In-situ measurements of vertical profiles of chemical tracers in the PBL using the airship Zeppelin NT

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ABSTRACT

This paper reports on the measurement of vertical profiles of chemical tracers in the planetary boundary layer (PBL) using the airship Zeppelin NT 07 as a carrier for a full suite of instruments to capture the photochemical state of this lowest part of our atmosphere. During the ZEPTER-2 field campaign in Oct. / Nov. 2008 around Lake Constance in Southern Germany short-lived radical species (OH, HO_2) were measured together with several longer lived trace gas components as well as radiation and meteorological parameters to investigate the self-cleansing capability of the PBL. Some technical details of the airship as well as measurement data will be presented.

1. INTRODUCTION

Chemical and meteorological processes in the planetary boundary layer (PBL, the lowest 1-2 km of the atmosphere) have an important influence on air quality and climate (e.g. [1]). Most emissions of natural and anthropogenic pollutants are released at the earth's surface and are distributed by wind and convection over the PBL. Due to its high loading with pollutants, the PBL is chemically the most active and complex part of the atmosphere. Through air mass exchange the PBL has a major influence on the chemical composition of the free troposphere and the overlying stratosphere, and it has a major impact on the health of men and natural ecosystems through production and deposition of oxidants and particulates.

The investigation of the complex interactions of gases and aerosols requires a large set of instrumentation for the simultaneous measurement of free radicals, trace gases, aerosol size and composition, solar radiation and meteorological parameters. In the past, field studies with such comprehensive equipment were mostly performed at ground or in the free troposphere on large aircraft. Only very few missions including radical measurements were carried out in-flight in the planetary boundary layer. The main reason is the difficulty to find an appropriate carrier for the complete instrumentation needed to quantify the oxidation chemistry of trace gases and the physico-chemical processing of aerosols. Large airplanes capable of carrying the necessary equipment are not permitted to fly for extended time periods at low altitudes in the PBL, at least not over densely populated regions in Europe. Moreover they are generally moving too fast to allow a reasonable resolution of small-scale spatial patterns as encountered in the PBL within the instrumental response times. Helicopters are not suitable for instruments requiring contamination free air-sampling due to the turbulent airflow around the cabin caused by the rotors. Blimps have no internal rigid structure. For that reason they are not well manoeuvrable and suffer from vibrations since the propellers are directly connected to the cabin. As a novel approach, we utilized a large rigid-frame Zeppelin as the ideal platform for chemical and physical observations in the planetary boundary layer.

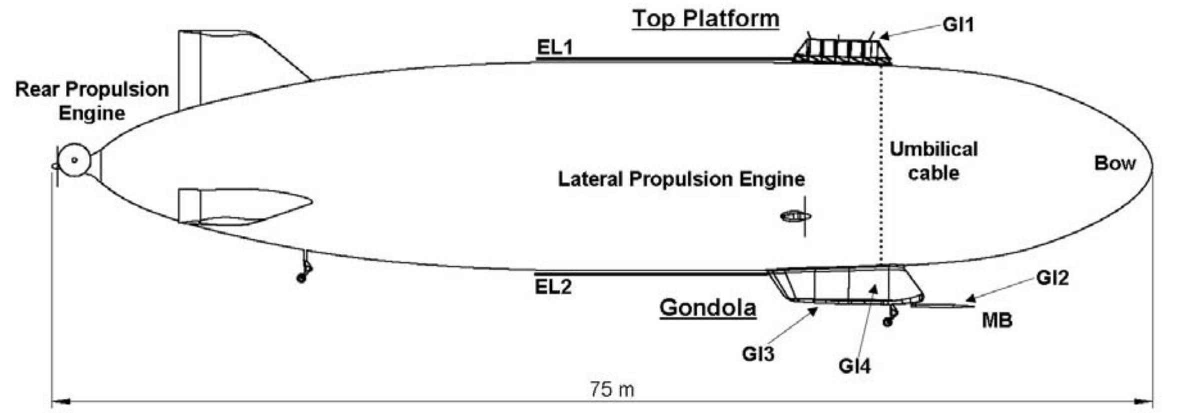

Figure 1. *Schematic drawing of the modified Zeppelin NT-07. Scientific instrumentation can be installed inside the gondola as well as on the top platform. An umbilical cable (gas-,el. power- and data exchange lines) fed through the airship body connects the top platform and the gondola. Gas inlets for measurements can be found at the positions GI1 (top platform), GI2 (meteorological boom, MB), GI3 (gondola bottom) and GI4 (gondola window). Exhaust gases from the measurement equipment are led through exhaust lines to the rear of the airship (EL1, EL2).*

2. THE AIRSHIP ZEPPELIN-NT

The Zeppelin NT-07 is an airship developed and built by ZLT Zeppelin Luftschifftechnik GmbH (ZLT) in Friedrichshafen, Germany. Usually used for touristic flights mainly in Southern Germany the airship recently has been modified in a cooperation between ZLT and Forschungszentrum Jülich (FZJ) to utilize it also as a carrier for complex scientific instruments in order to investigate the chemical and physical state of the lowest part of the atmosphere. The airship is an ideal flight platform for this kind of measurements, since it is designed to continuously fly, hover, or drift in the lowest 2000 m of the atmosphere. Three swivelling propellers and a lateral fan give the airship a high manoeuvrability even at very low flight speed allowing for precise flight patterns to obtain height profiles of chemical trace constituents. The Zeppelin NT can carry a large scientific payload of about 1000 kg. Instruments can be mounted inside the gondola or on a specially designed instrument platform on top of the airships hull.

A schematic drawing of the Zeppelin NT is shown in Figure 1 and important specifications are presented in Table 1. The instrument platform, also called “top platform”, provides space for instruments whose measurements would be influenced by the shadow of the airship body (e.g. measurements of HO_x radical concentrations or solar actinic flux spectra). This platform is supported by the inner Zeppelin structure. It is a lightweight construction with a weight of 150 kg and can carry a payload of 350 kg. The platform is connected to the gondola with an umbilical cable carrying power supply, gas supply, and communication lines. During flight the instruments on the top platform can be accessed from a computer in the airship cabin. Here, also instruments for the measurement of longer-lived chemical species are installed. A meteorological boom extending from the nose of the cabin carried a 5-hole probe for high frequency 3d-wind measurements and relative humidity and temperature sensors.

Table 1. *Specifications of the modified airship Zeppelin Z-NT07 and mission / flight parameters during ZEPTER-2*

Property	**Value**
Length	75 m
Diameter	14 m
Total Height	19 m
Maximal ascend rate	6 m/s
Maximal descend rate	5 m/s
Mission Power	8.4 kW @ 28 VDC
Mission / Flight parