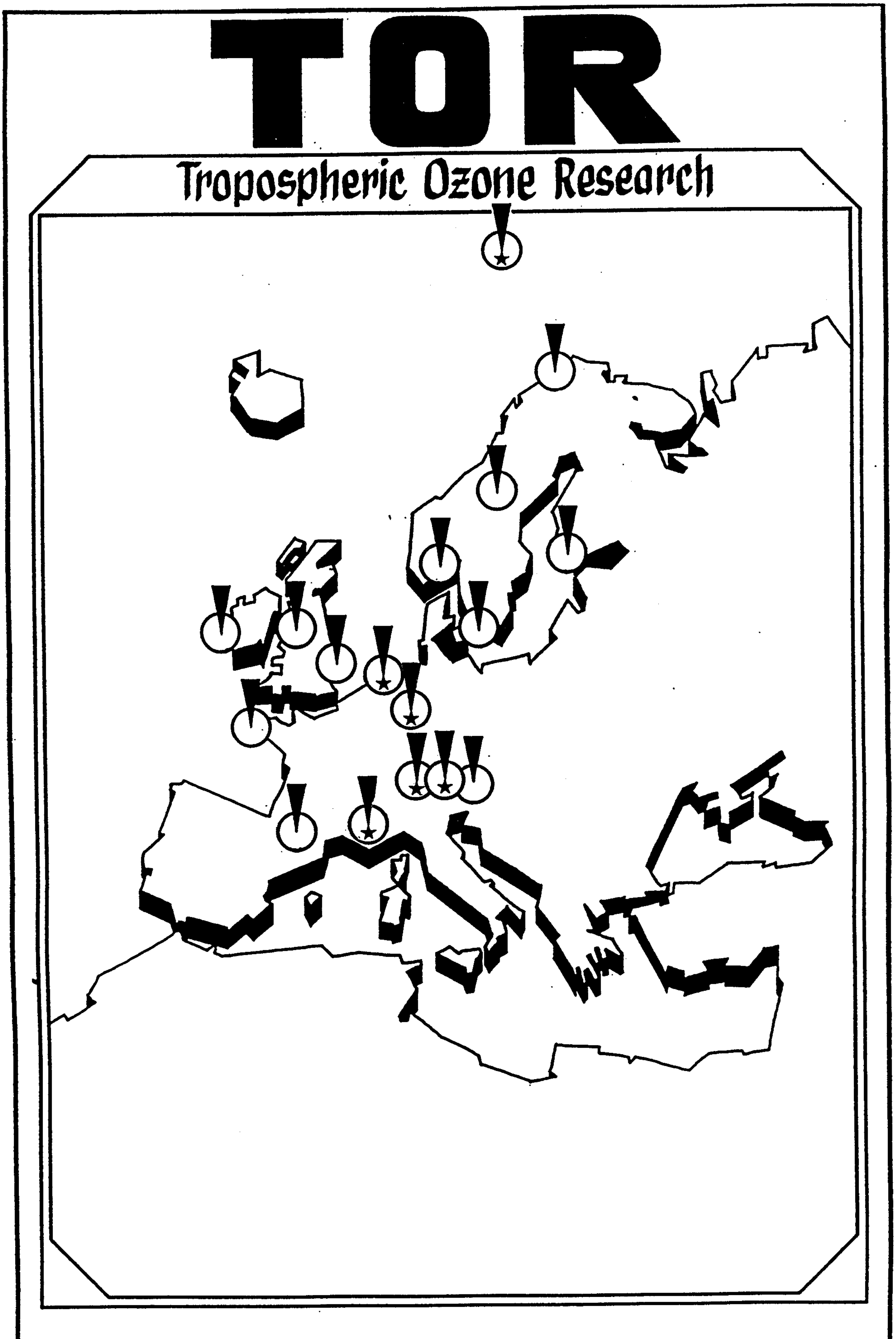


Figure 1

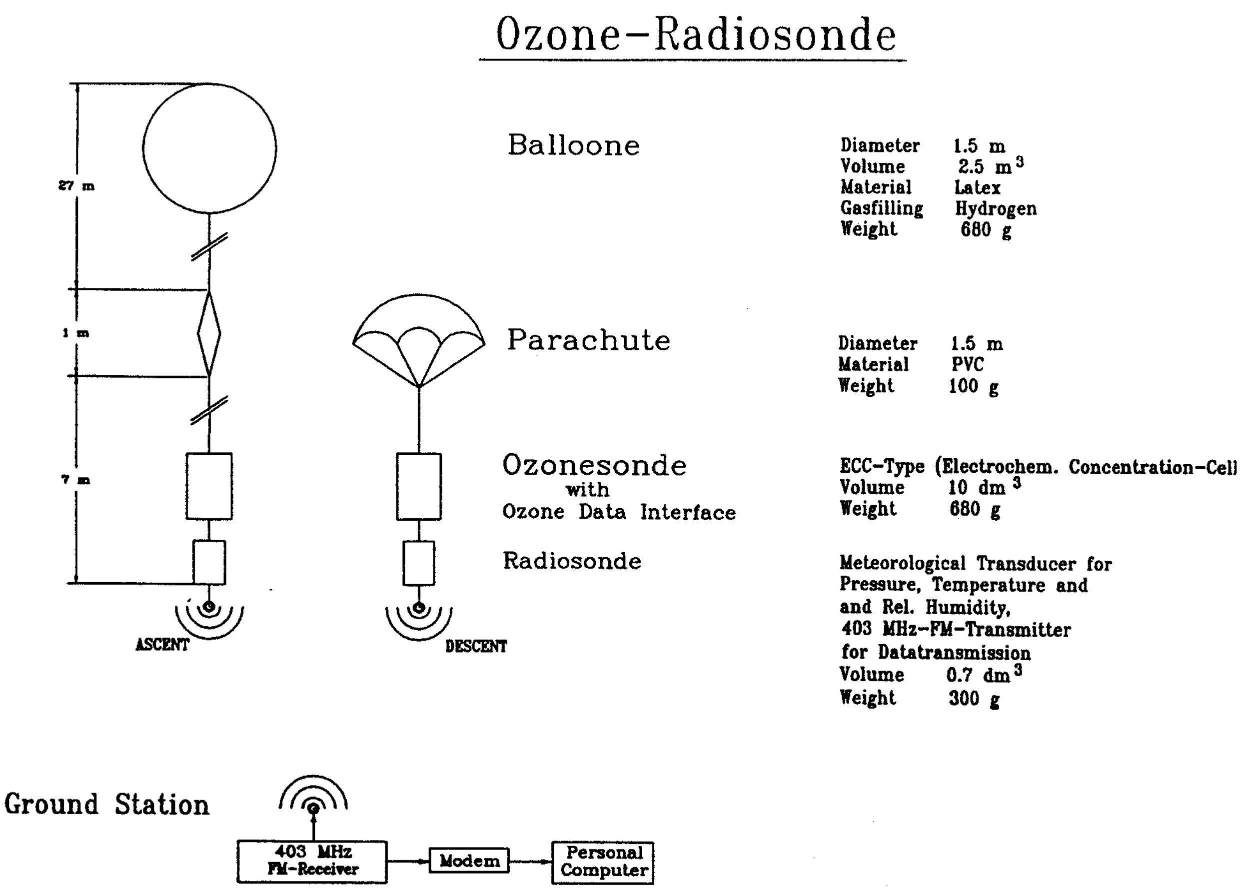


Figure 2 : Ozone sounding system

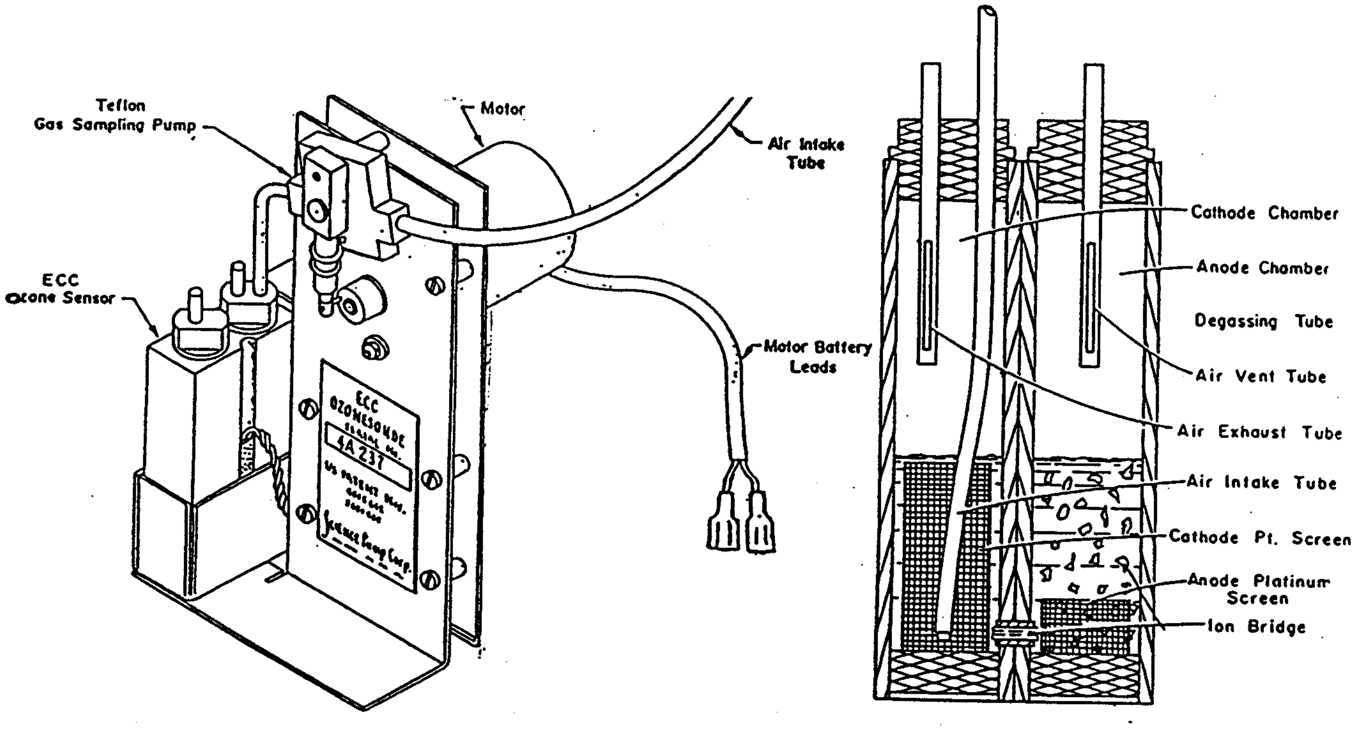


Figure 3A , B : Ozone sonde, type ECC

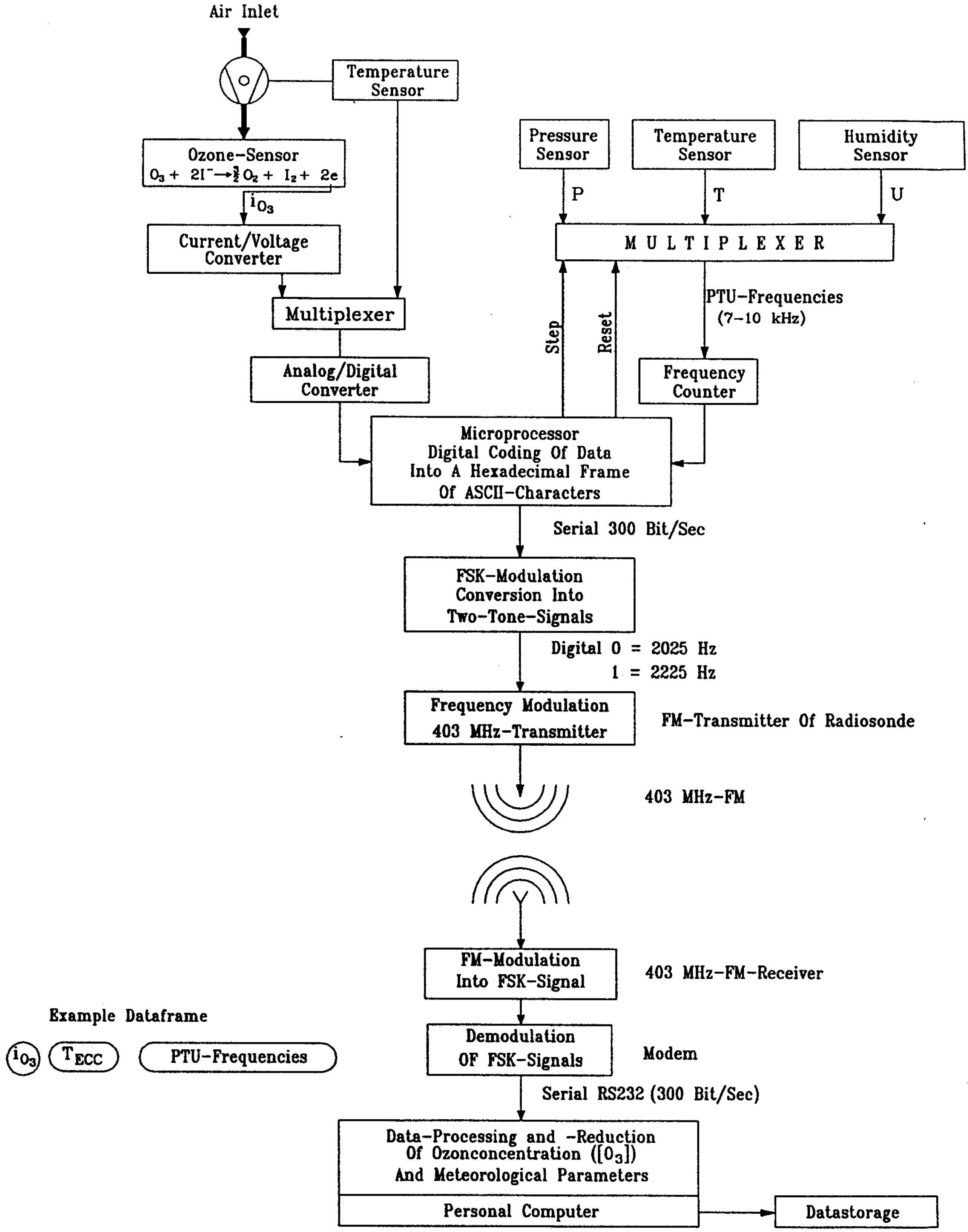


Figure 4 : Data transmission of the sounding system

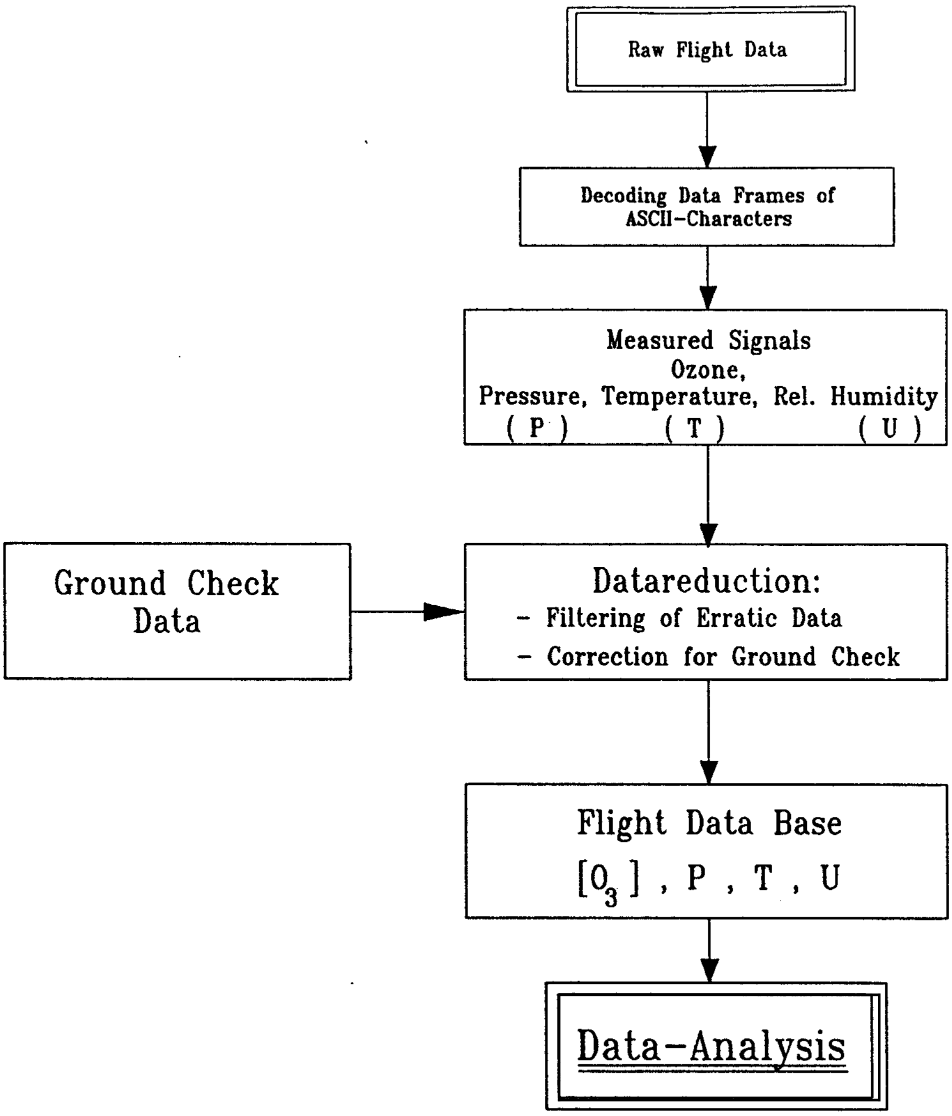
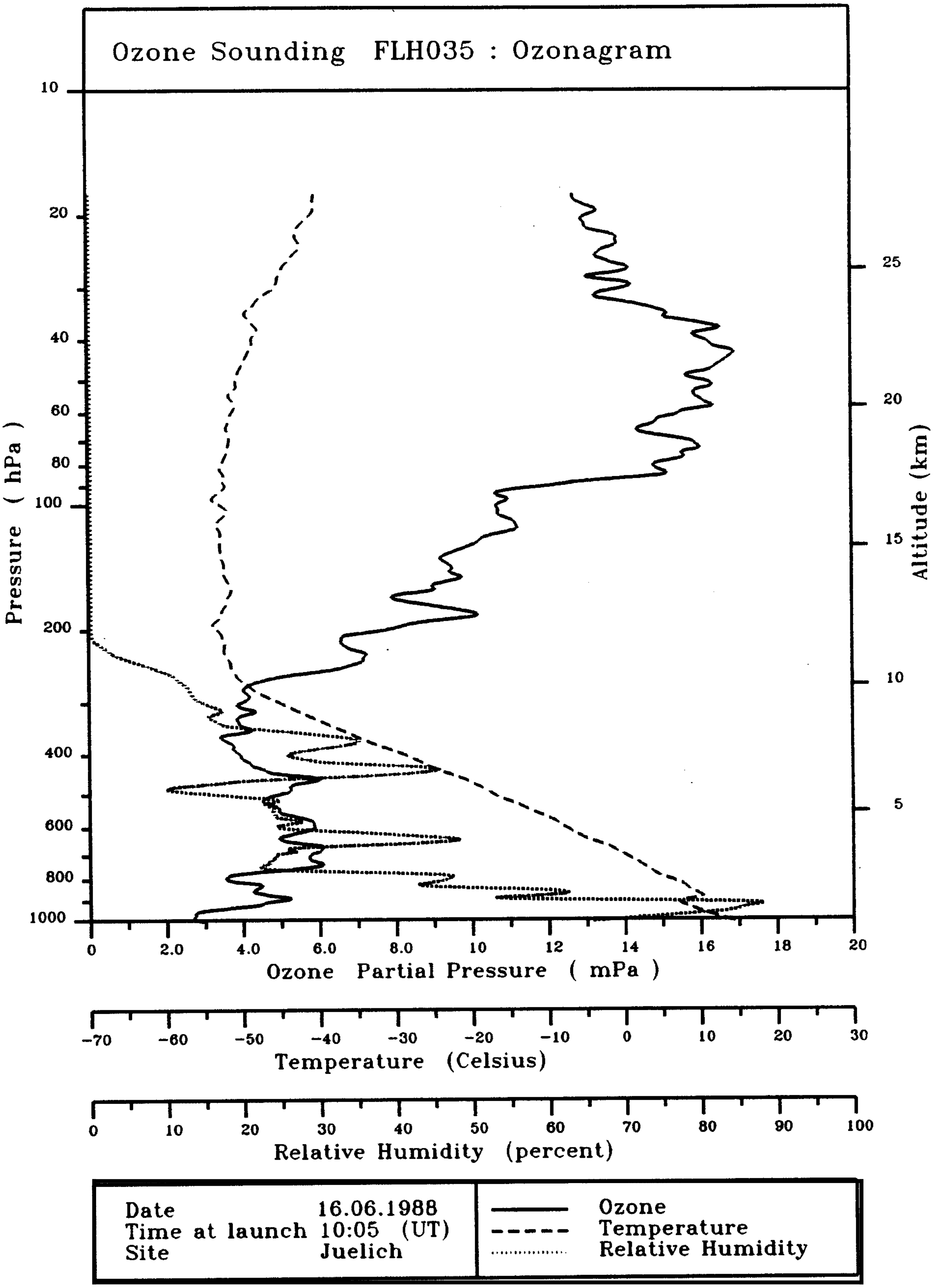
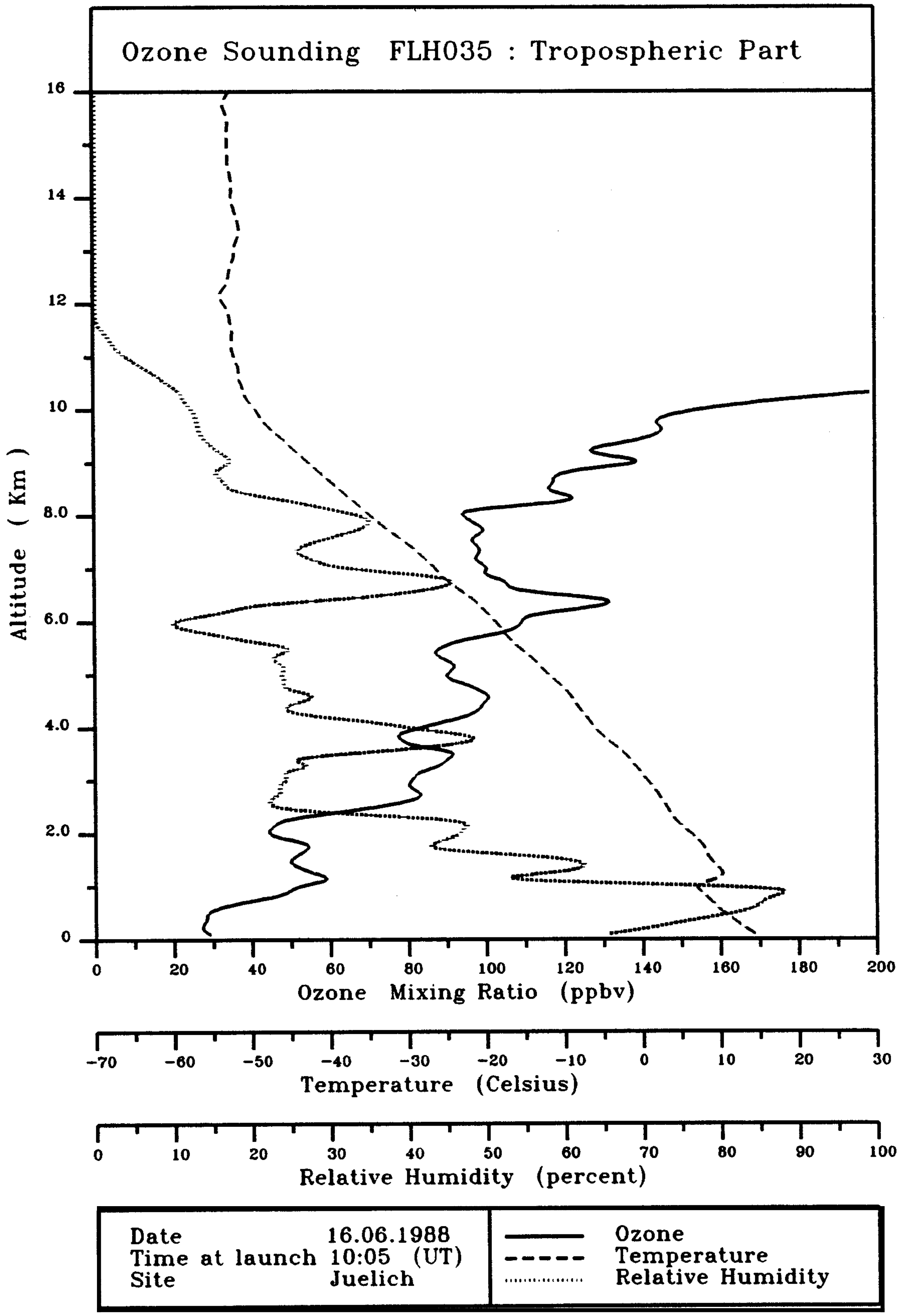


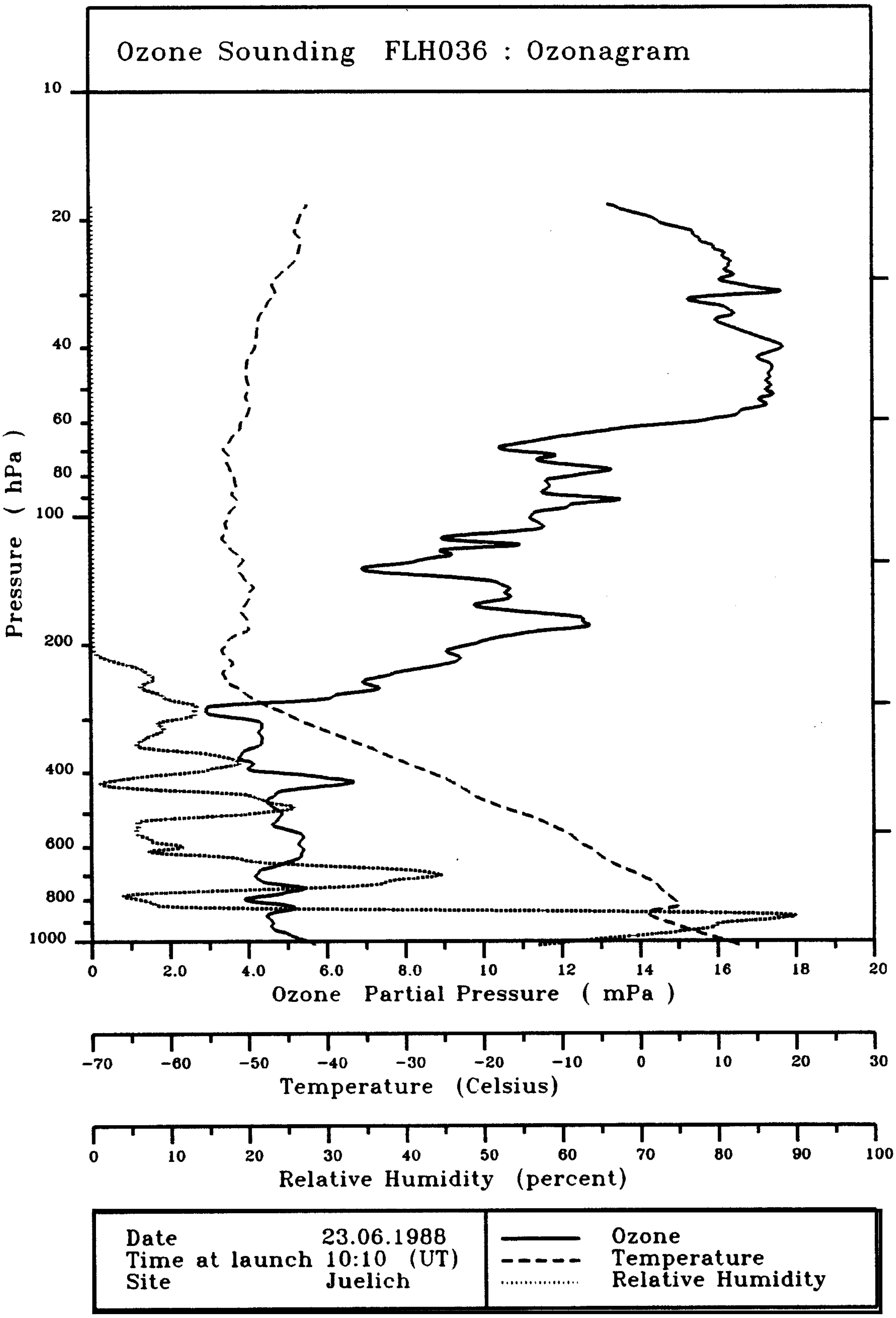
Figure 2 : Ozone sounding system

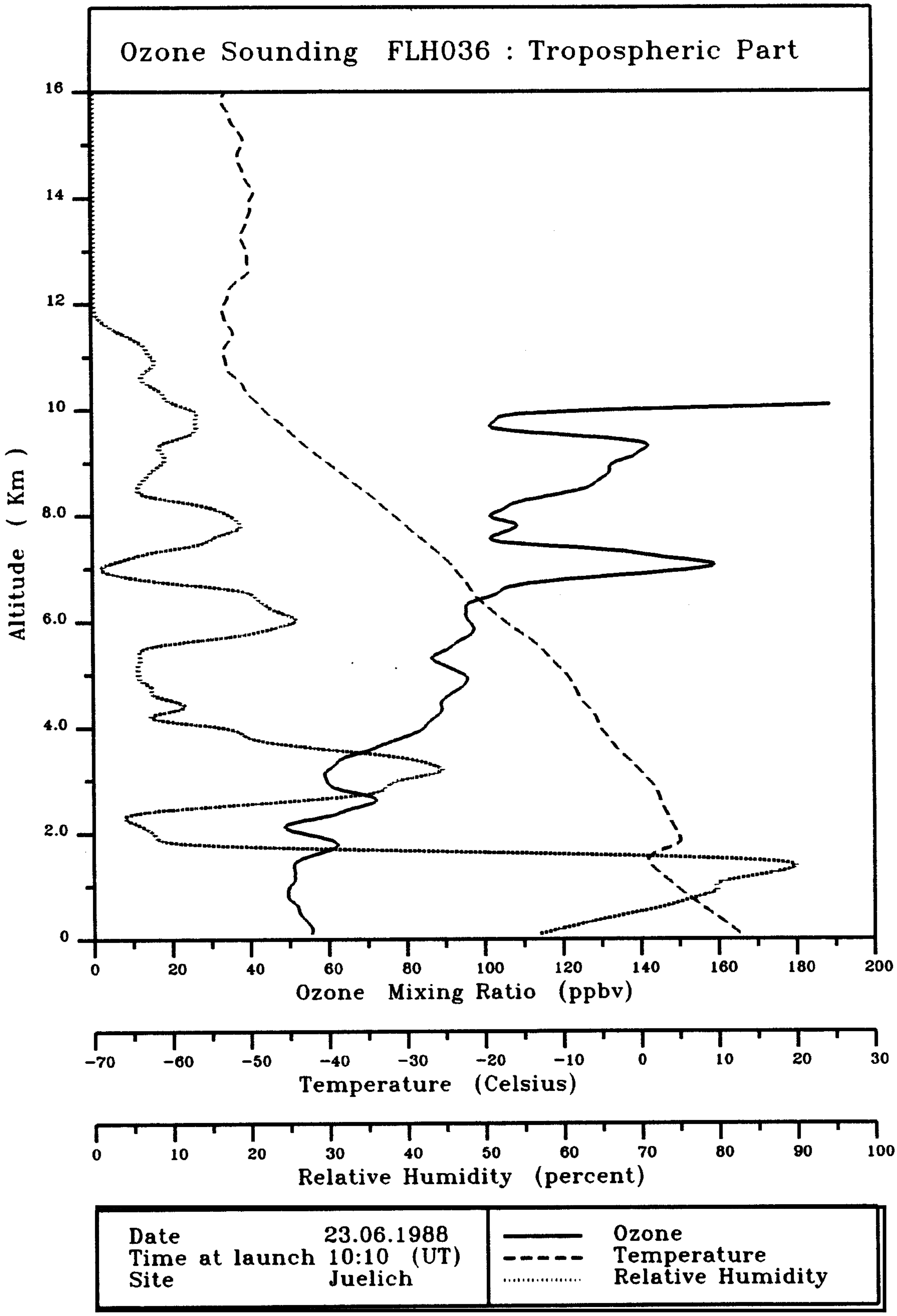
Figure 5 : Data processing

Individual vertical profiles

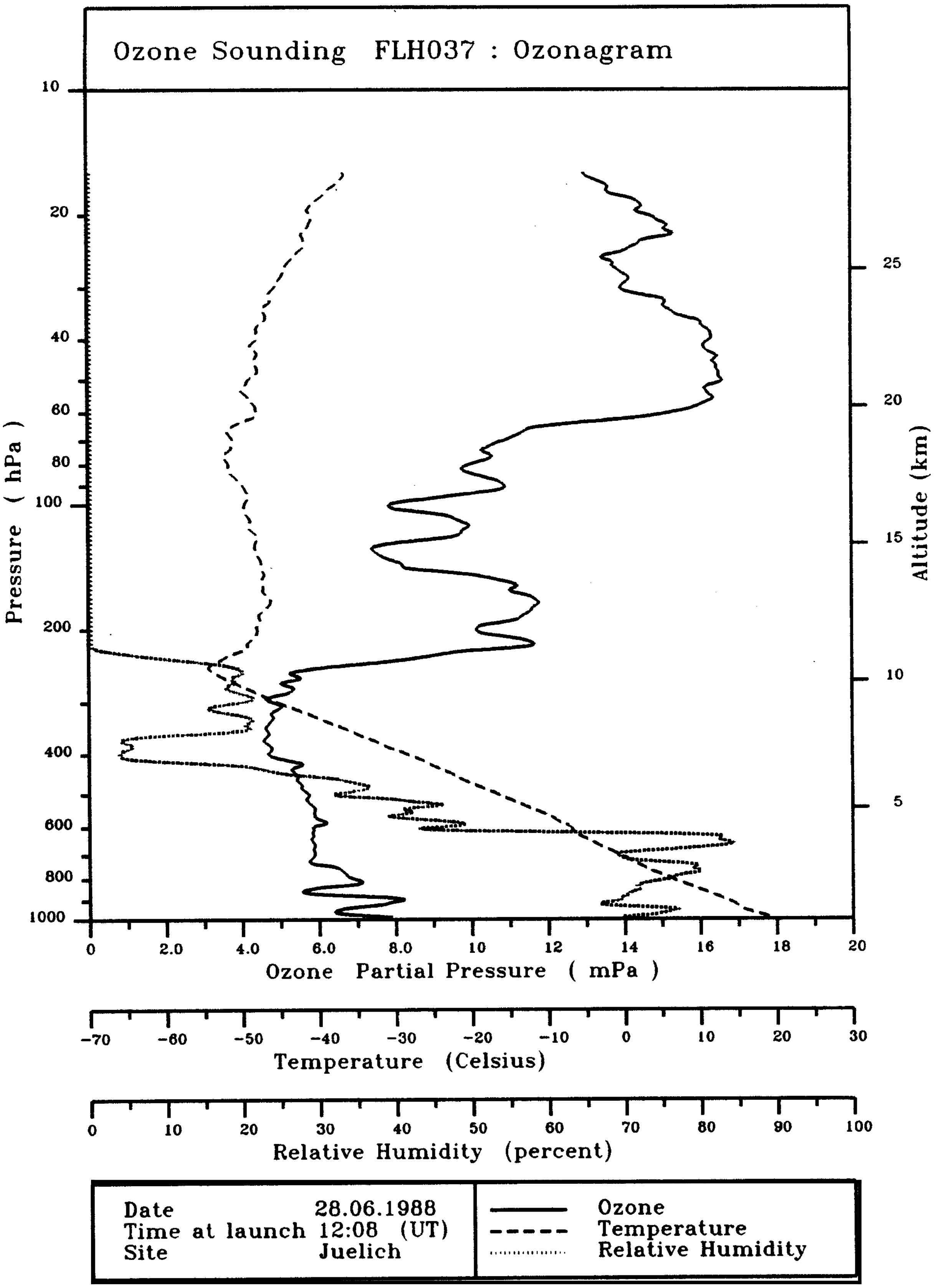

Ozone Sounding FLH035 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0 2.0 4.0 6.0 8.0 10 12 14 16 18 20
Ozone Partial Pressure (mPa)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 16.06.1988
Time at launch 10:05 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

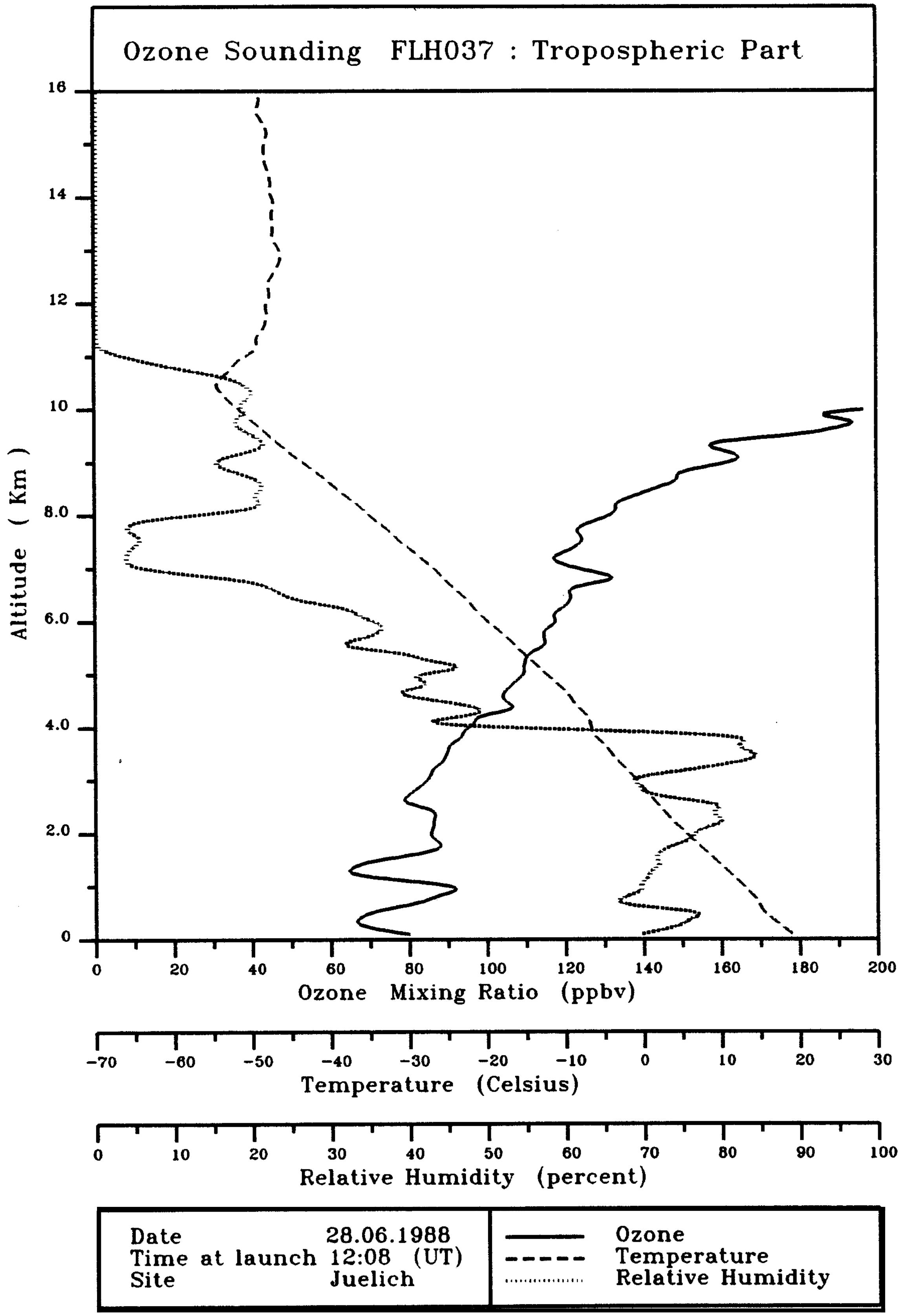

Ozone Sounding FLH035 : Tropospheric Part
16
14
12
10
8.0
6.0
4.0
2.0
0
Altitude (Km)
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 16.06.1988
Time at launch 10:05 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH036 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 23.06.1988
Time at launch 10:10 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

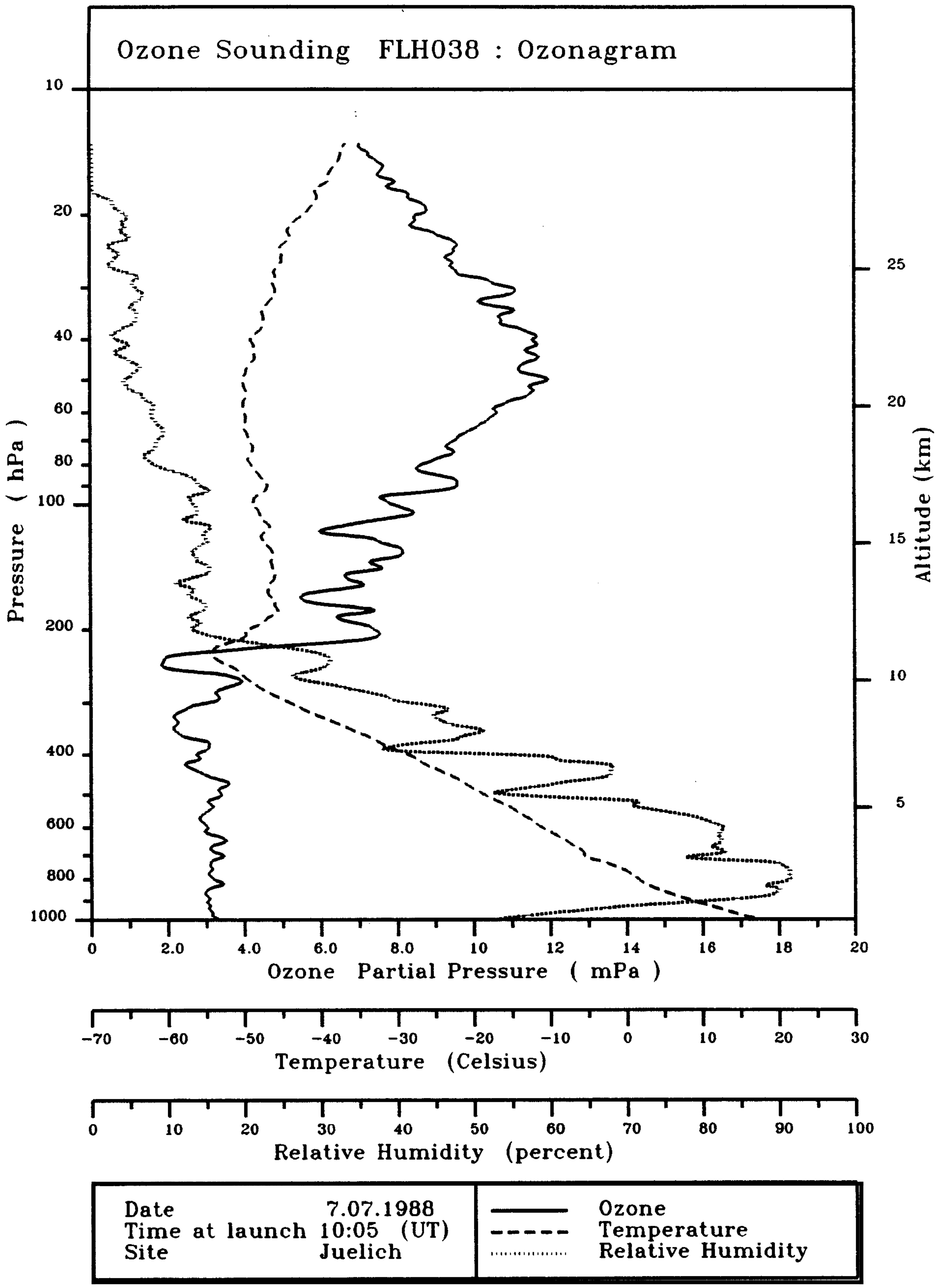


Ozone Sounding FLH036 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 23.06.1988
Time at launch 10:10 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

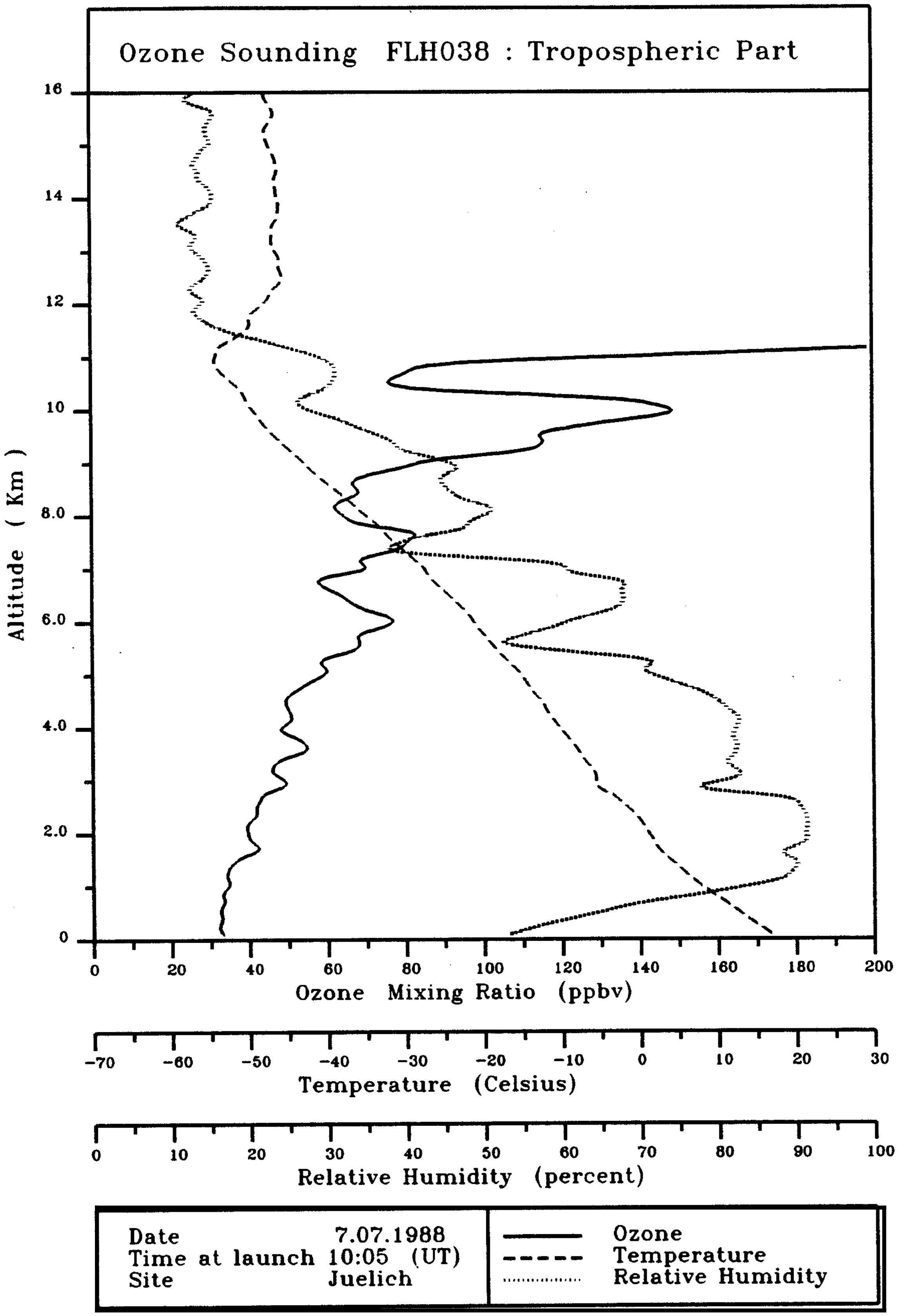

Ozone Sounding FLH037 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 28.06.1988
Time at launch 12:08 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



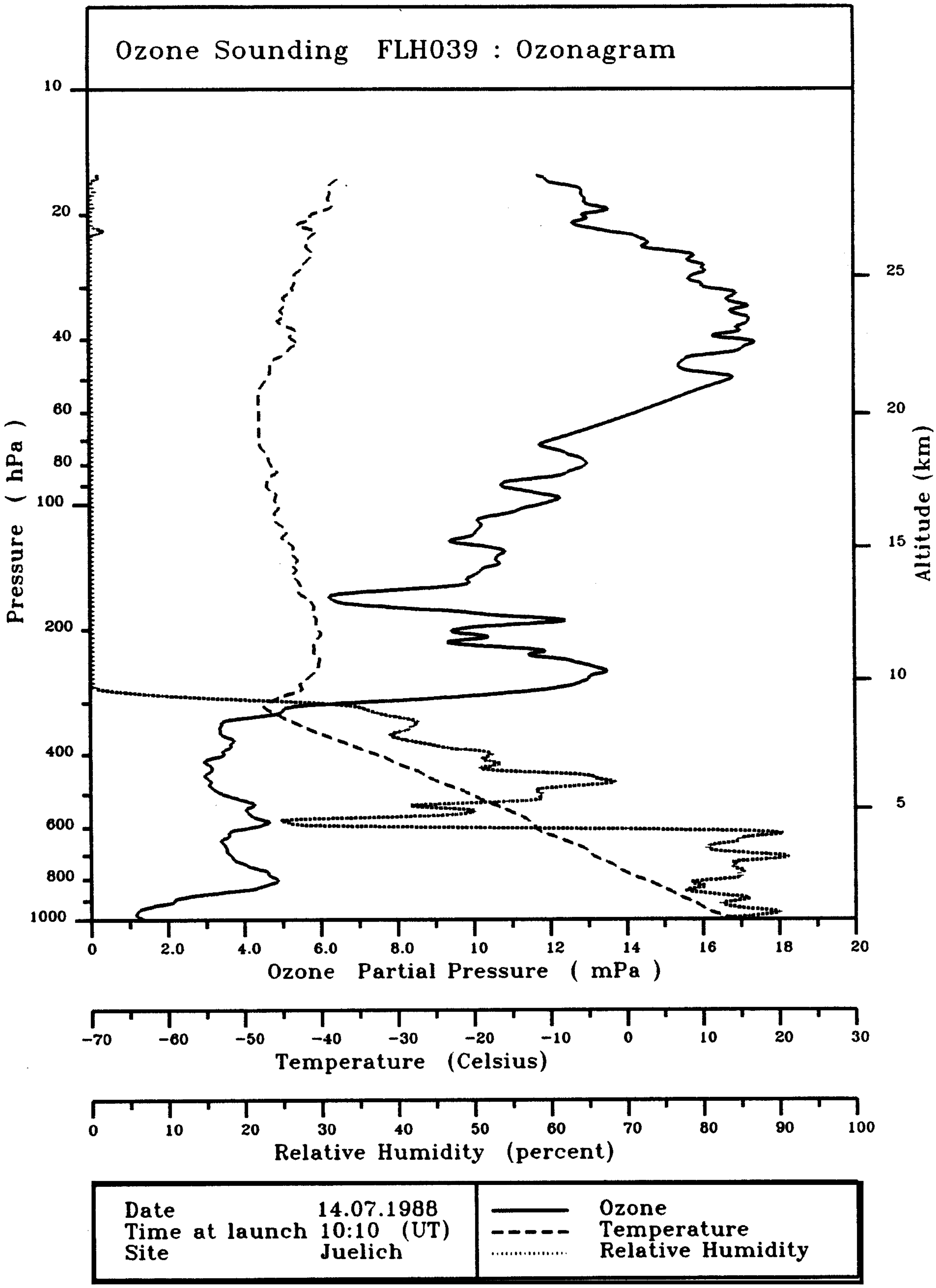
Ozone Sounding FLH037 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 28.06.1988
Time at launch 12:08 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



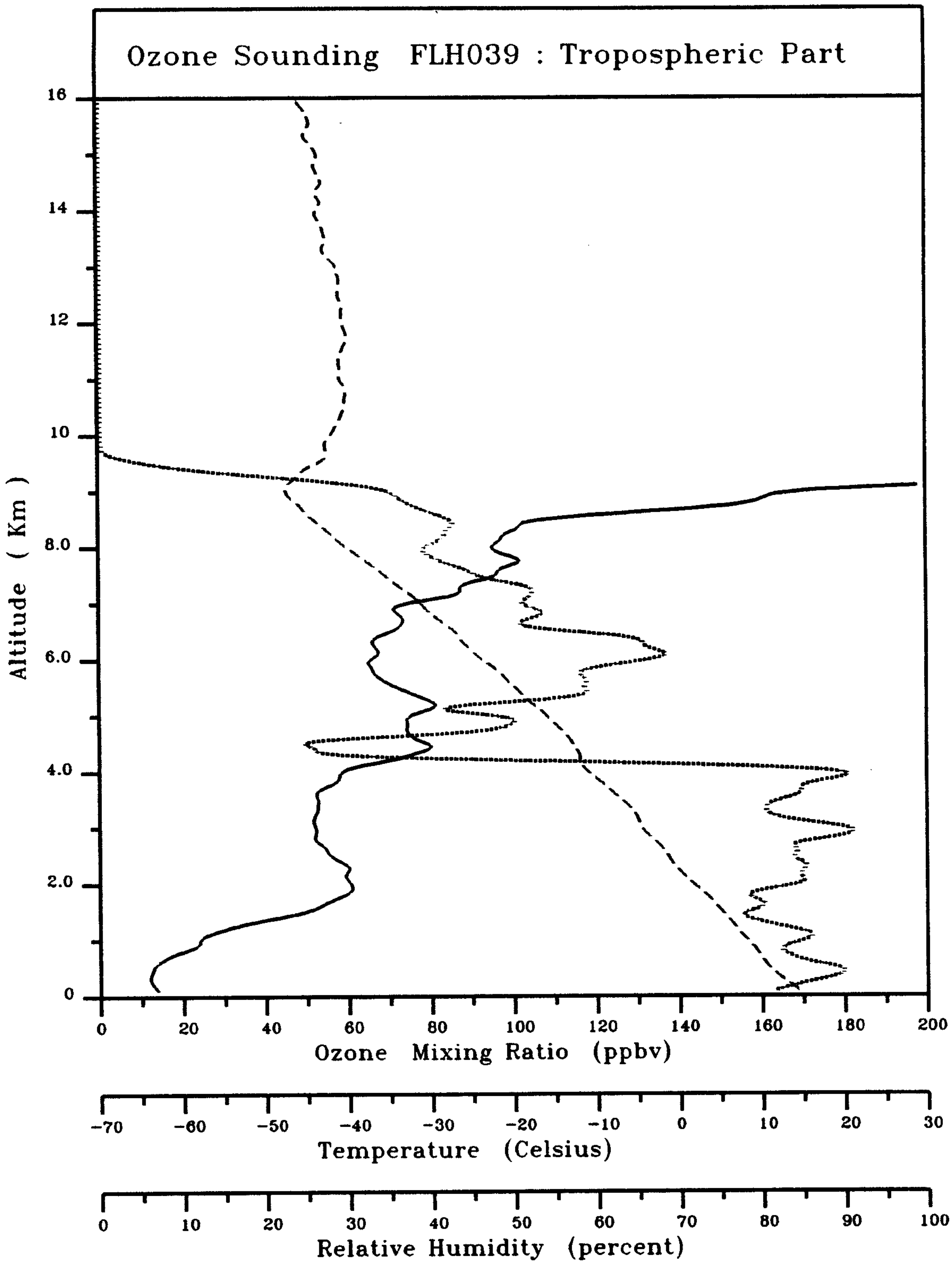
Ozone Sounding FLH038 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 7.07.1988
Time at launch 10:05 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



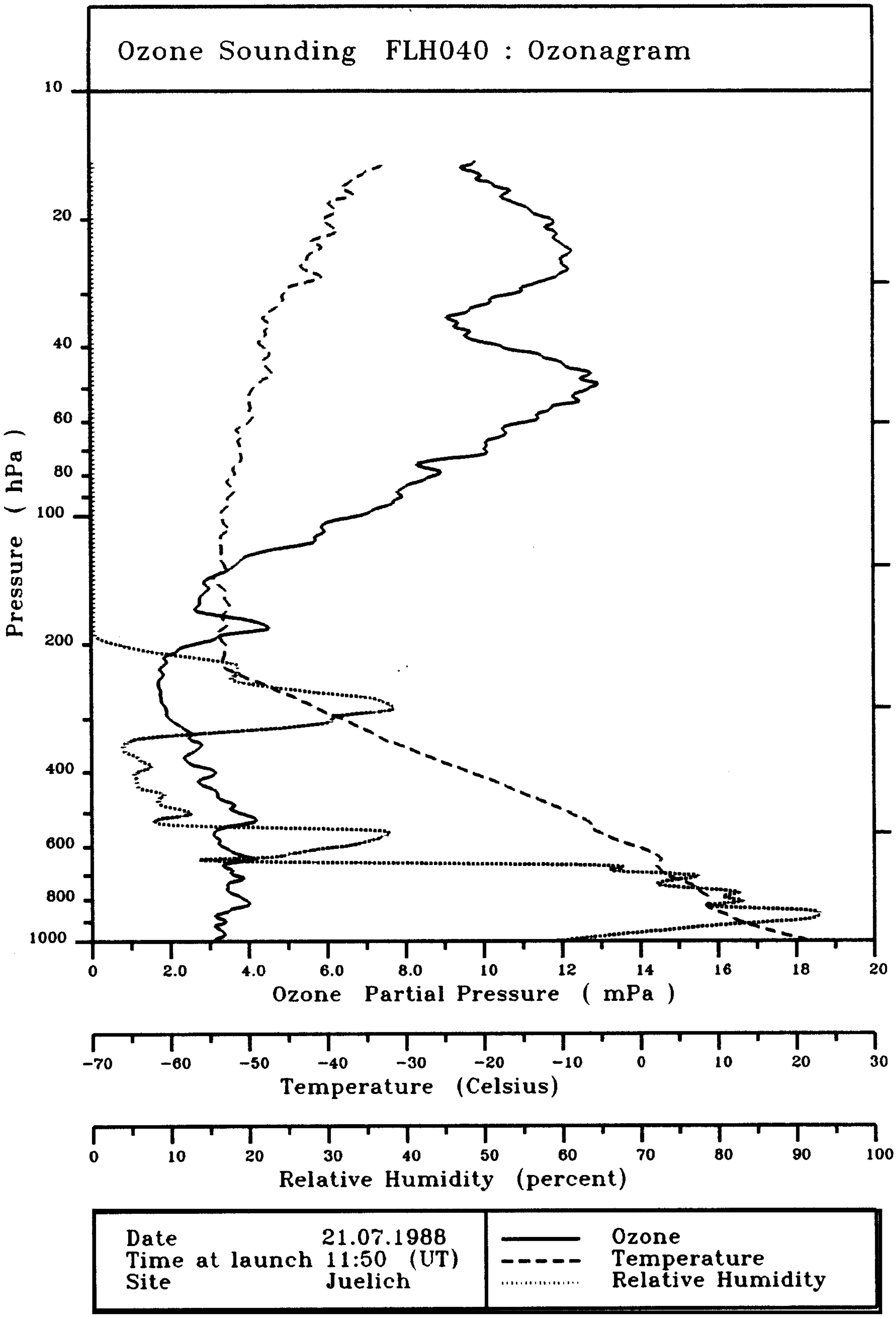
Ozone Sounding FLH038 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 7.07.1988
Time at launch 10:05 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

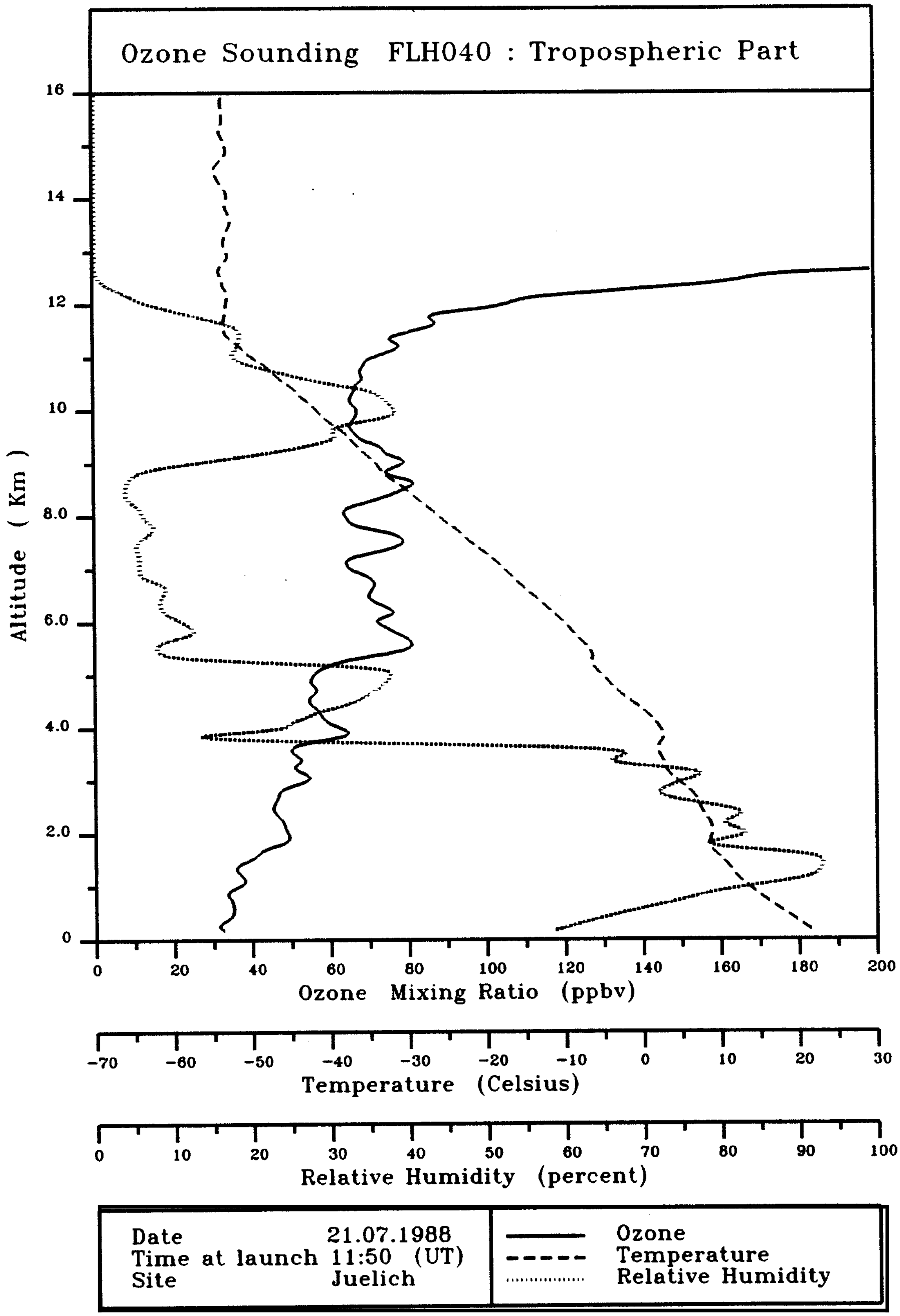


Ozone Sounding FLH039 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 14.07.1988
Time at launch 10:10 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

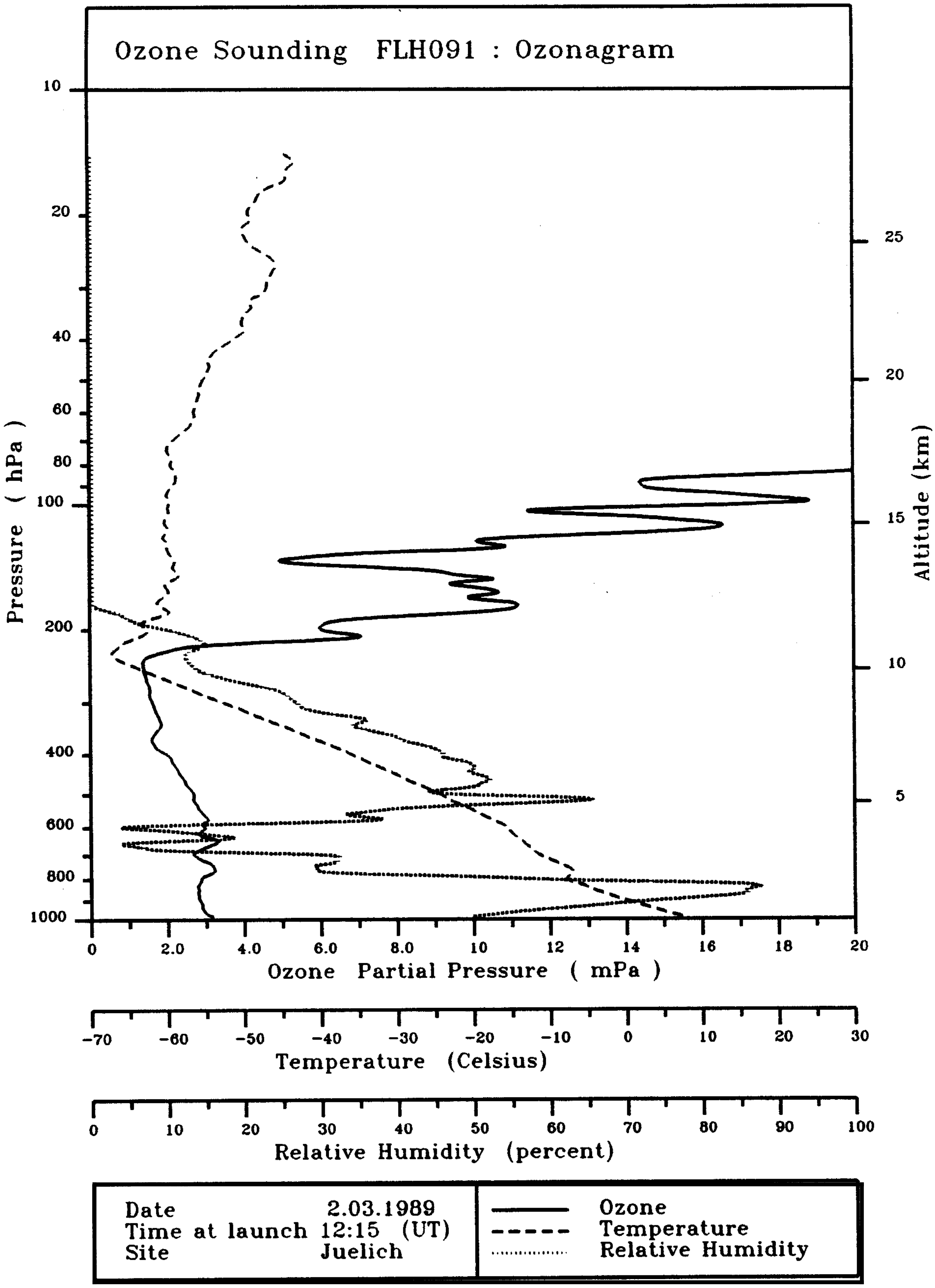


Date	14.07.1988	Ozone
Time at launch	10:10 (UT)	Temperature
Site	Juelich	Relative Humidity

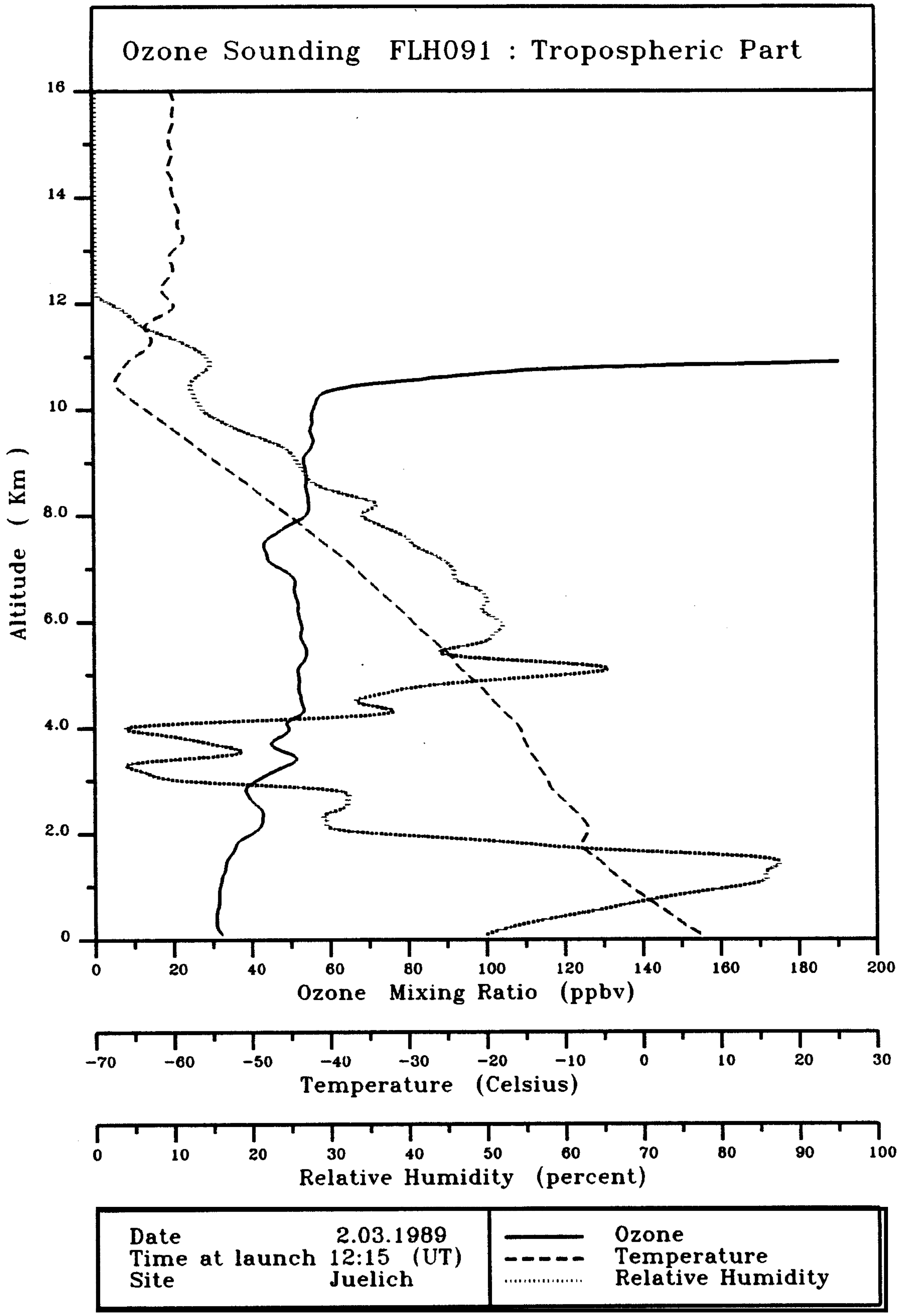

Ozone Sounding FLH040 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 21.07.1988
Time at launch 11:50 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



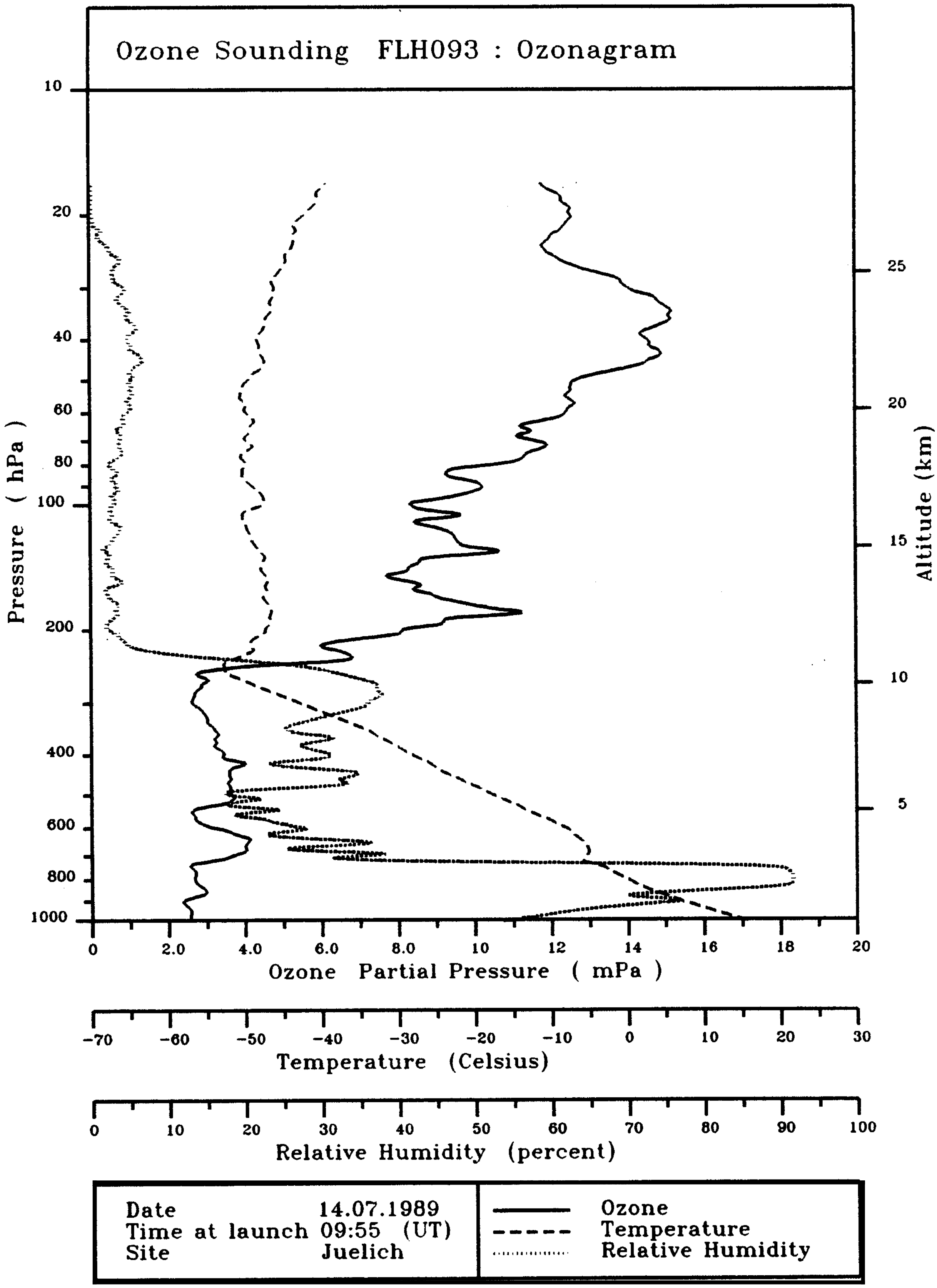
Ozone Sounding FLH040 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 21.07.1988
Time at launch 11:50 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

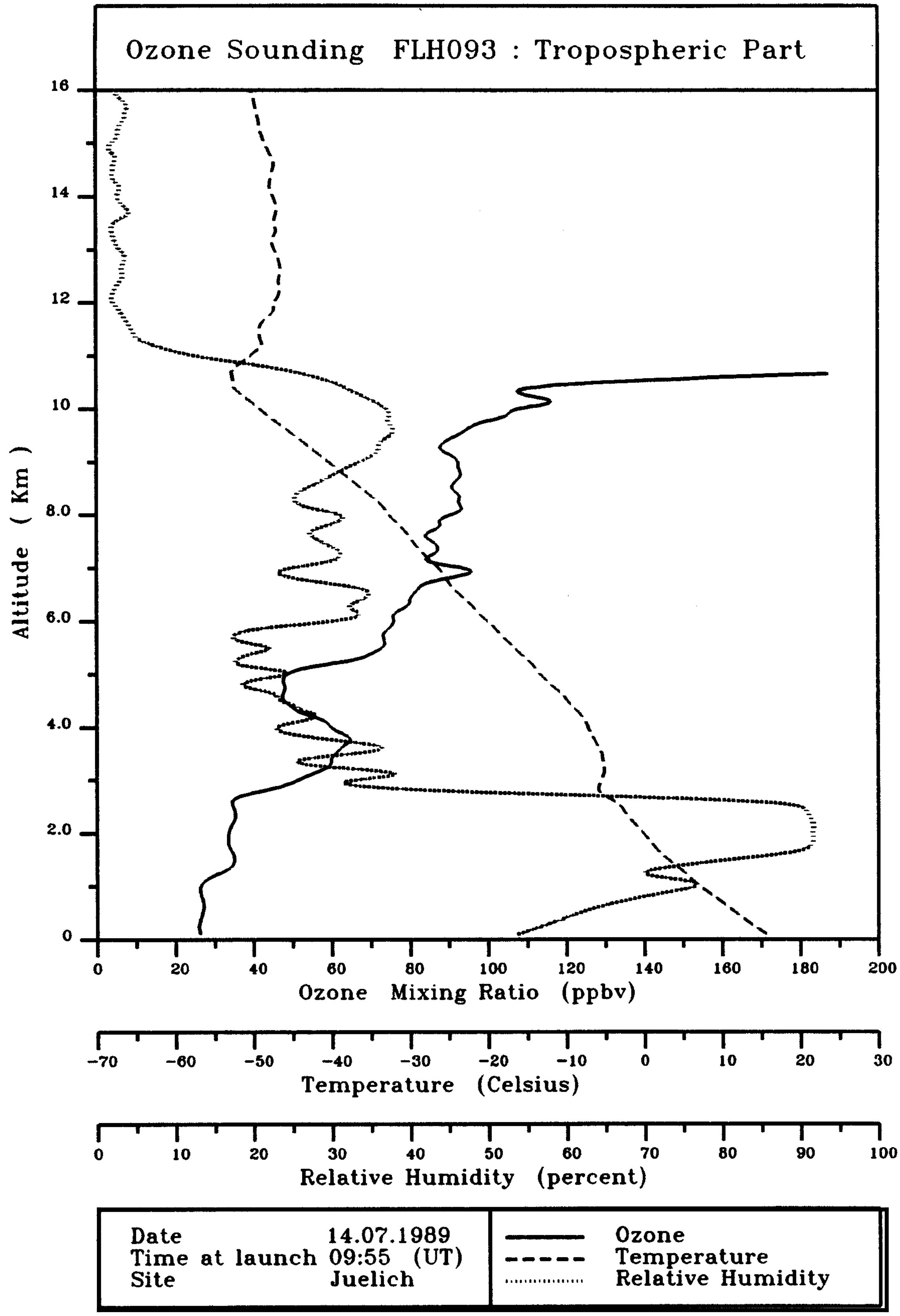


Ozone Sounding FLH091 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0 2.0 4.0 6.0 8.0 10 12 14 16 18 20
Ozone Partial Pressure (mPa)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 2.03.1989
Time at launch 12:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

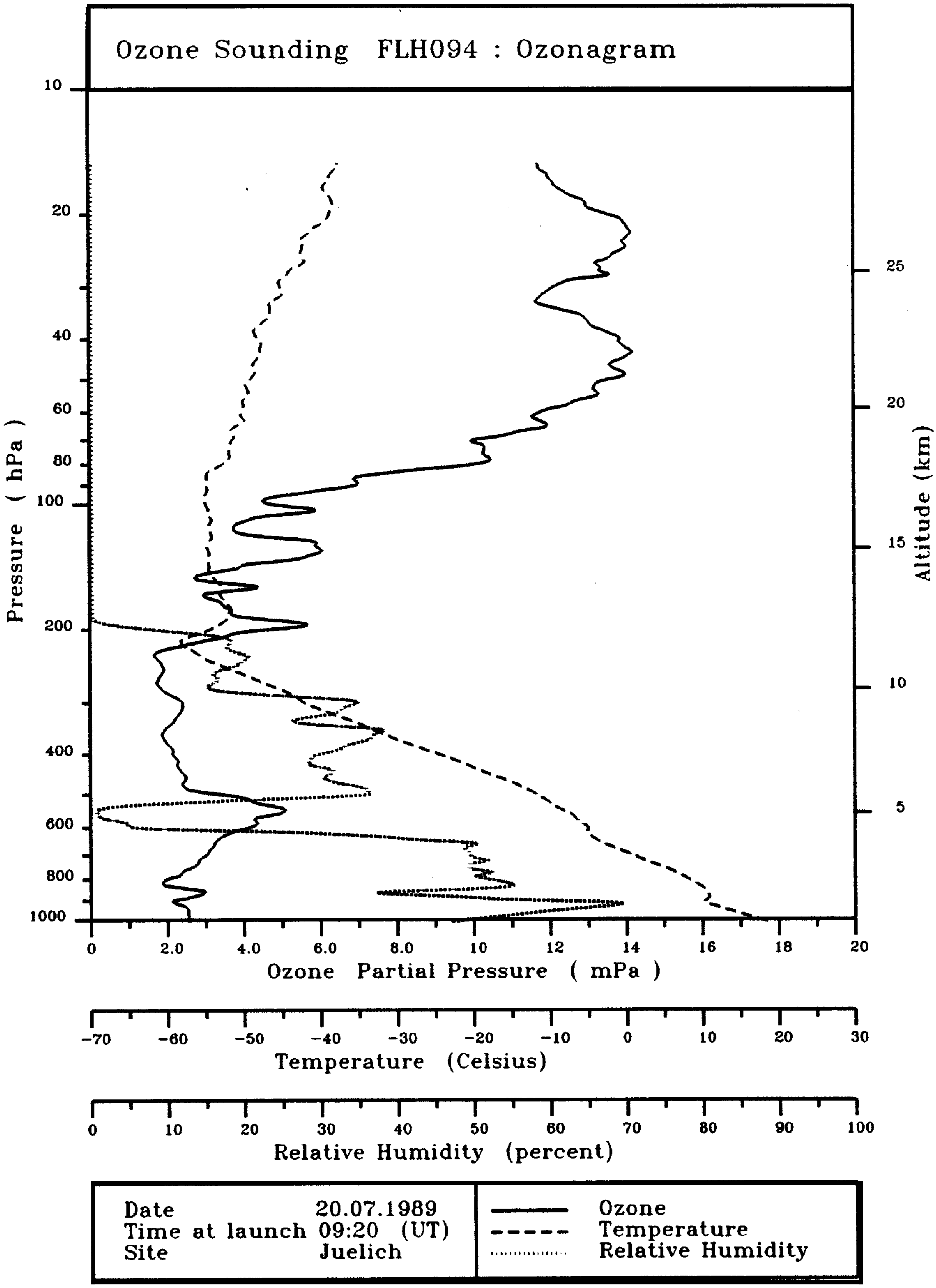


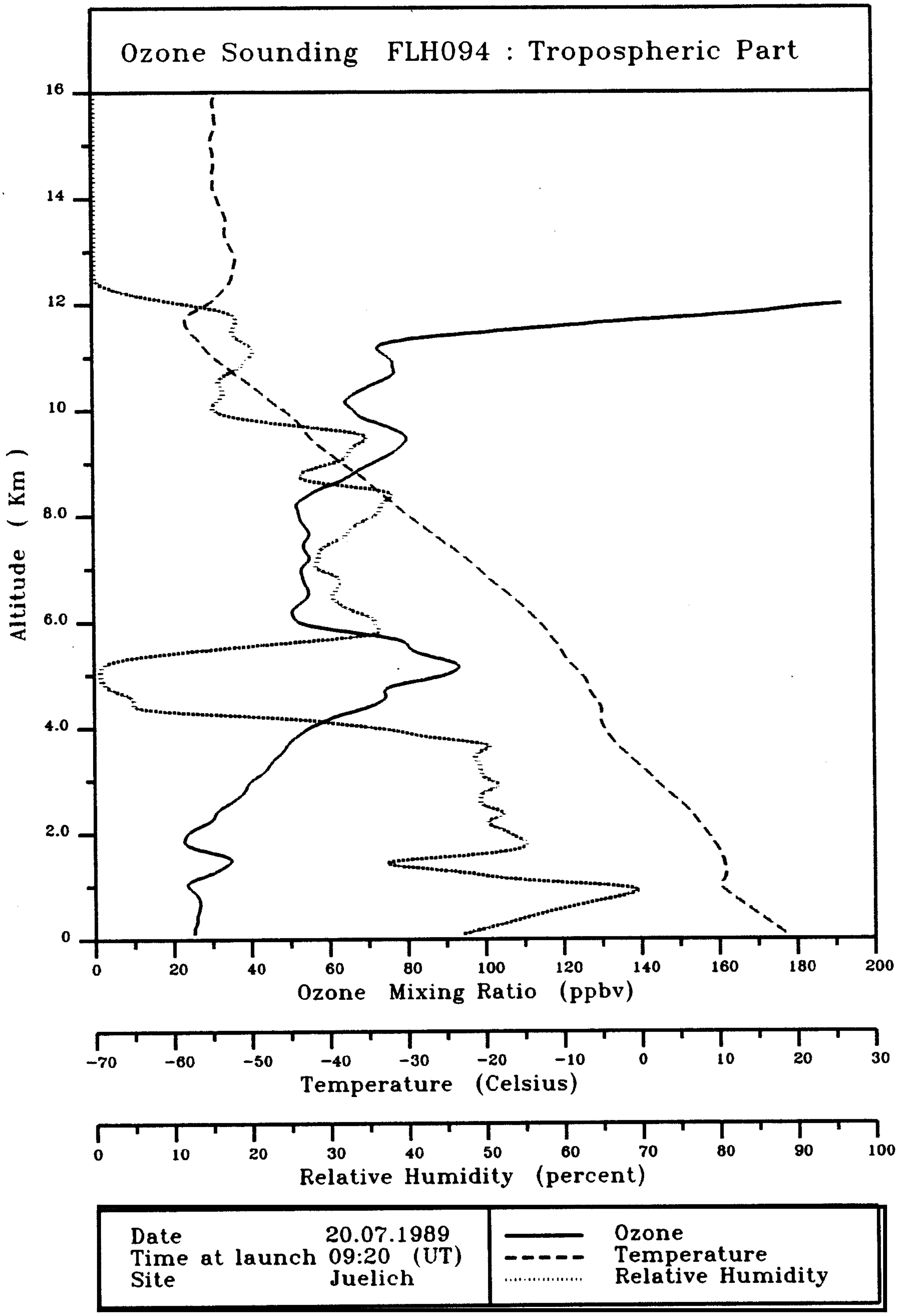
Ozone Sounding FLH091 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 2.03.1989
Time at launch 12:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

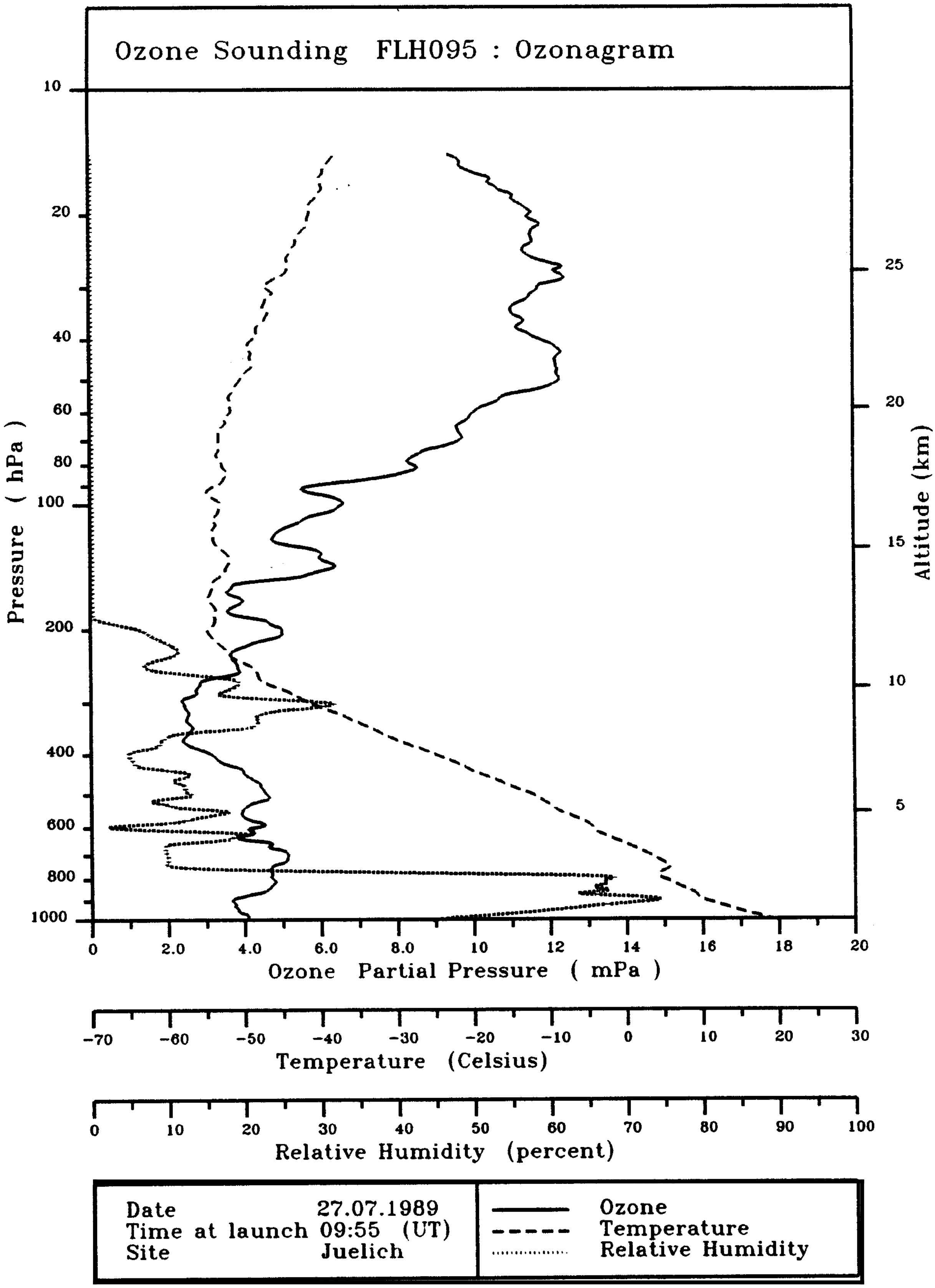

Ozone Sounding FLH093 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 14.07.1989
Time at launch 09:55 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

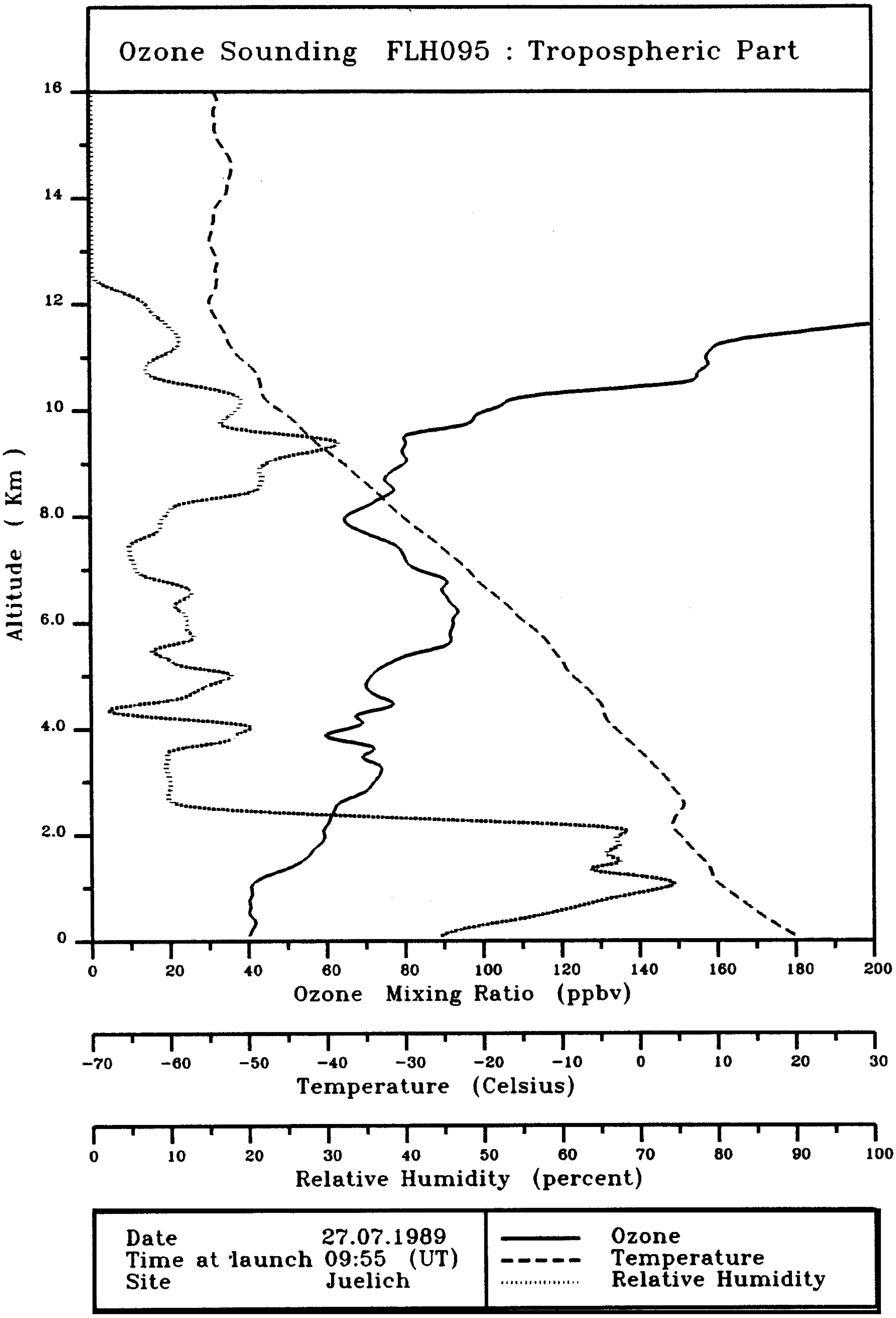


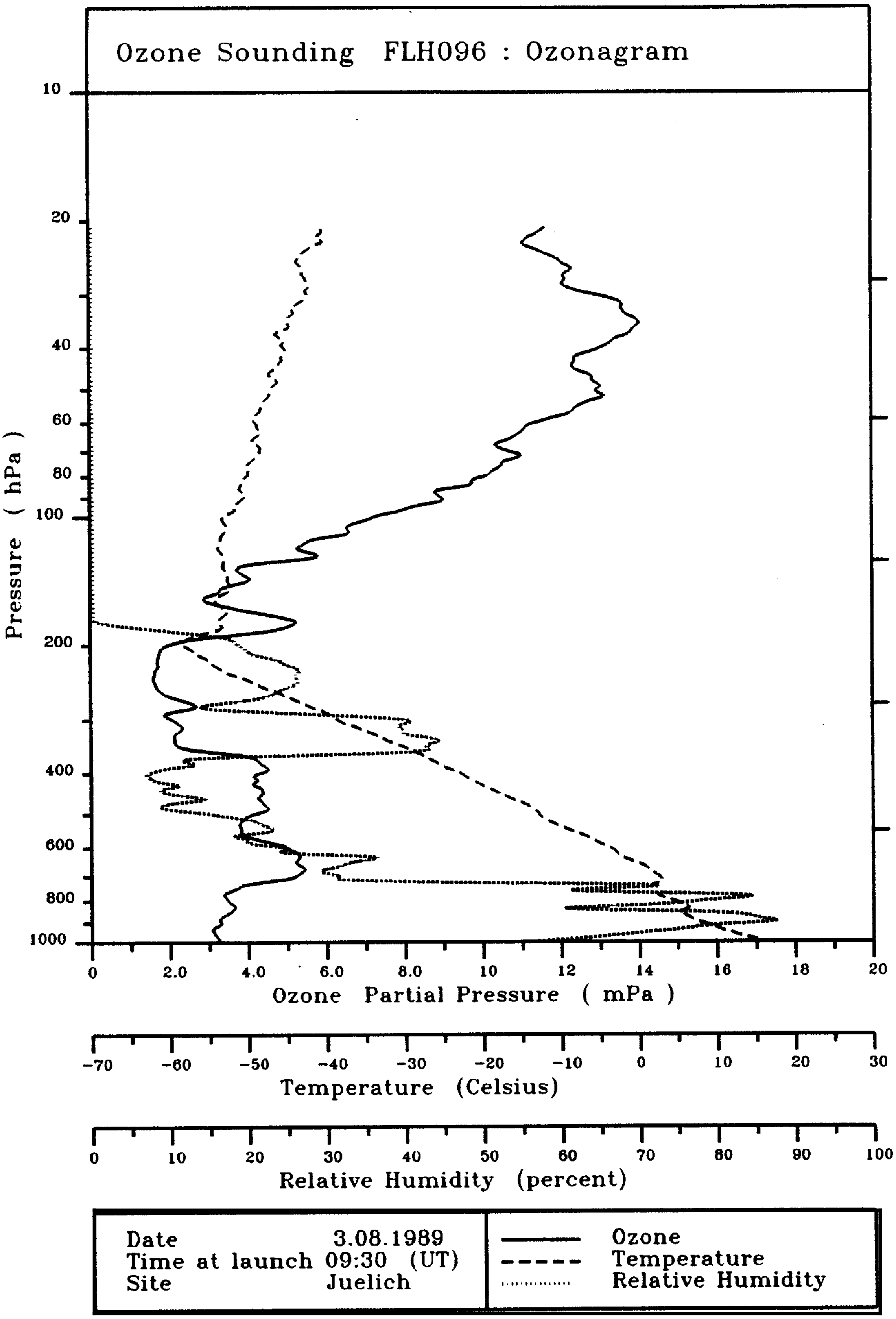
Ozone Sounding FLH093 : Tropospheric Part
Altitude (Km)
0
2.0
4.0
6.0
8.0
10
12
14
16
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 14.07.1989
Time at launch 09:55 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

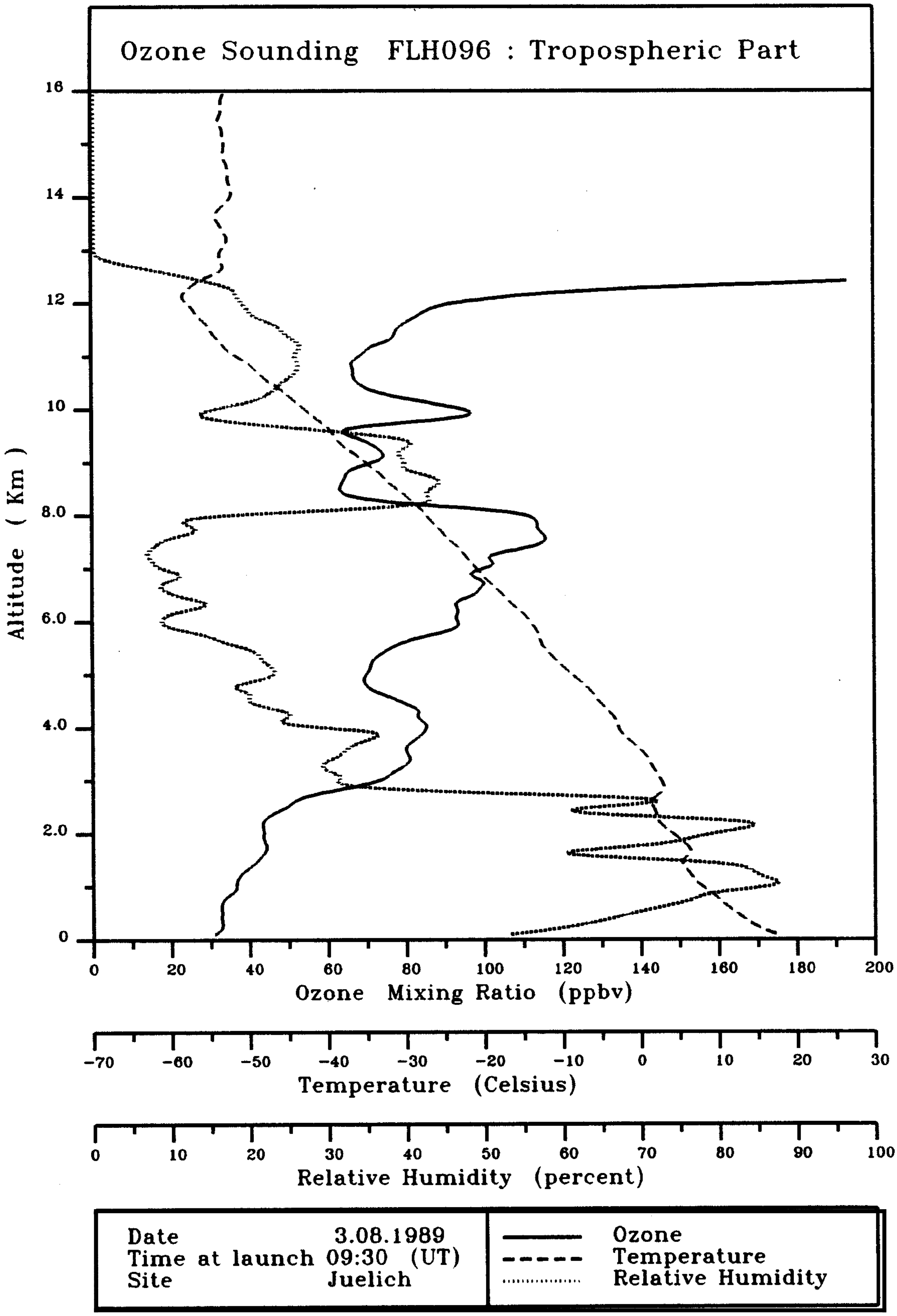

Ozone Sounding FLH094 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 20.07.1989
Time at launch 09:20 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH094 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 20.07.1989
Time at launch 09:20 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

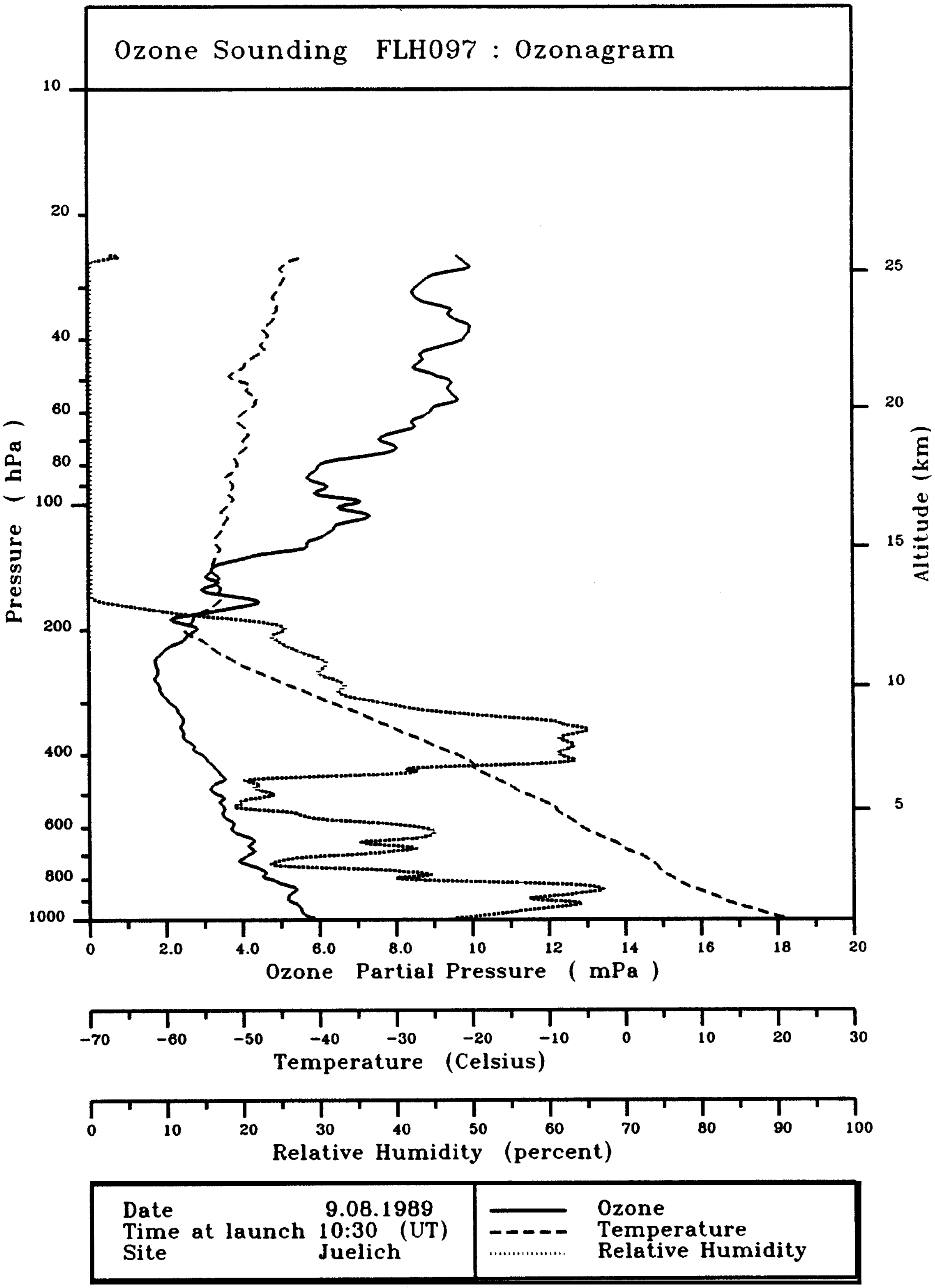

Ozone Sounding FLH095 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 27.07.1989
Time at launch 09:55 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH095 : Tropospheric Part
16
14
12
10
8.0
6.0
4.0
2.0
0
Altitude (Km)
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 27.07.1989
Time at launch 09:55 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

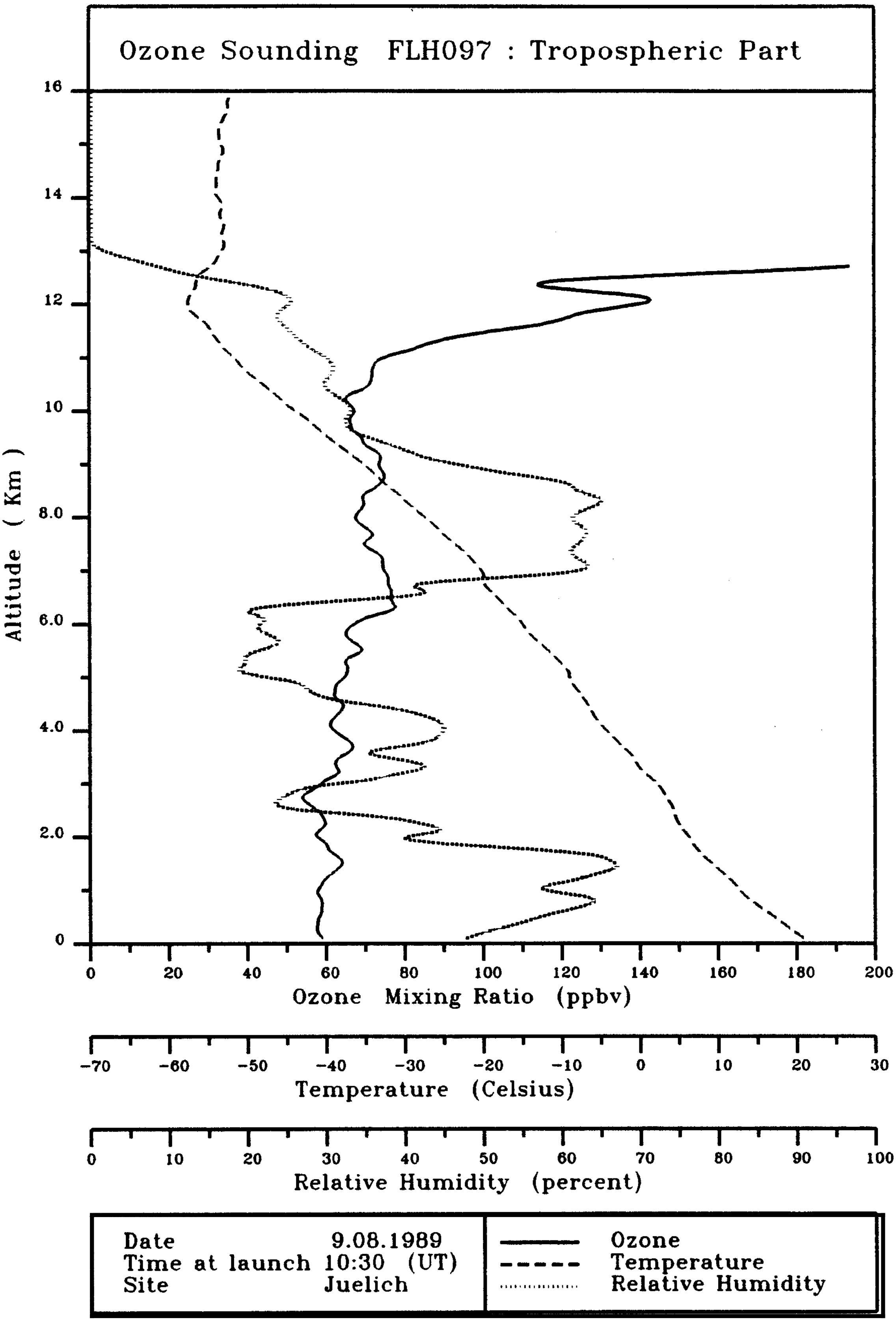

Ozone Sounding FLH096 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 3.08.1989
Time at launch 09:30 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

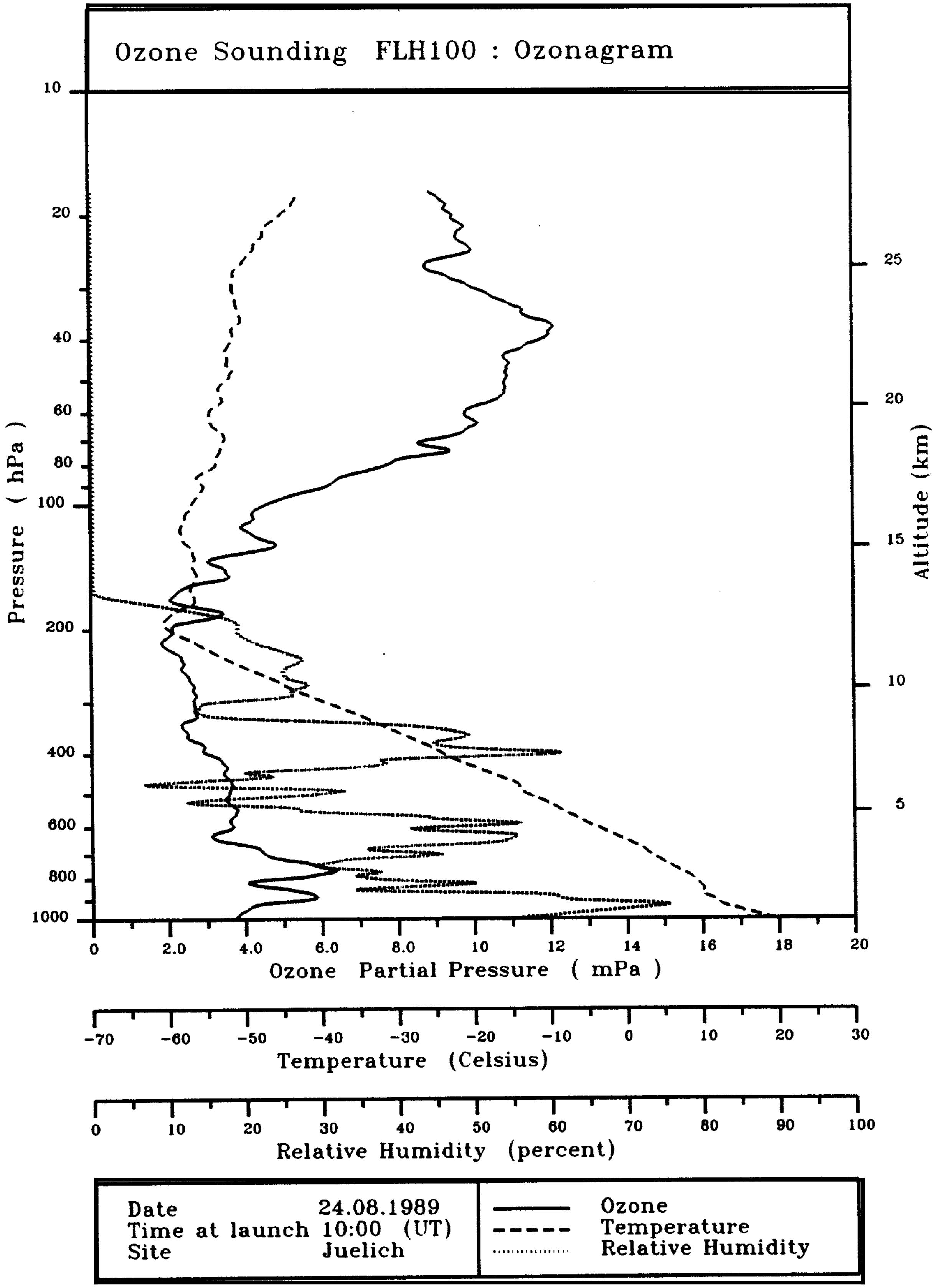


Ozone Sounding FLH096 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 3.08.1989
Time at launch 09:30 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

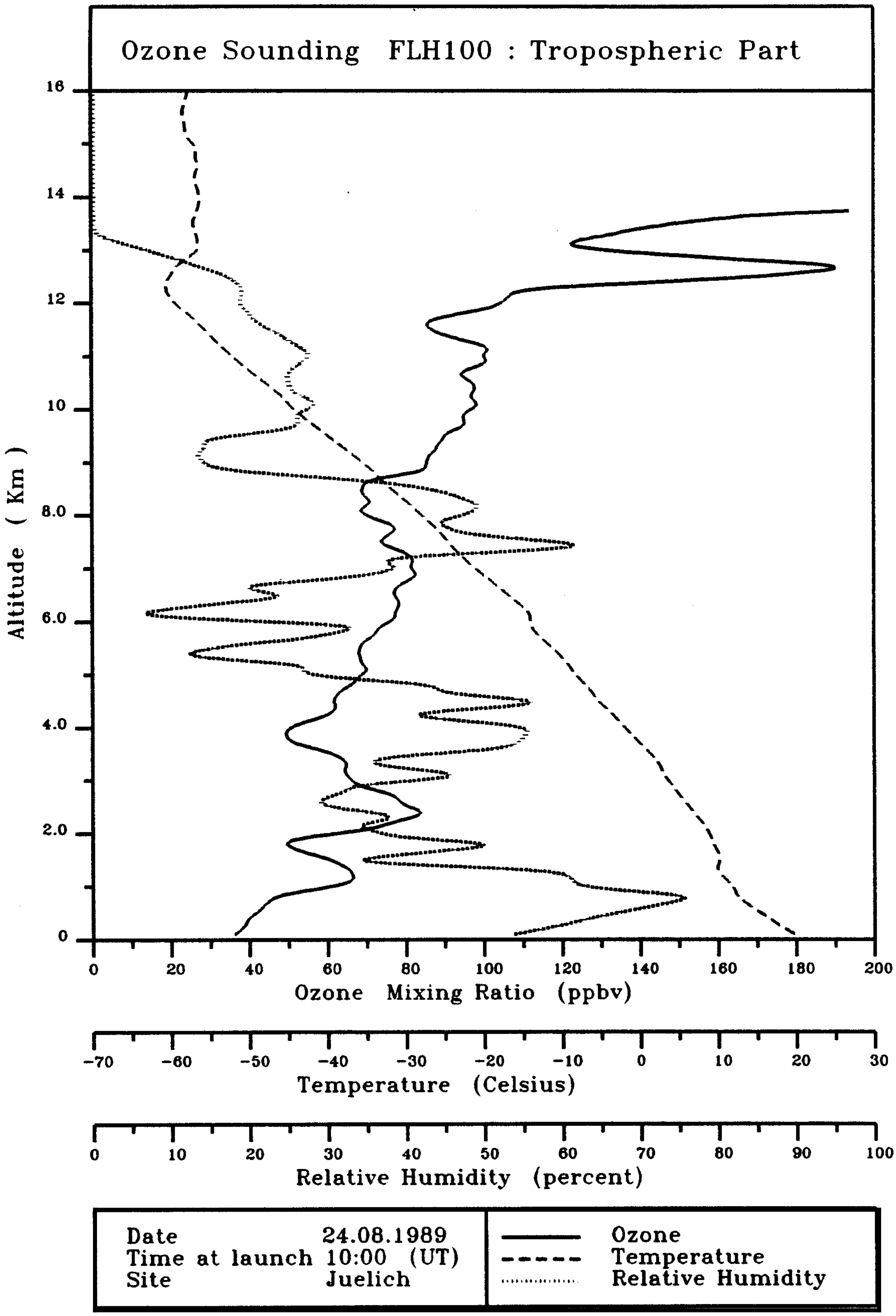


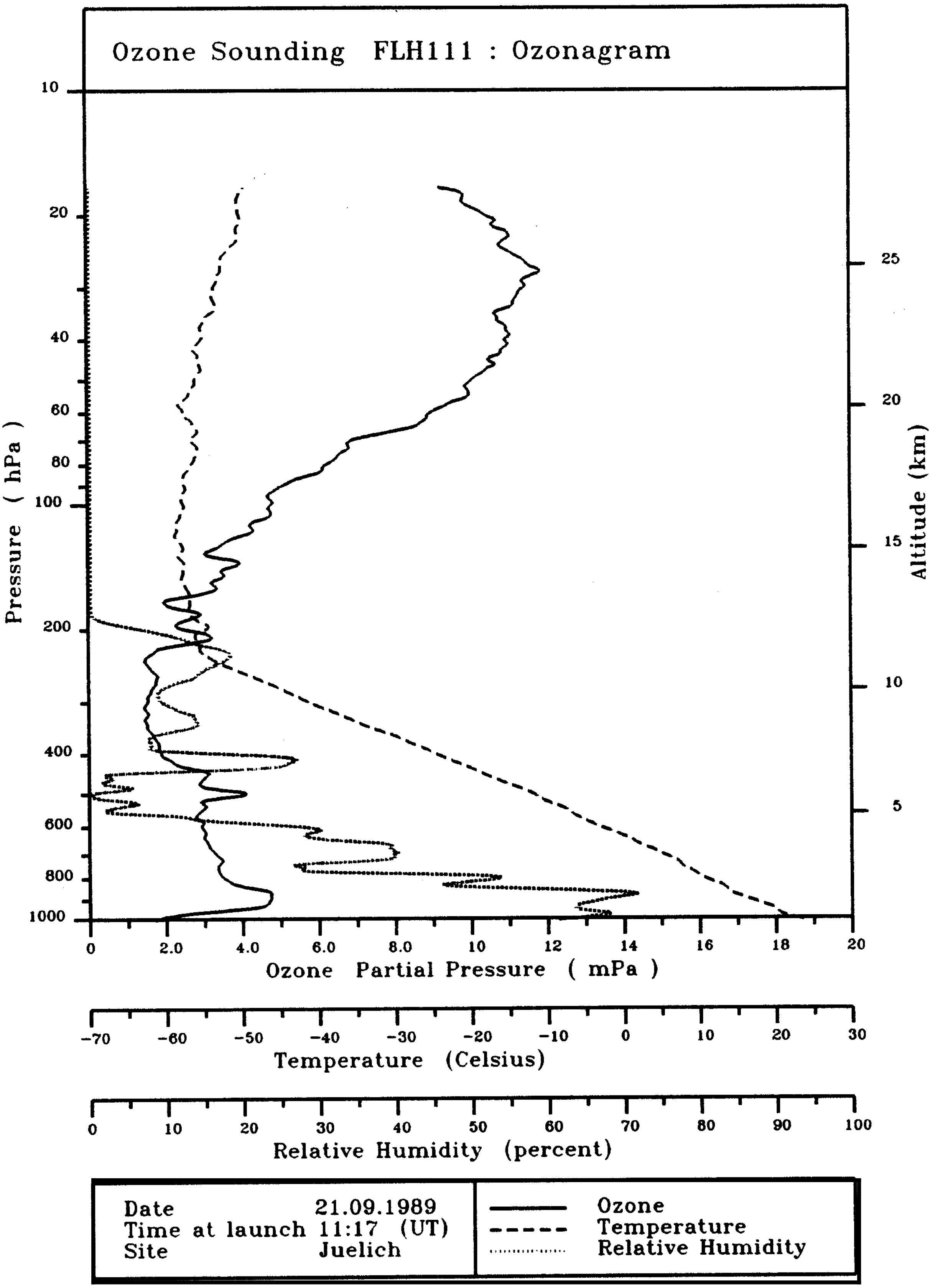
Ozone Sounding FLH097 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 9.08.1989
Time at launch 10:30 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

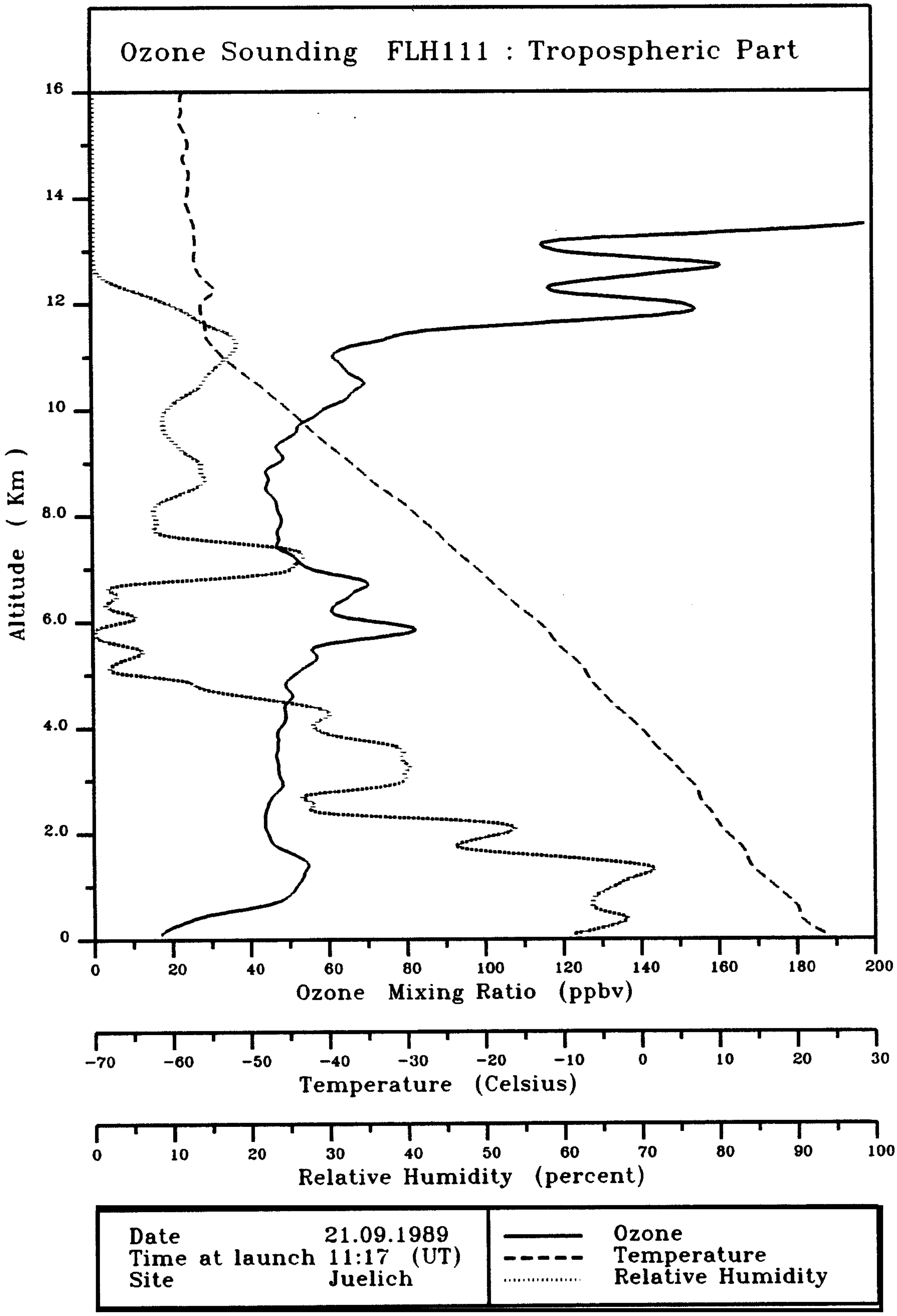

Ozone Sounding FLH097 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 9.08.1989
Time at launch 10:30 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



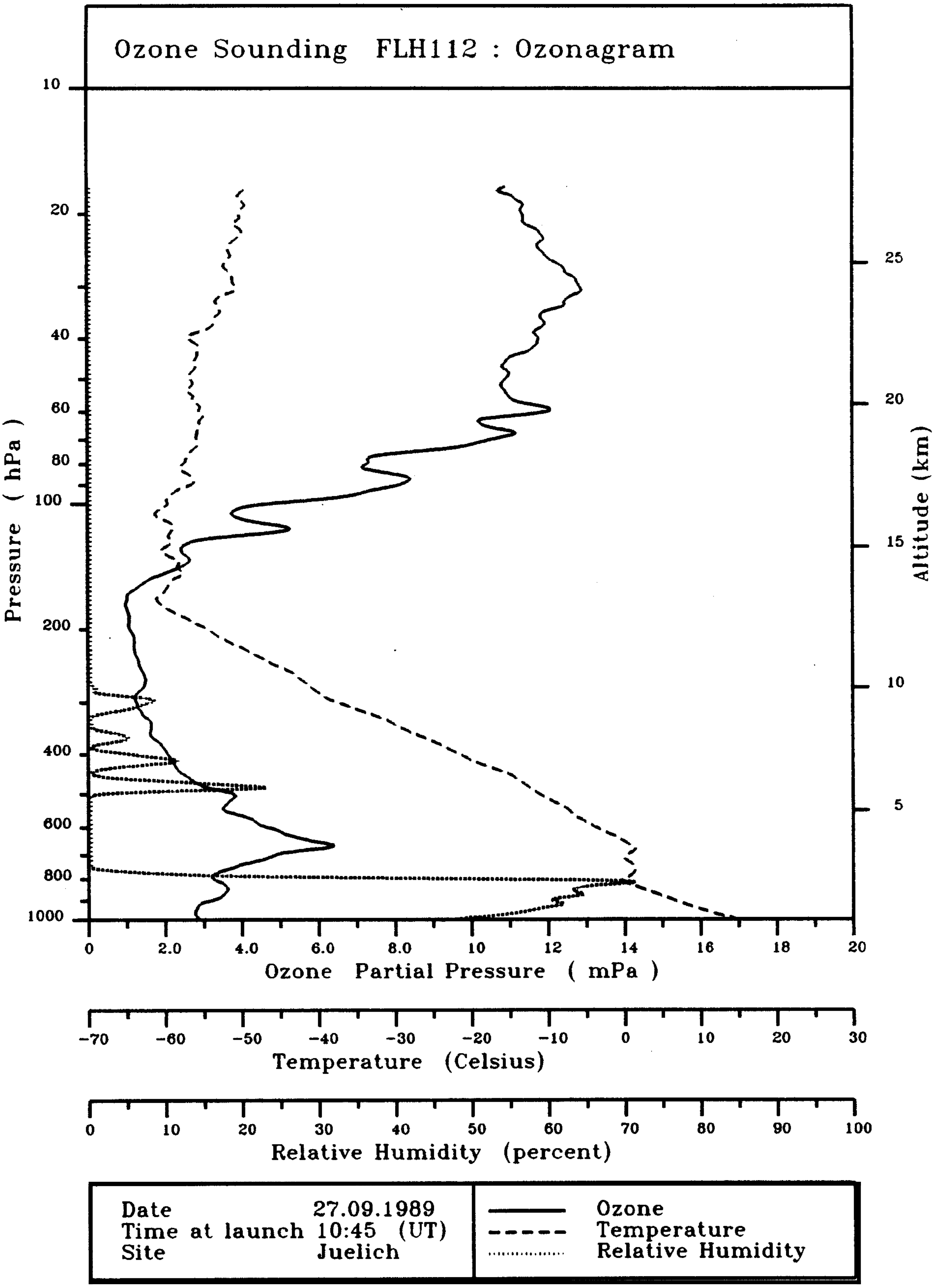
Ozone Sounding FLH100 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 24.08.1989
Time at launch 10:00 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

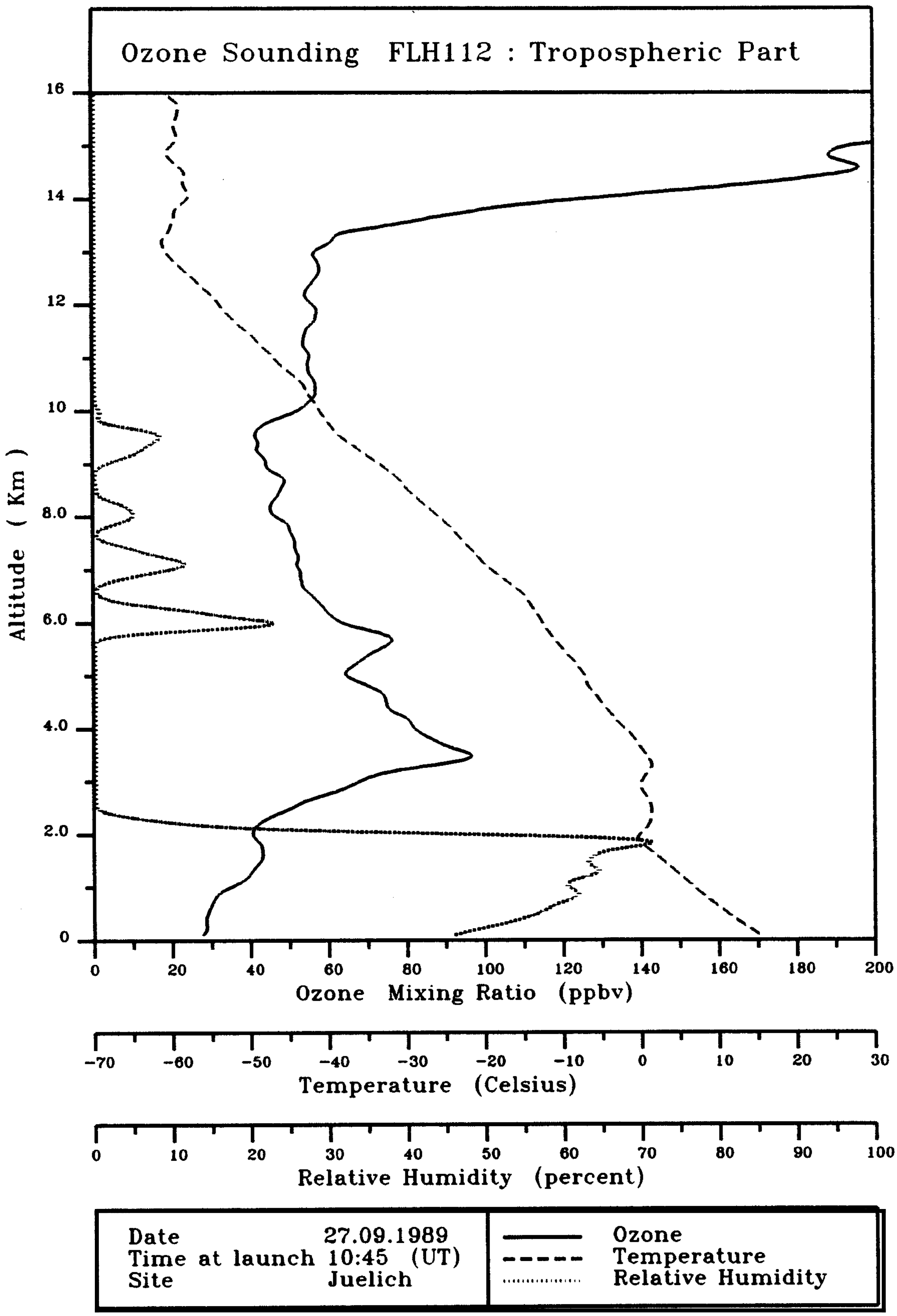

Ozone Sounding FLH100 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 24.08.1989
Time at launch 10:00 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

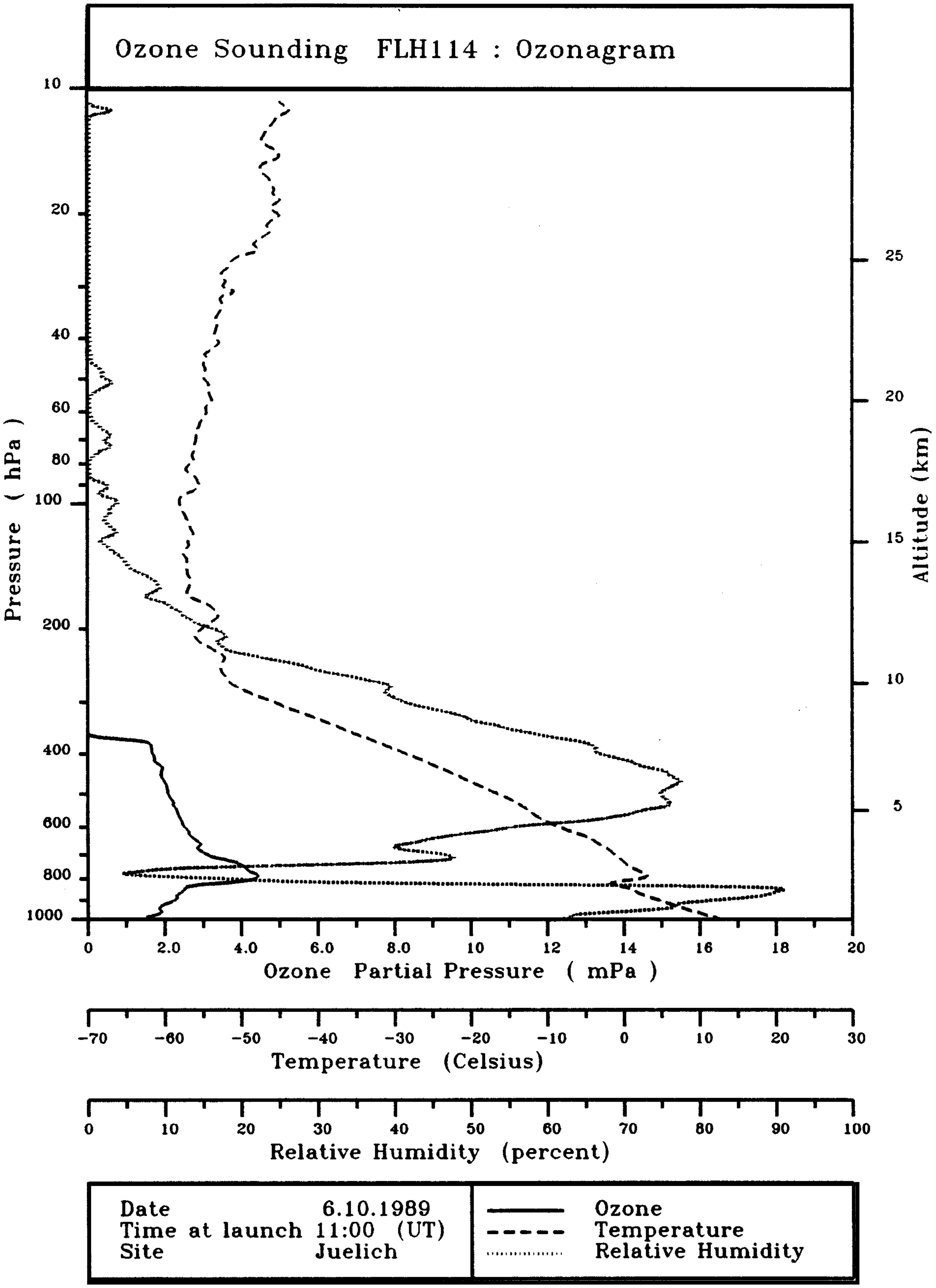

Ozone Sounding FLH111 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 21.09.1989
Time at launch 11:17 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

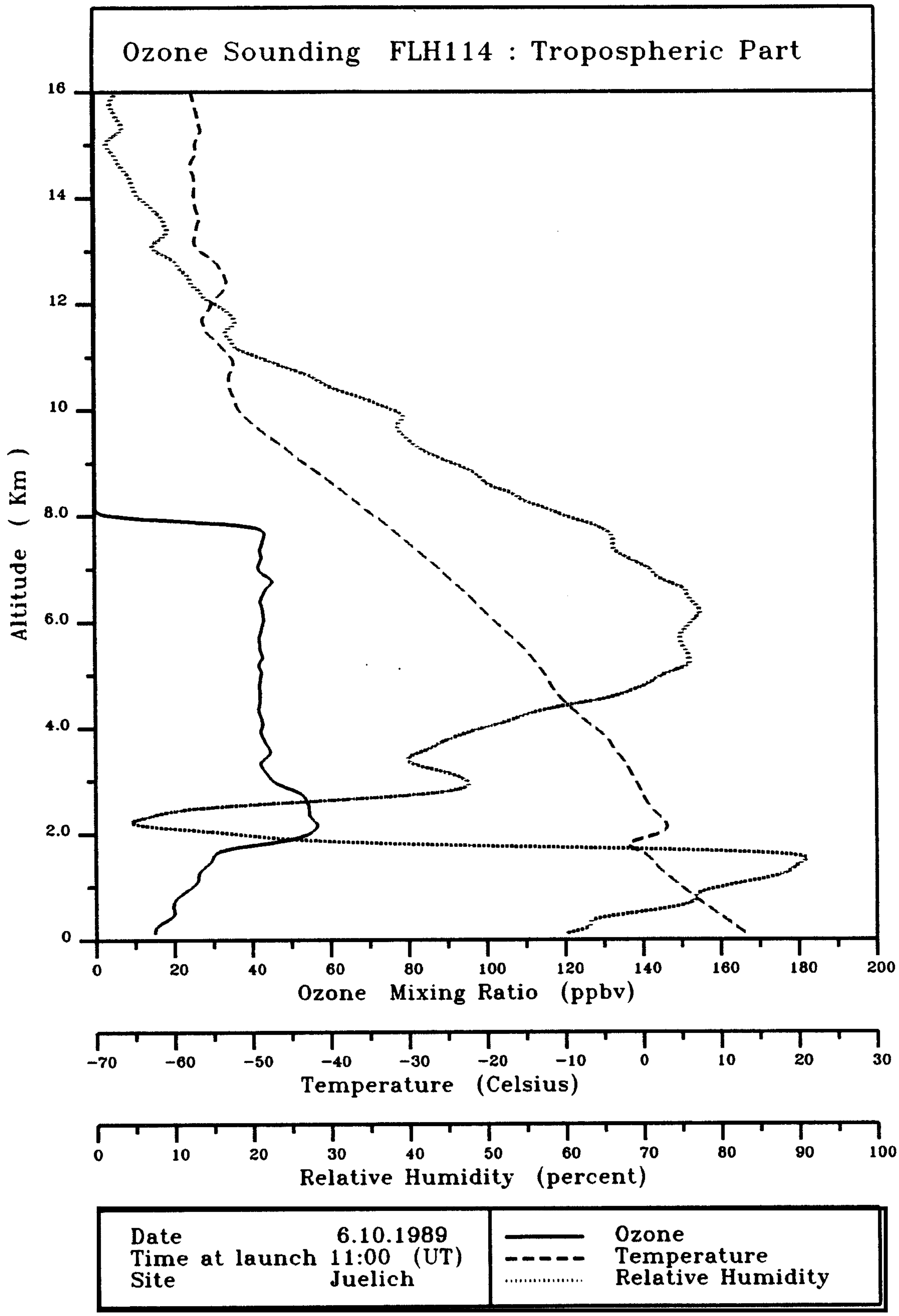


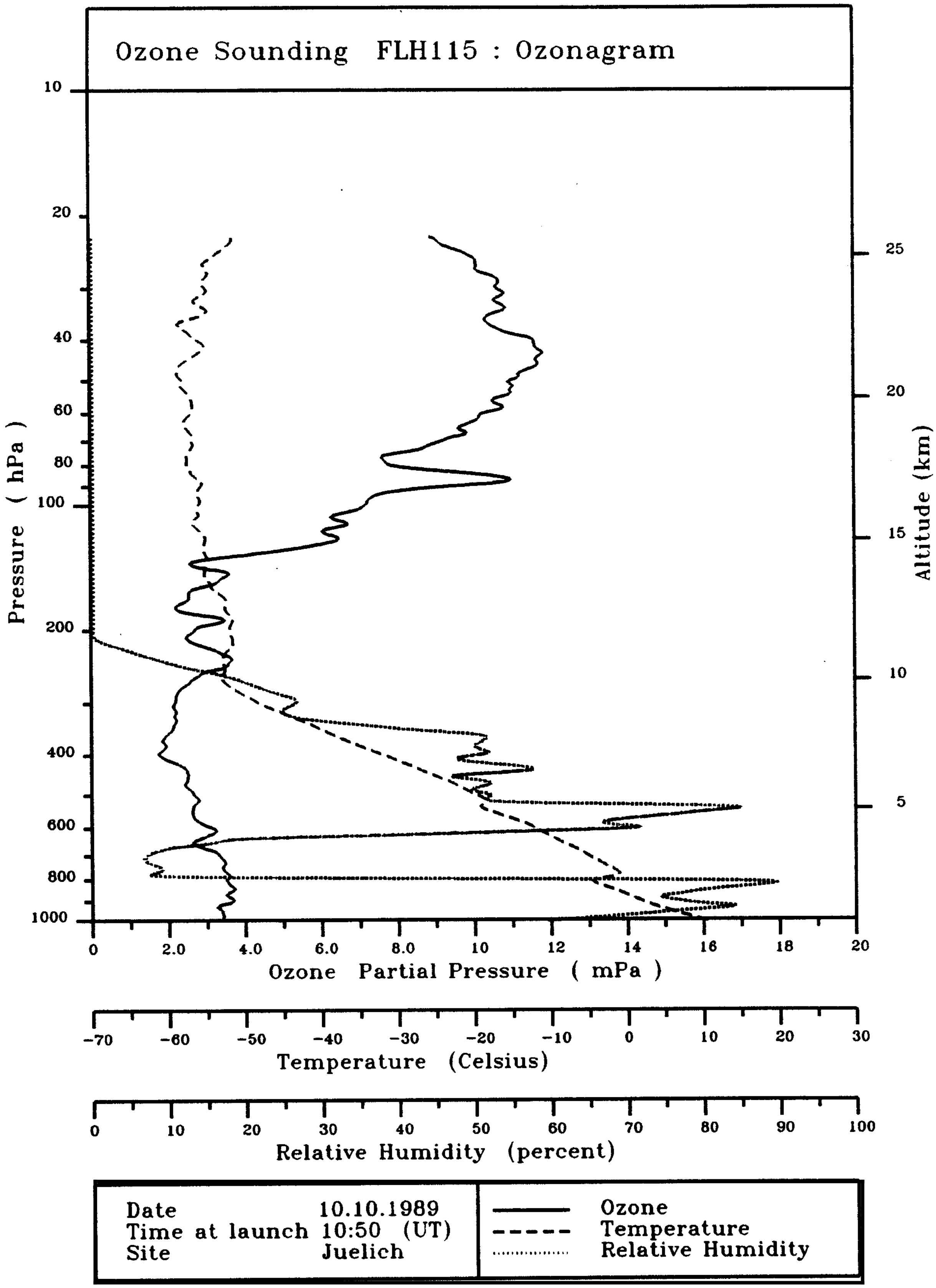
Ozone Sounding FLH111 : Tropospheric Part
16
14
12
10
8.0
6.0
4.0
2.0
0
Altitude (Km)
0
20
40
60
80
100
120
140
160
180
200
Ozone Mixing Ratio (ppbv)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 21.09.1989
Time at launch 11:17 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

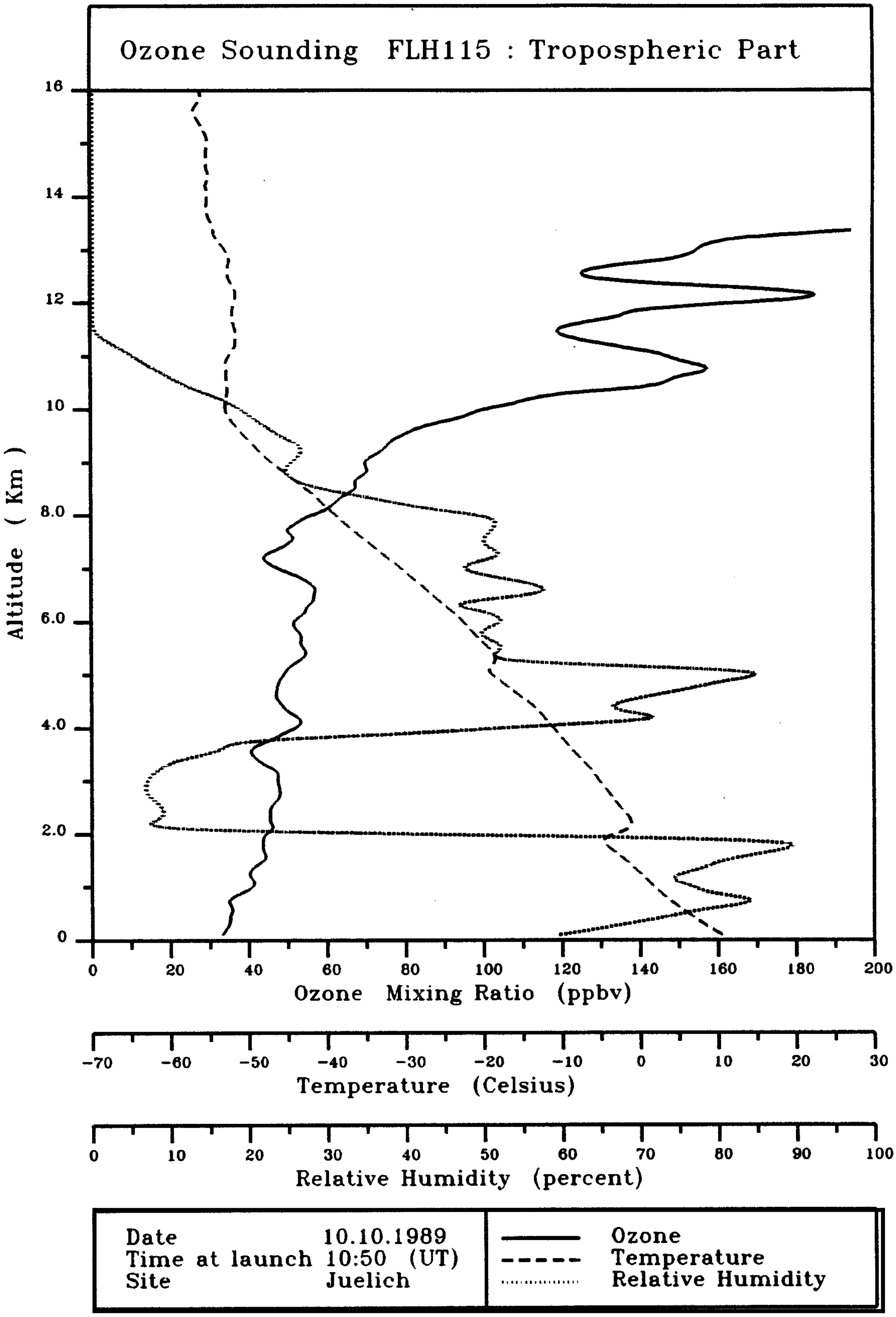

Ozone Sounding FLH112 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0 2.0 4.0 6.0 8.0 10 12 14 16 18 20
Ozone Partial Pressure (mPa)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 27.09.1989
Time at launch 10:45 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

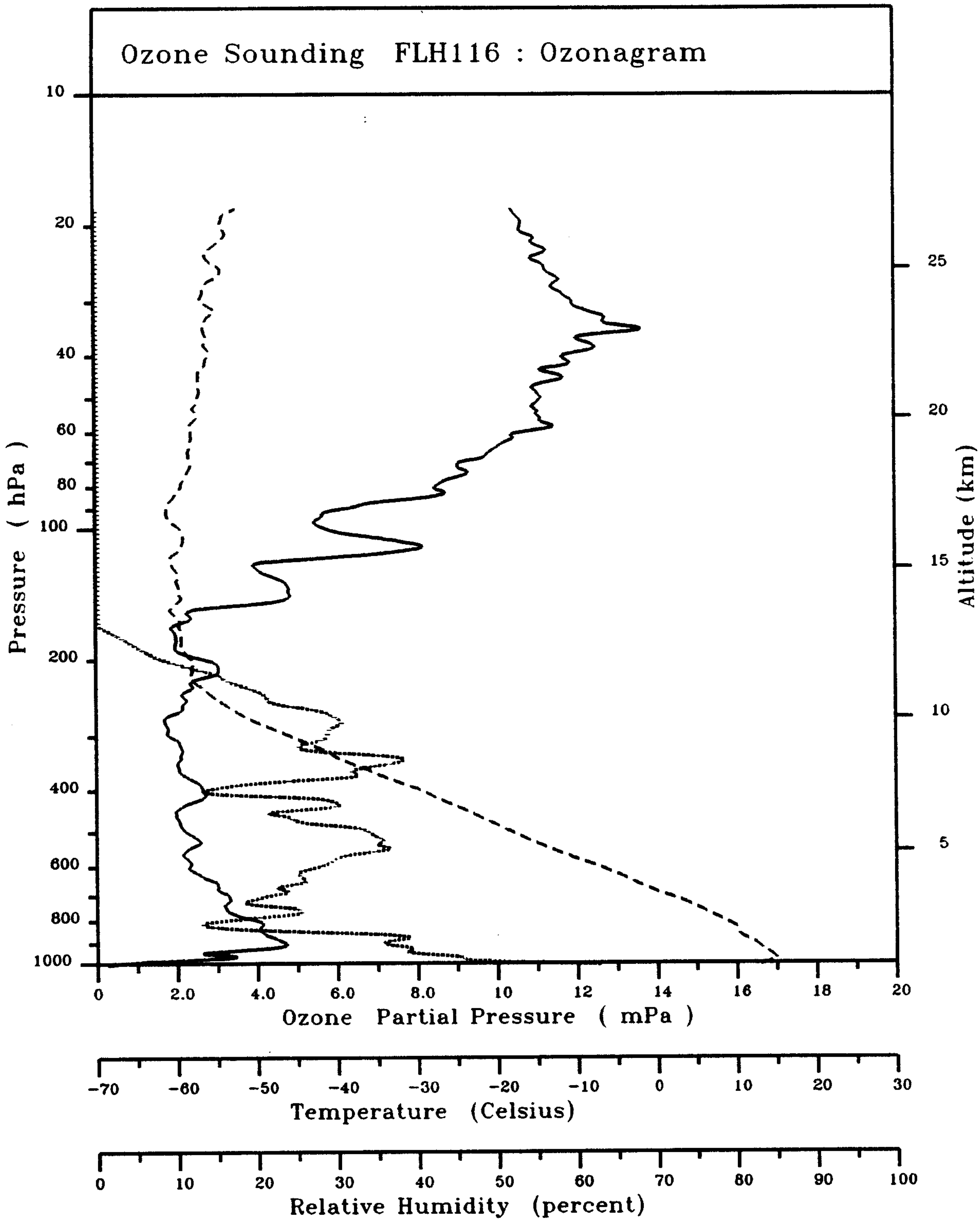

Ozone Sounding FLH112 : Tropospheric Part
Altitude (Km)
0
2.0
4.0
6.0
8.0
10
12
14
16
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 27.09.1989
Time at launch 10:45 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH114 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 6.10.1989
Time at launch 11:00 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

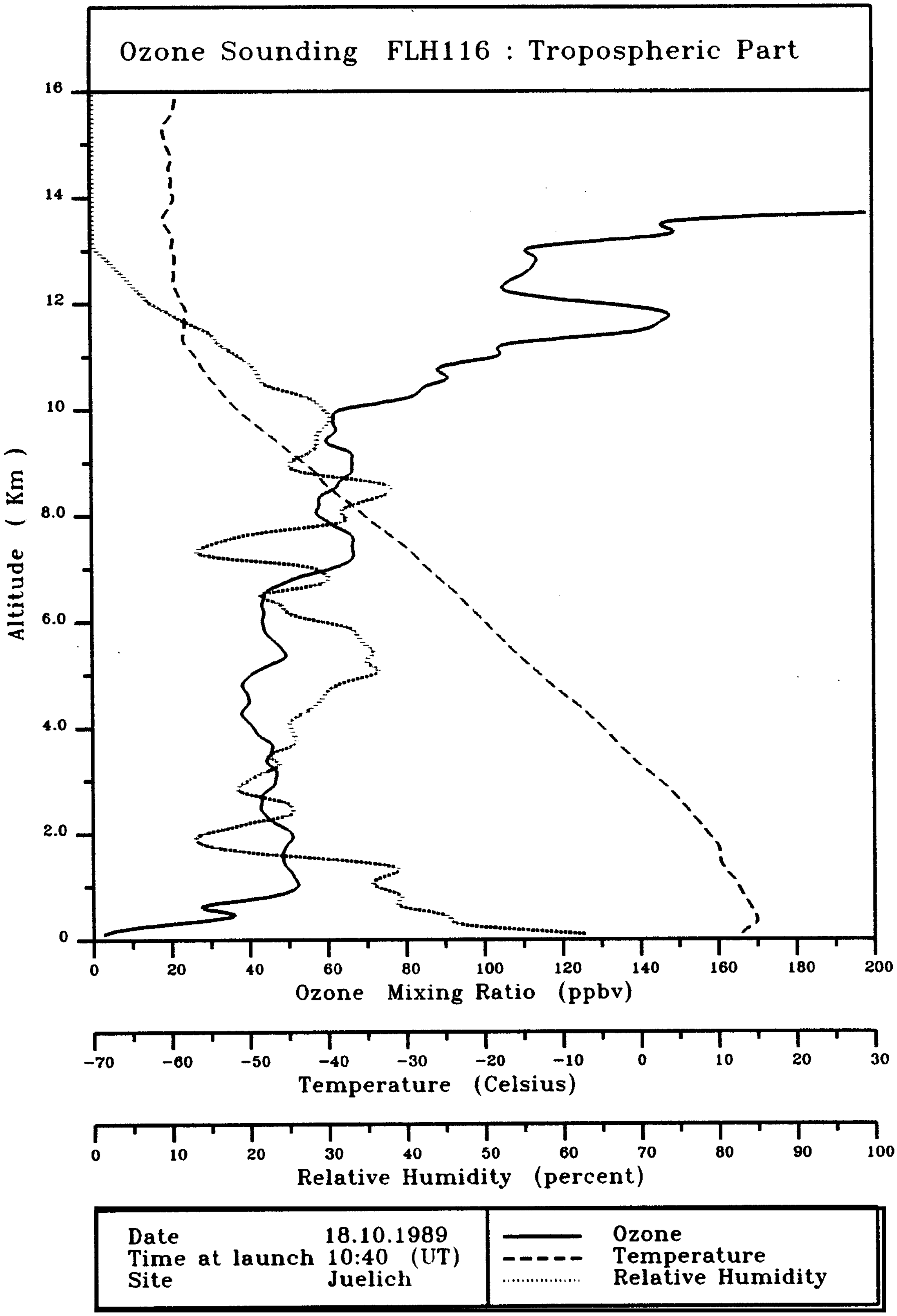

Ozone Sounding FLH114 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 6.10.1989
Time at launch 11:00 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH115 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 10.10.1989
Time at launch 10:50 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

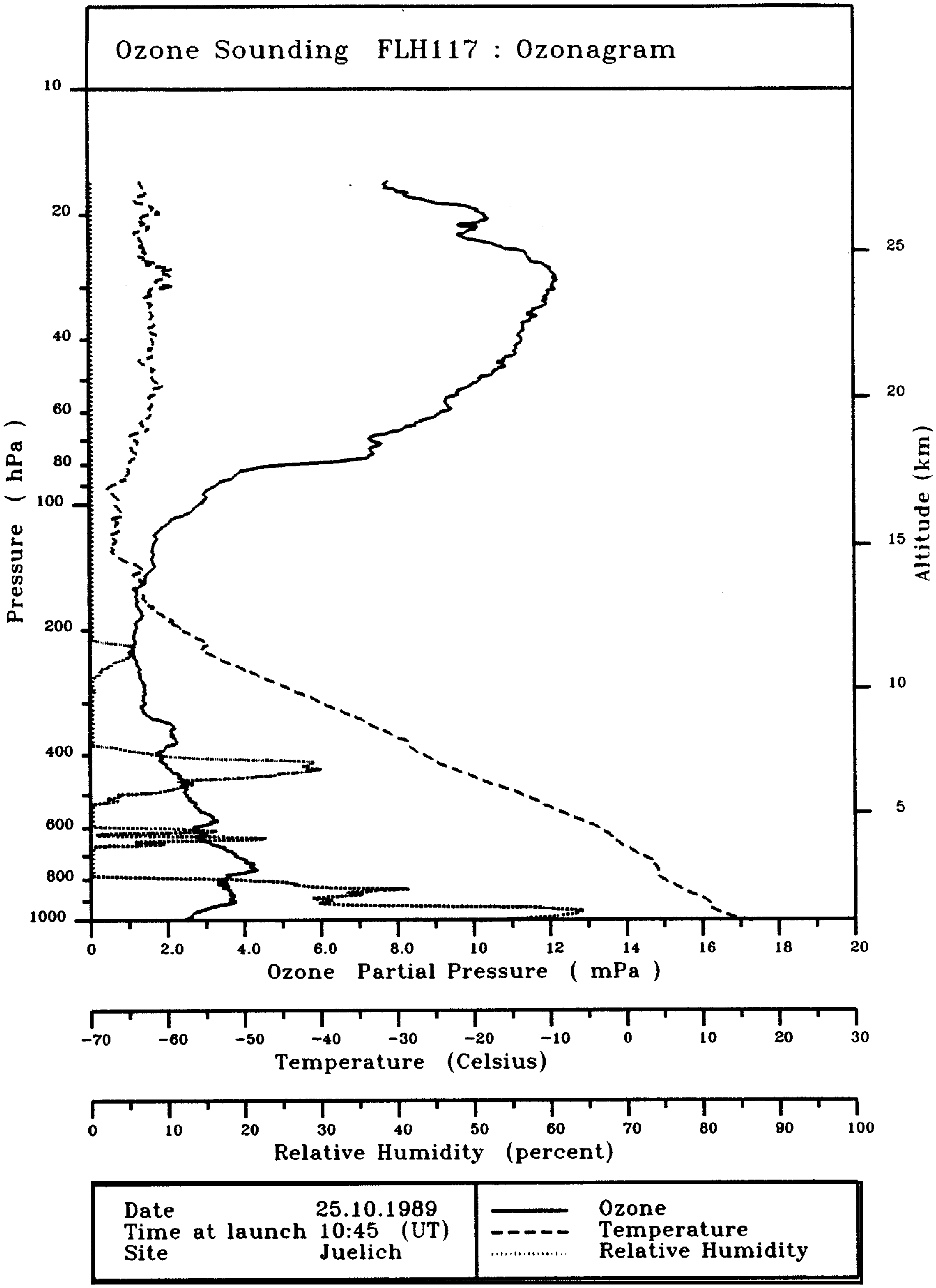

Ozone Sounding FLH115 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 10.10.1989
Time at launch 10:50 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

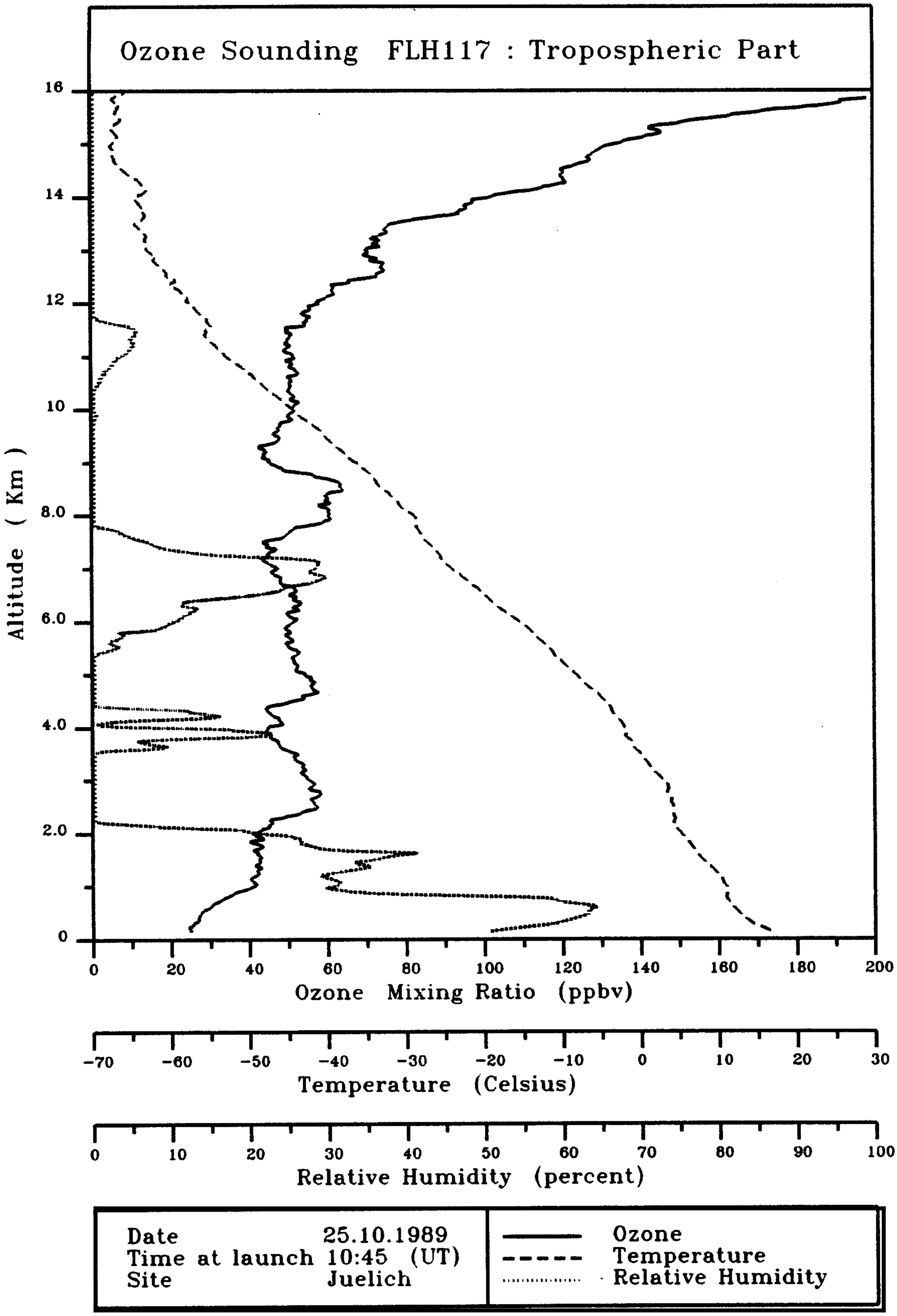


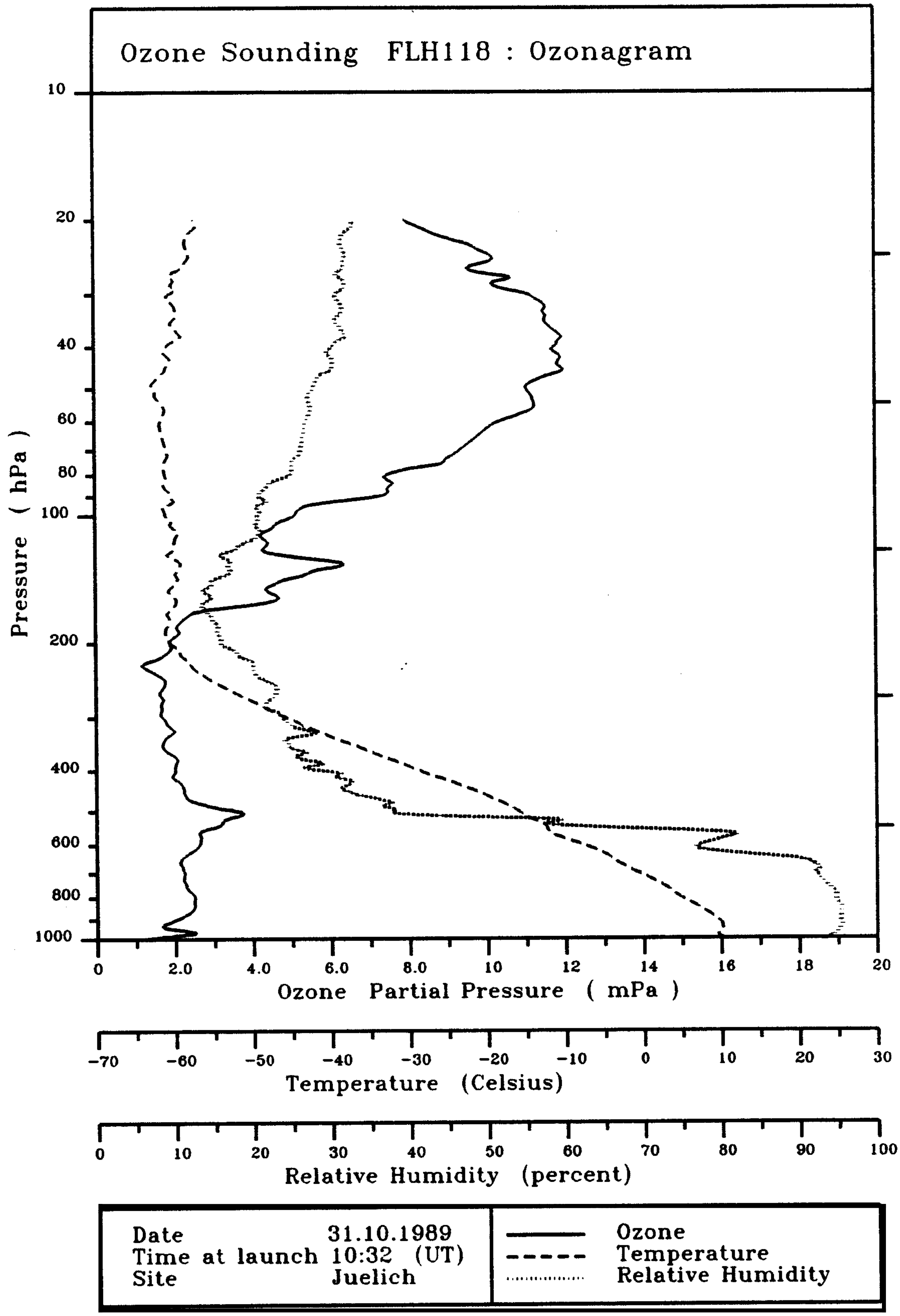
Date	18.10.1989	———	Ozone
Time at launch	10:40 (UT)	- - - -	Temperature
Site	Juelich	....	Relative Humidity

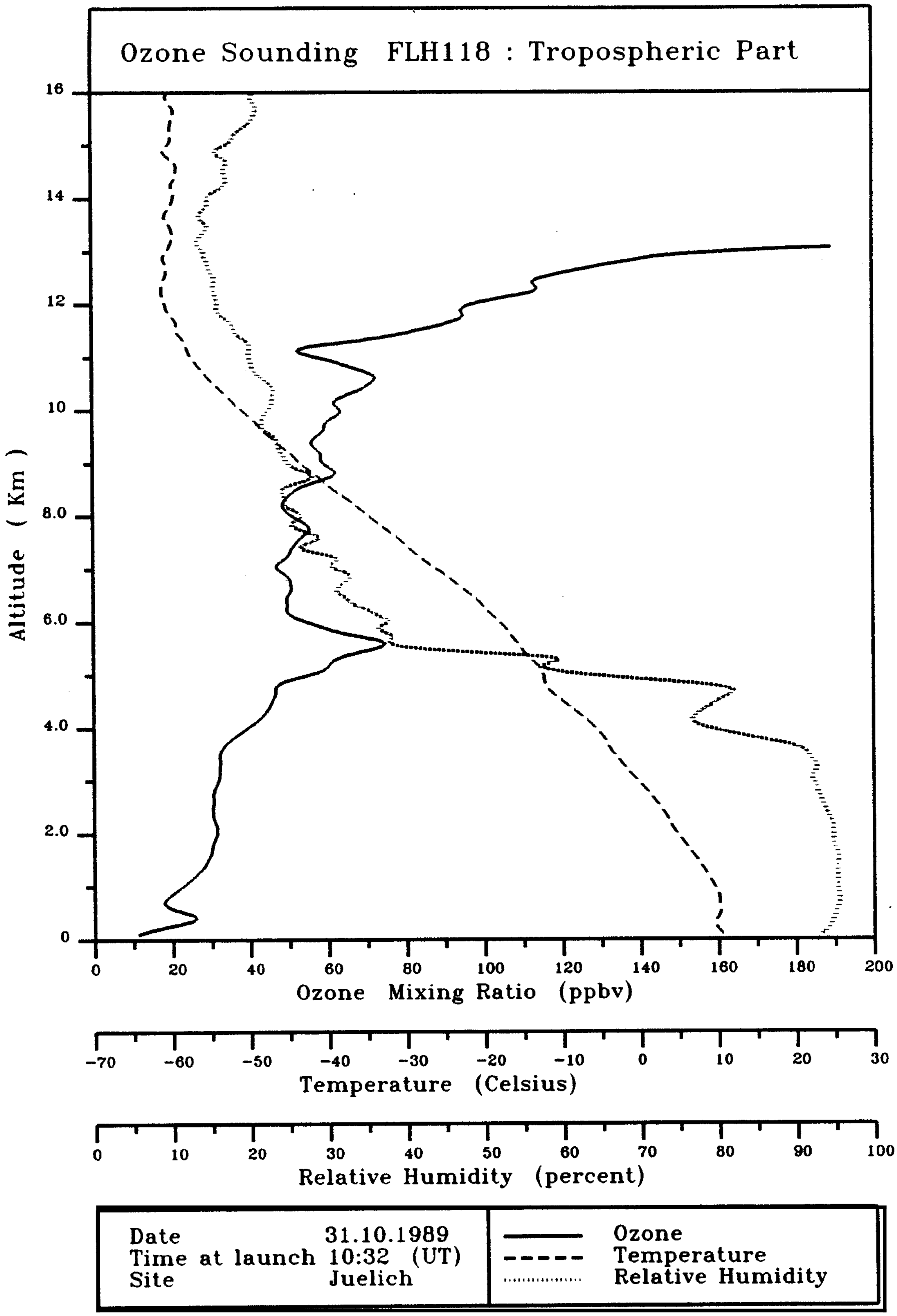


Ozone Sounding FLH116 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 18.10.1989
Time at launch 10:40 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

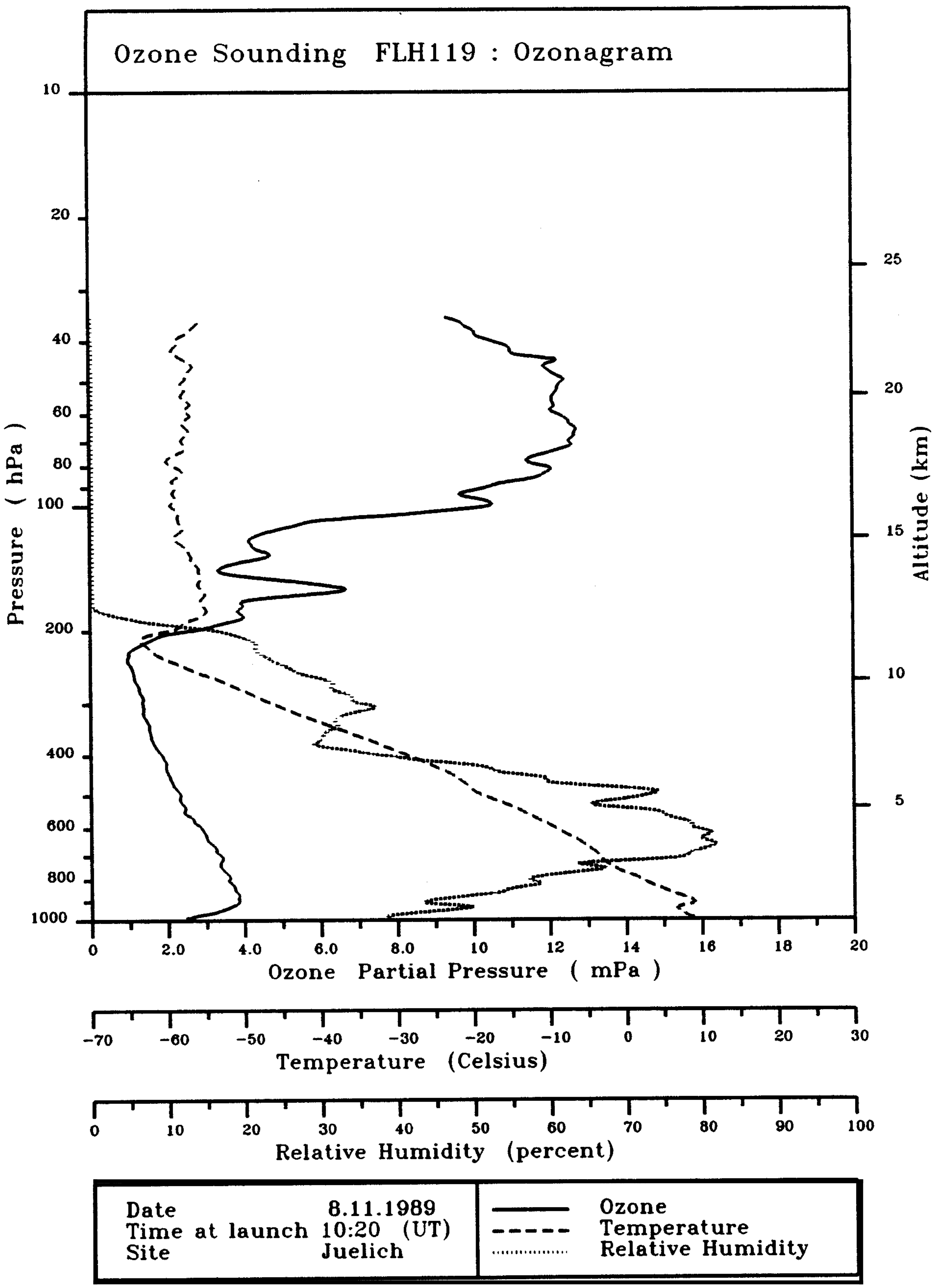

Ozone Sounding FLH117 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 25.10.1989
Time at launch 10:45 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

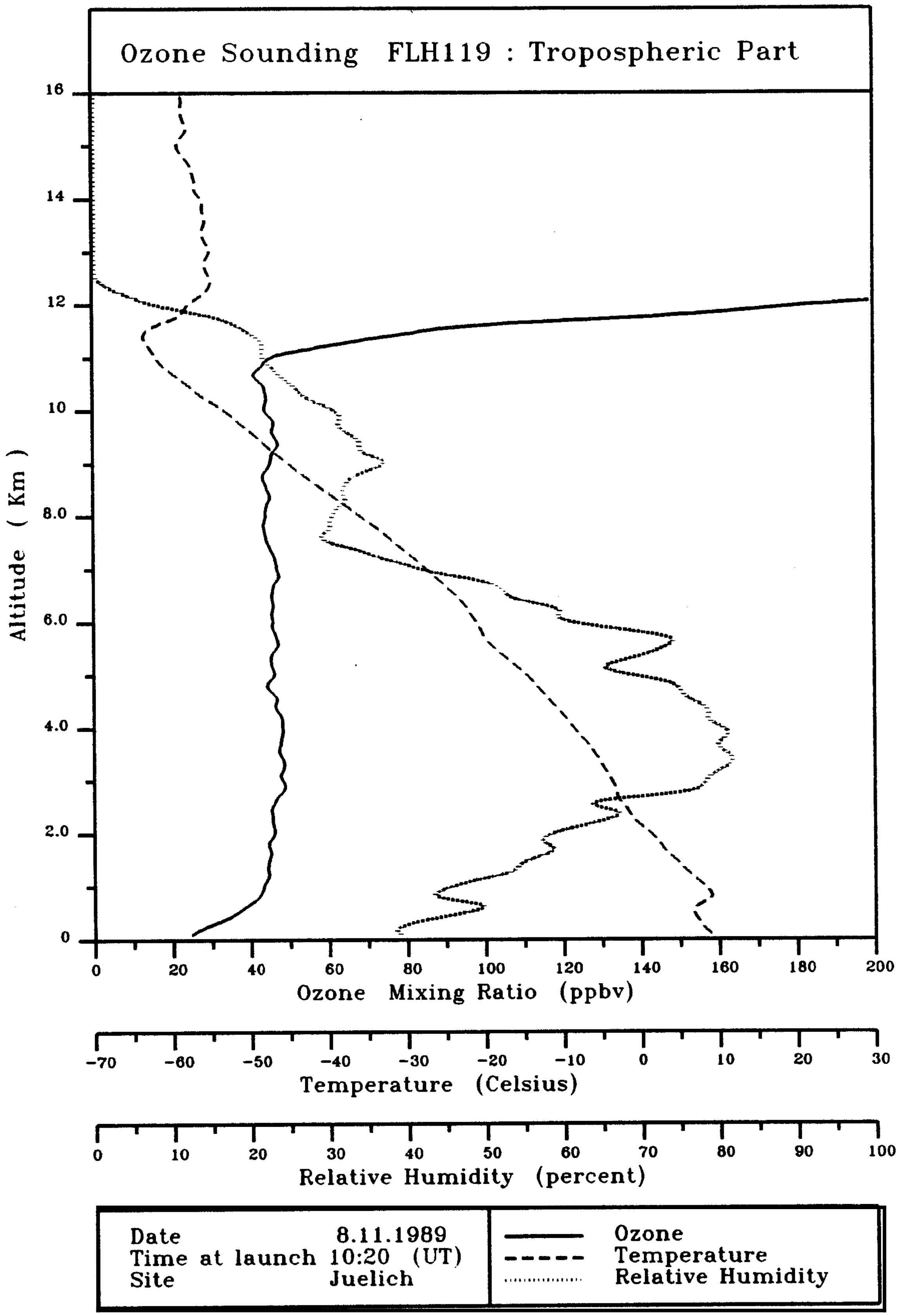

Ozone Sounding FLH117 : Tropospheric Part
Altitude (Km)
0
2.0
4.0
6.0
8.0
10
12
14
16
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 25.10.1989
Time at launch 10:45 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH118 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 31.10.1989
Time at launch 10:32 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

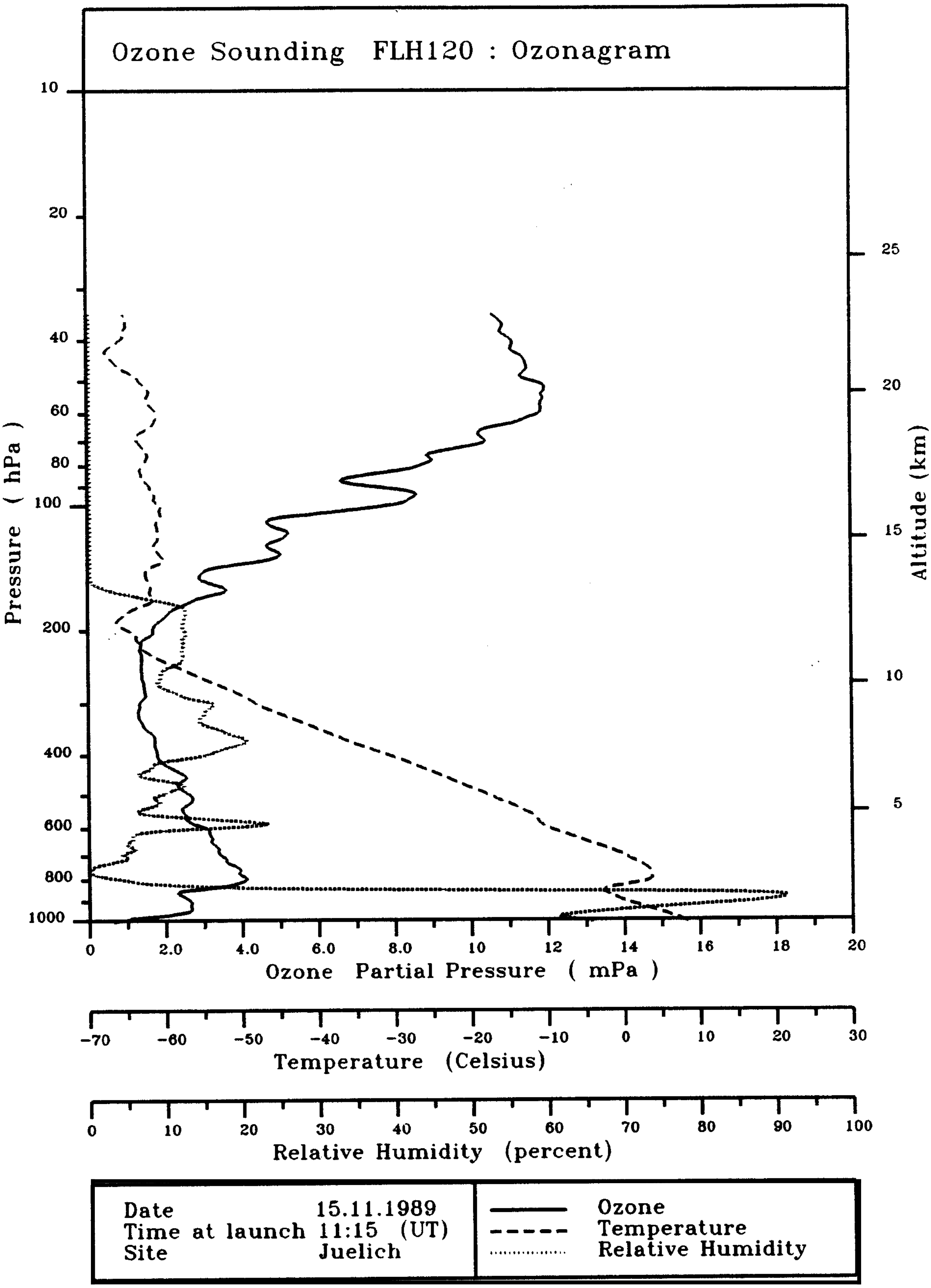


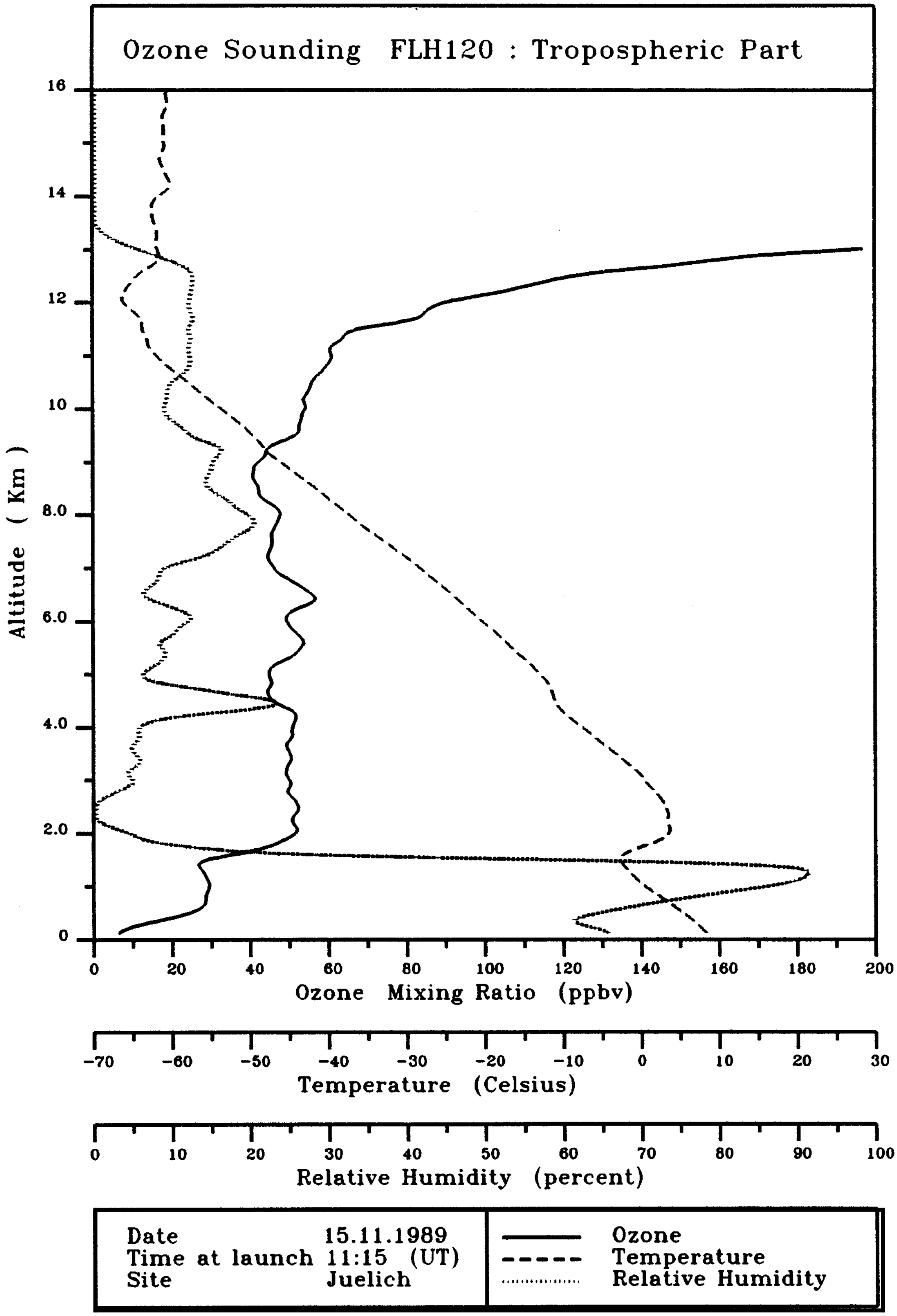
Ozone Sounding FLH118 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 31.10.1989
Time at launch 10:32 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH119 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 8.11.1989
Time at launch 10:20 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

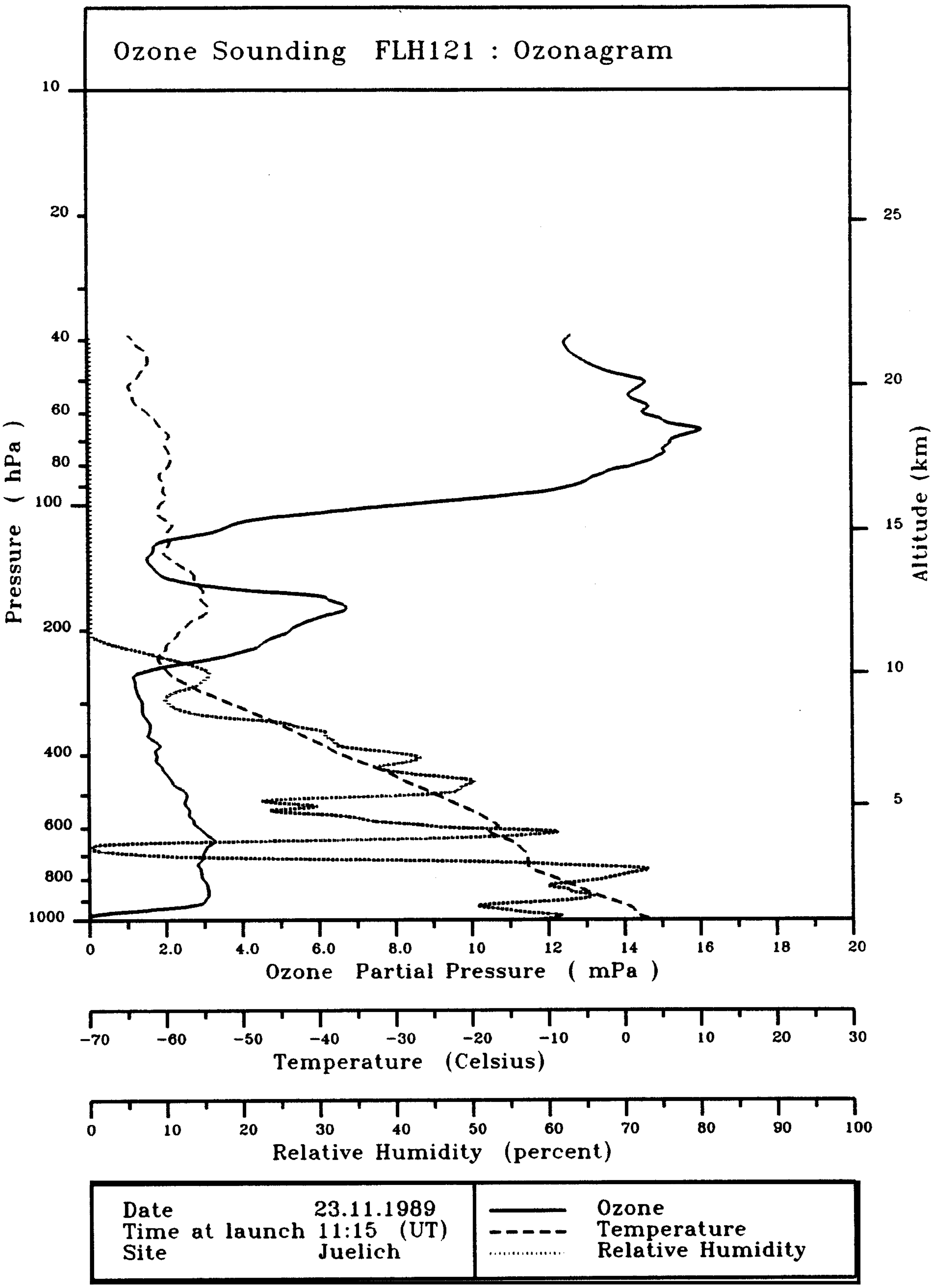


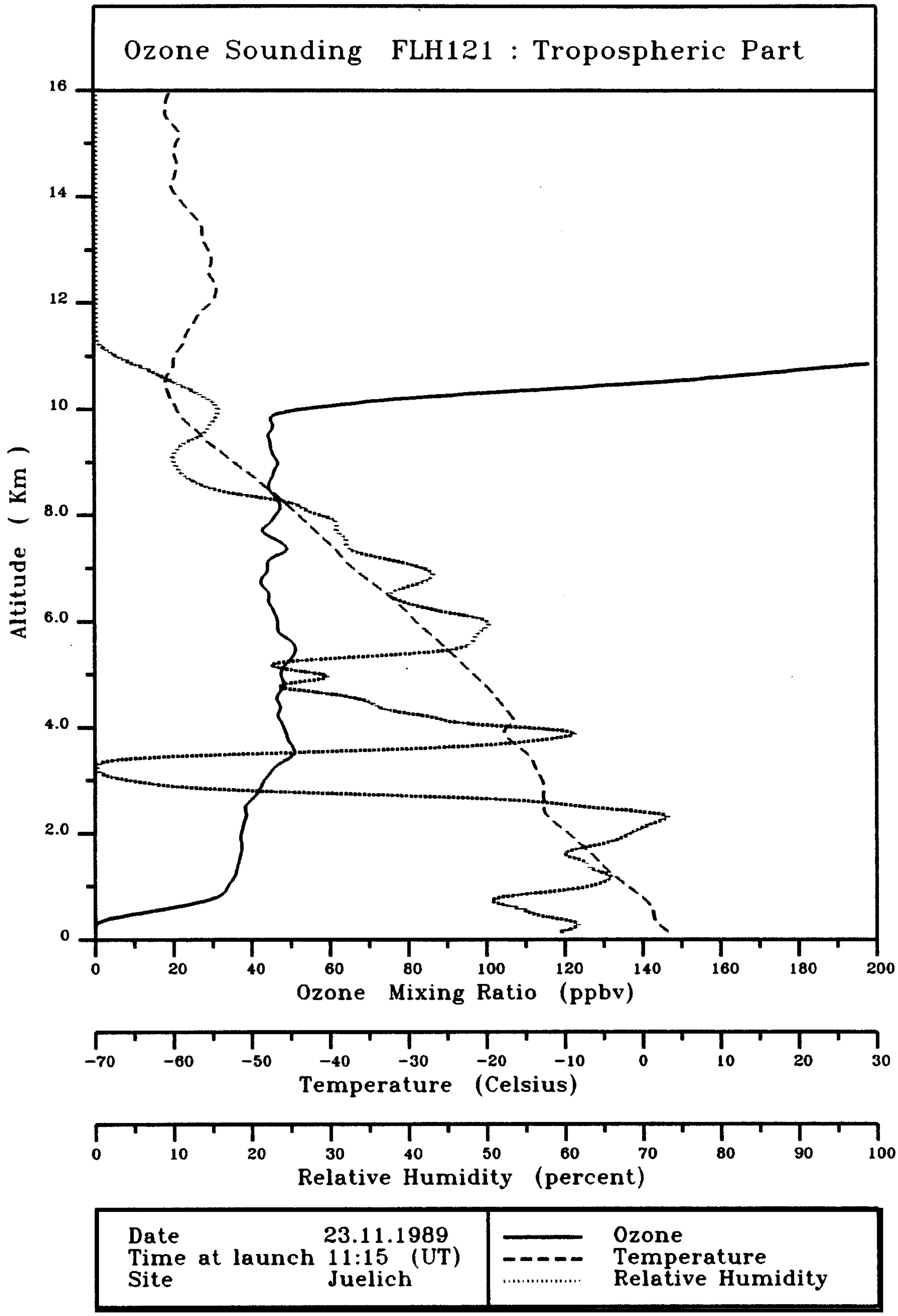
Ozone Sounding FLH119 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 8.11.1989
Time at launch 10:20 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH120 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 15.11.1989
Time at launch 11:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

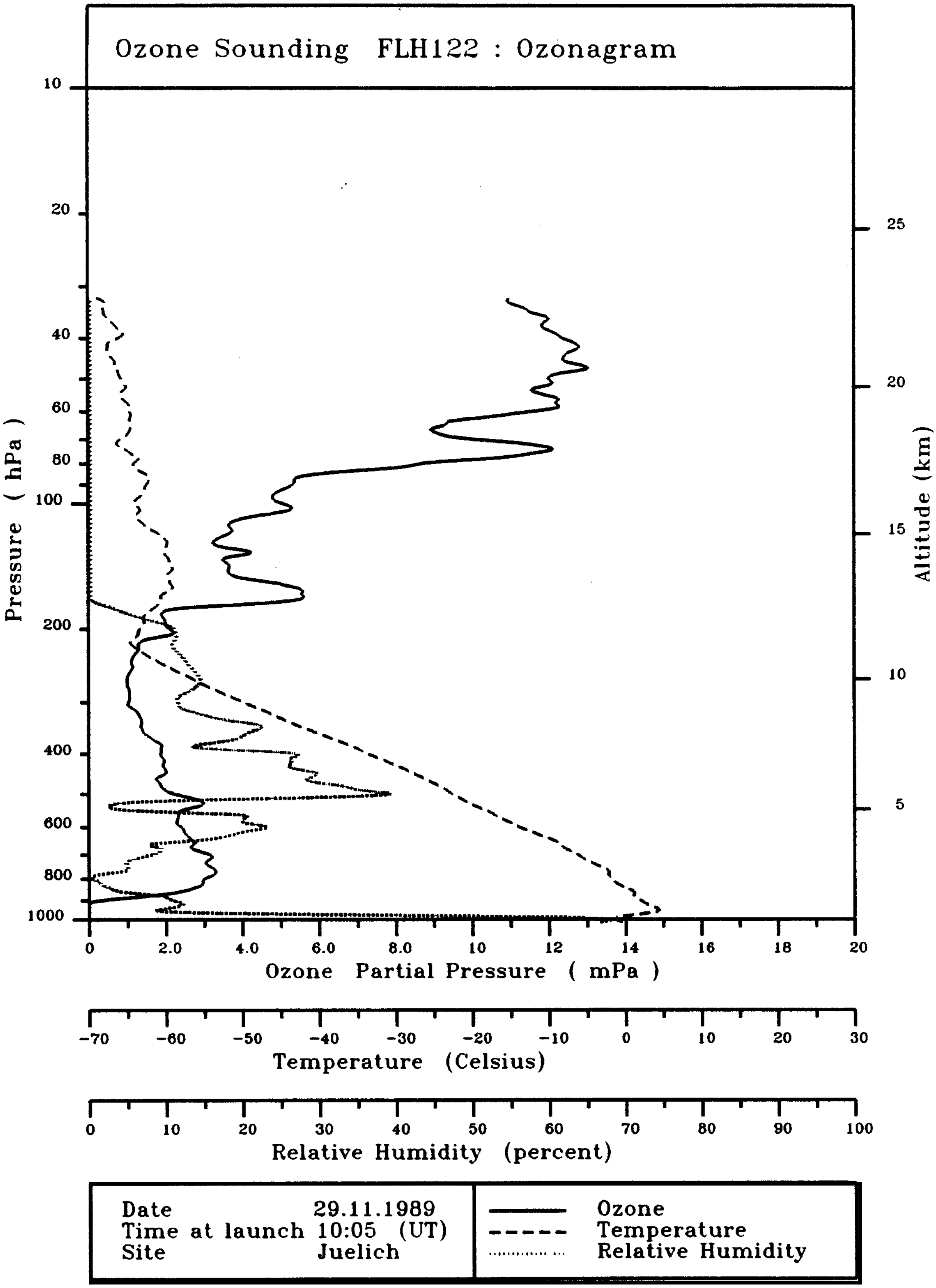


Ozone Sounding FLH120 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 15.11.1989
Time at launch 11:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

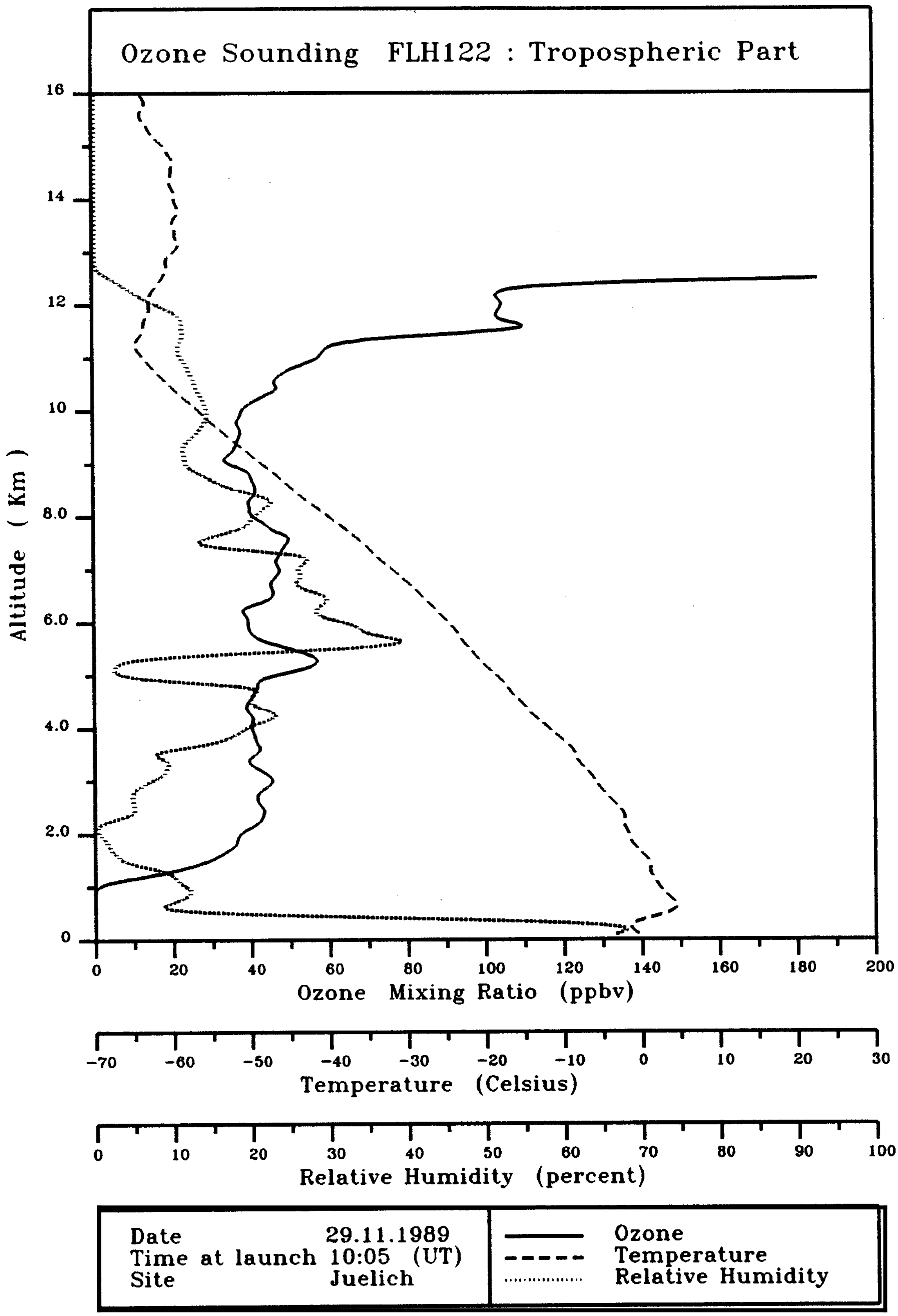

Ozone Sounding FLH121 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 23.11.1989
Time at launch 11:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



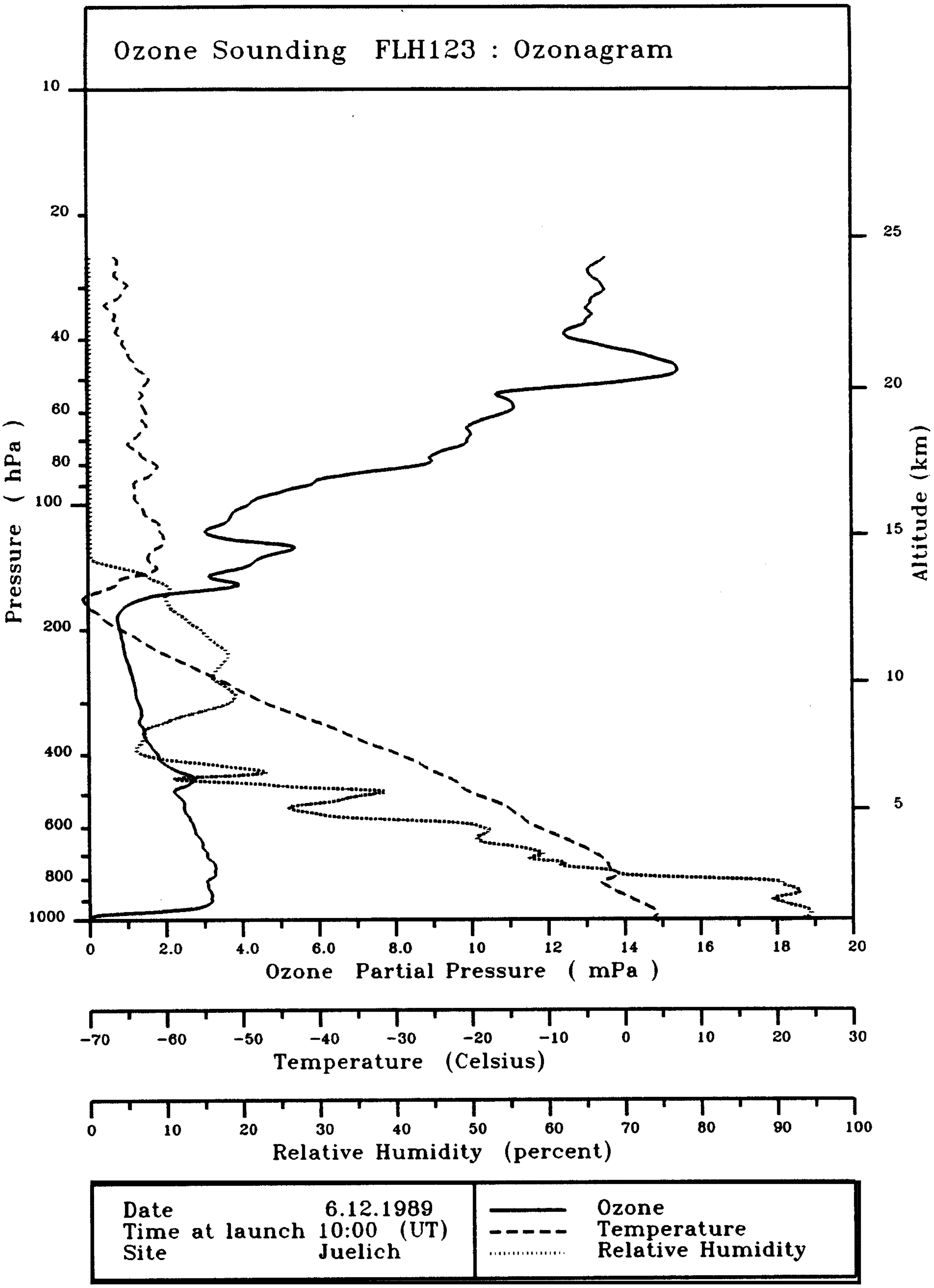
Ozone Sounding FLH121 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 23.11.1989
Time at launch 11:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

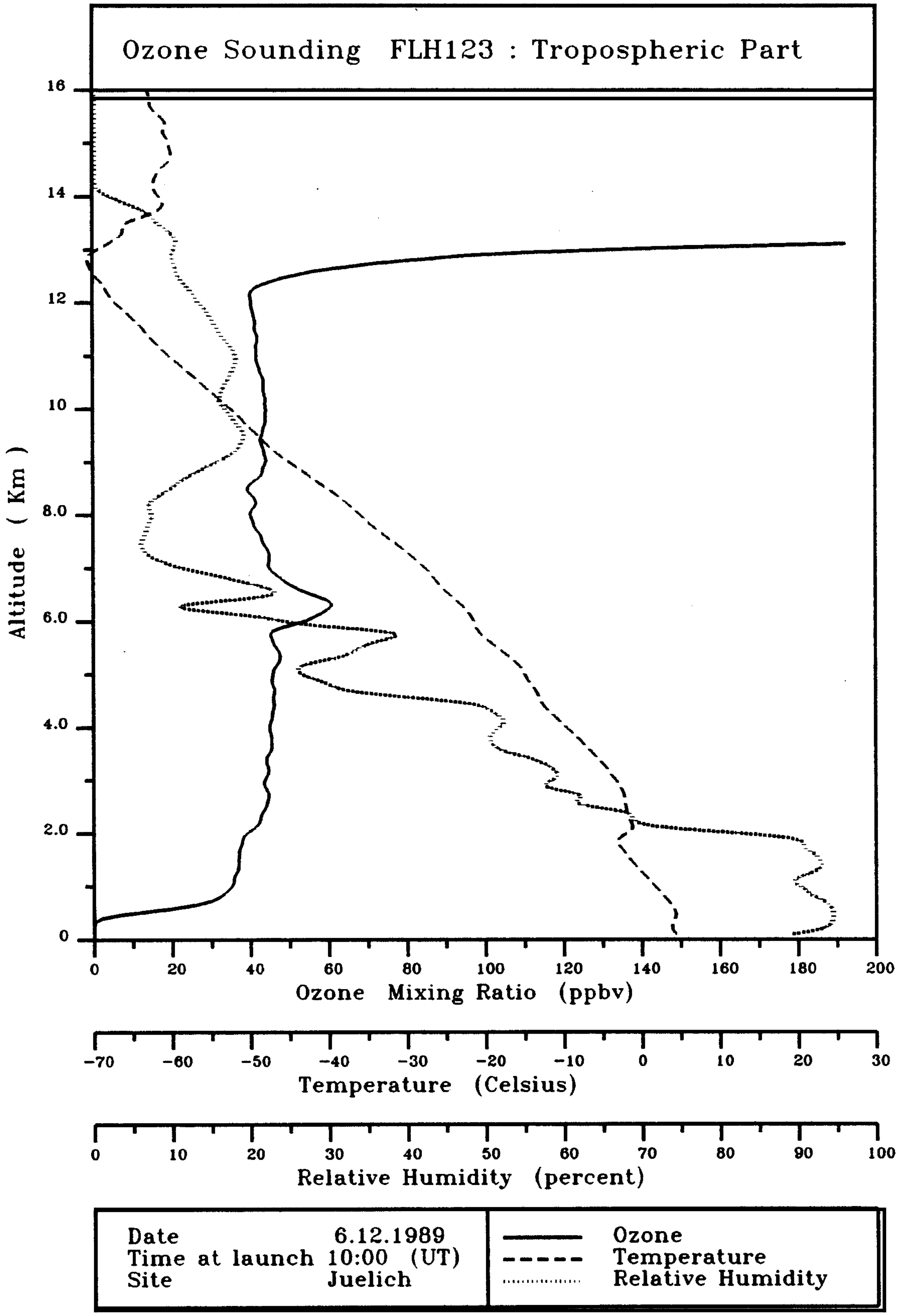


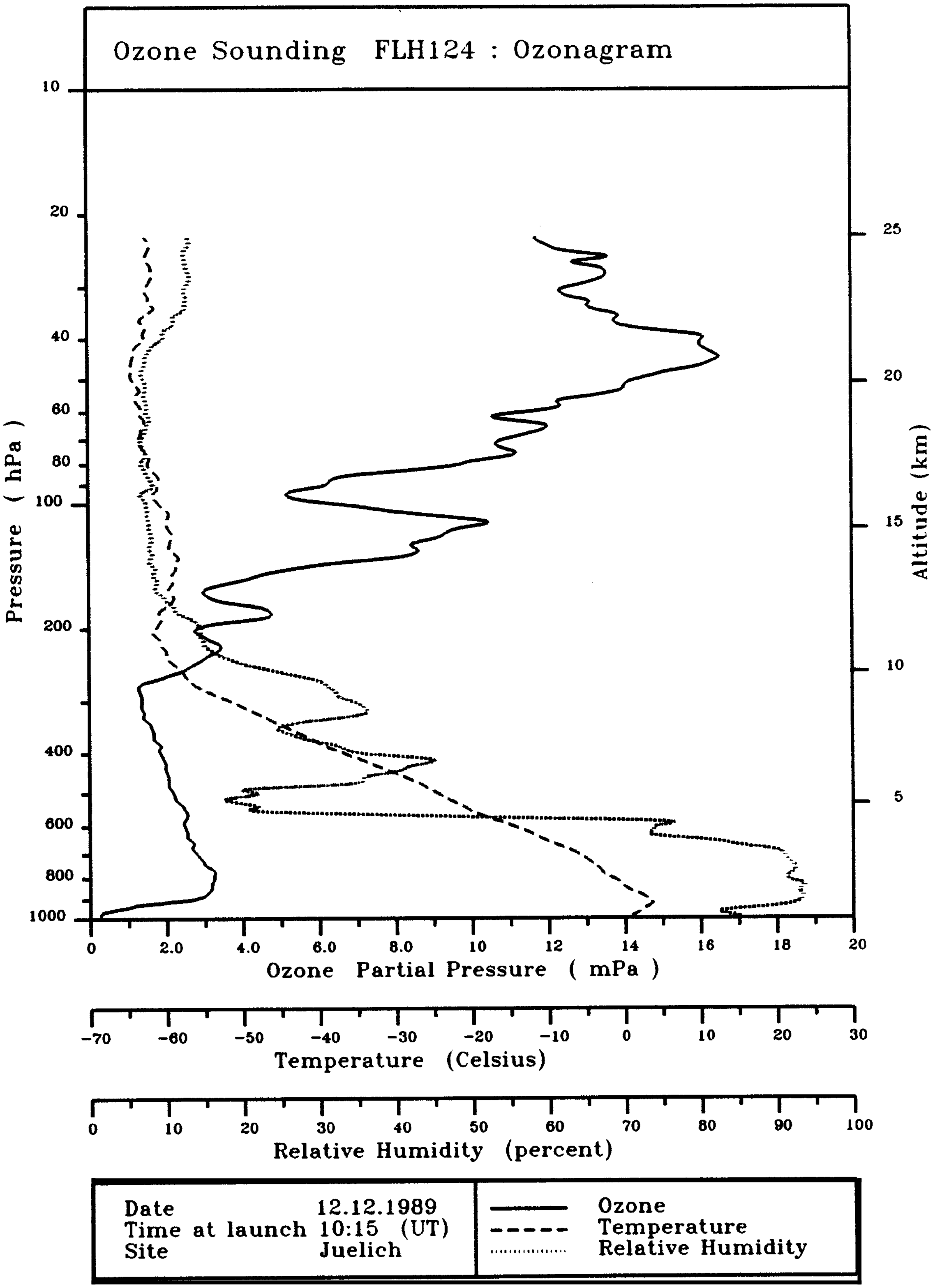
Ozone Sounding FLH122 : Ozonagram
10
20
40
60
80
100
200
400
600
800
1000
Pressure (hPa)
25
20
15
10
5
Altitude (km)
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 29.11.1989
Time at launch 10:05 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

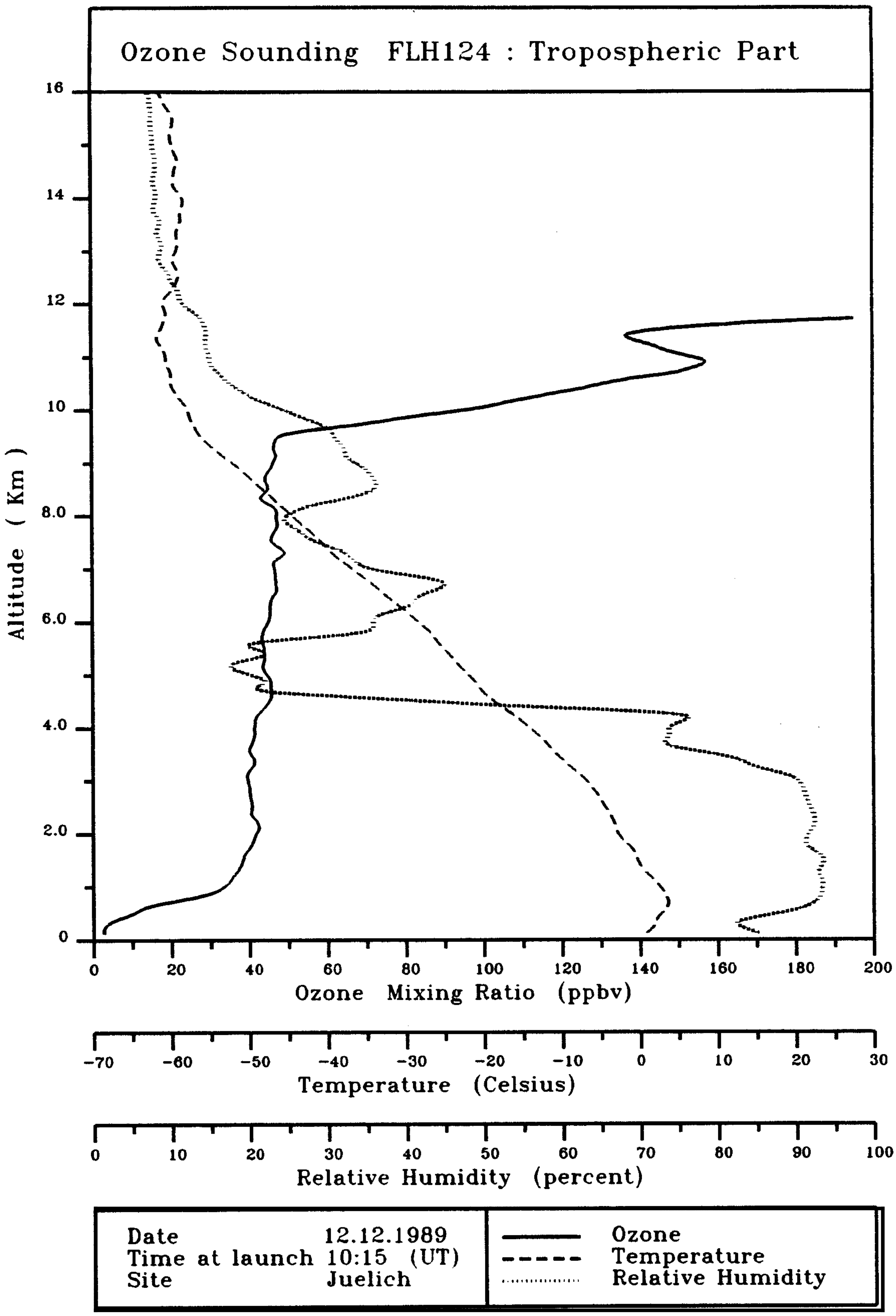


Ozone Sounding FLH122 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 29.11.1989
Time at launch 10:05 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

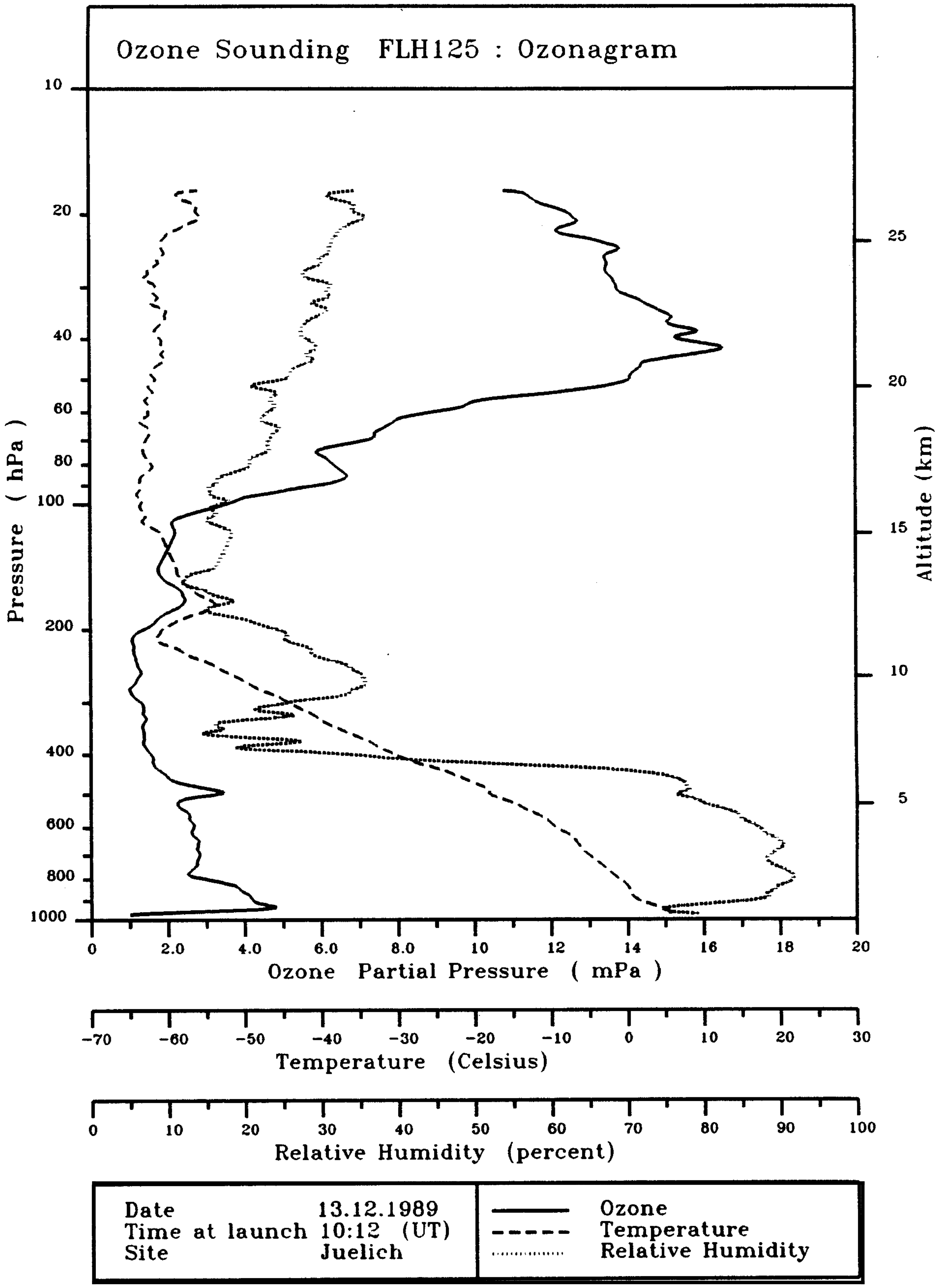

Ozone Sounding FLH123 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
Ozone Partial Pressure (mPa)
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (percent)
Date 6.12.1989
Time at launch 10:00 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity


Ozone Sounding FLH123 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 6.12.1989
Time at launch 10:00 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity

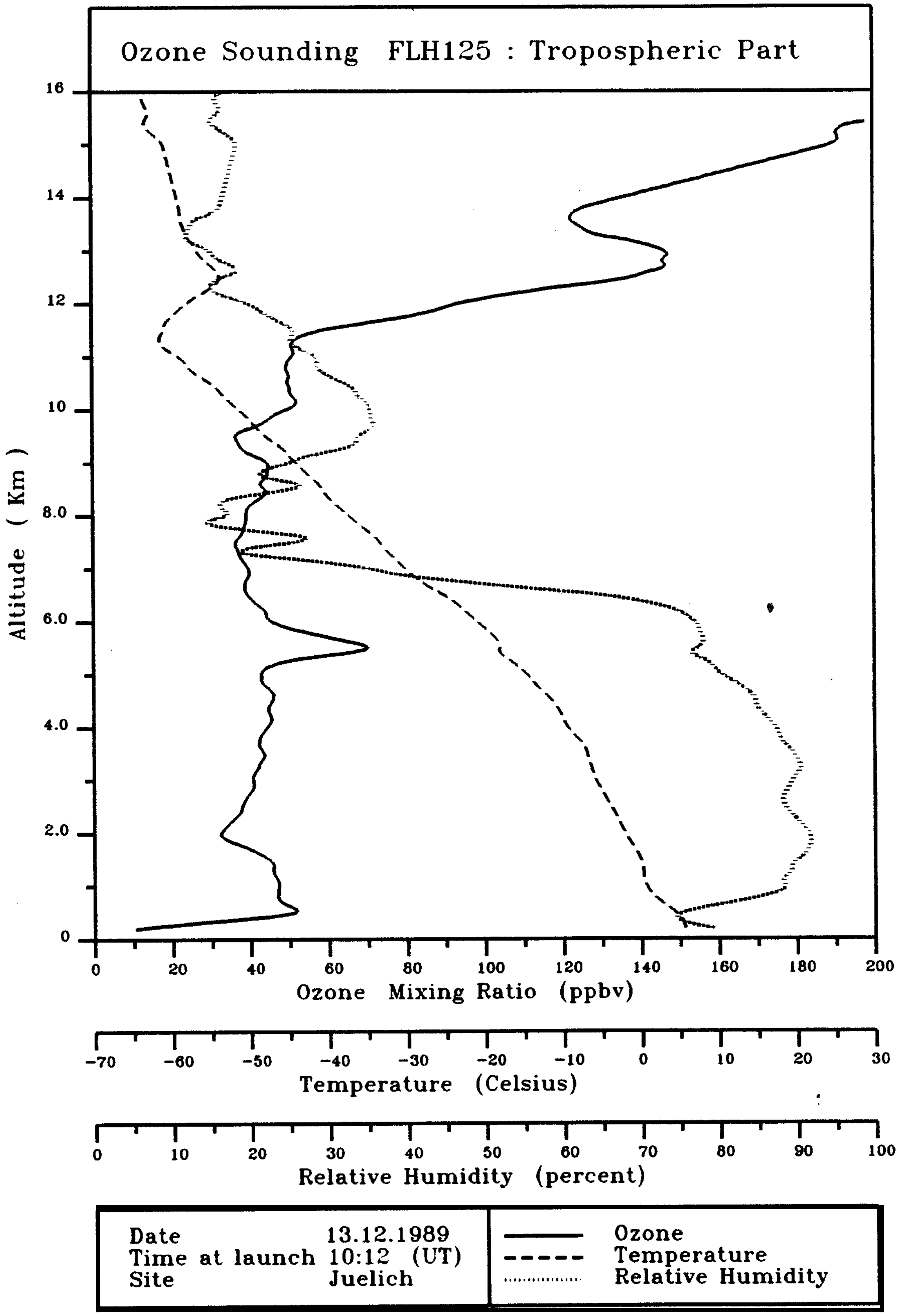

Ozone Sounding FLH124 : Ozonagram
Pressure (hPa)
10
20
40
60
80
100
200
400
600
800
1000
Altitude (km)
25
20
15
10
5
0 2.0 4.0 6.0 8.0 10 12 14 16 18 20
Ozone Partial Pressure (mPa)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 12.12.1989
Time at launch 10:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



Ozone Sounding FLH124 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 12.12.1989
Time at launch 10:15 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity



OT AUTHOR: ICH203 01/10/90 11:49:12



Ozone Sounding FLH125 : Tropospheric Part
Altitude (Km)
16
14
12
10
8.0
6.0
4.0
2.0
0
0 20 40 60 80 100 120 140 160 180 200
Ozone Mixing Ratio (ppbv)
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90 100
Relative Humidity (percent)
Date 13.12.1989
Time at launch 10:12 (UT)
Site Juelich
Ozone
Temperature
Relative Humidity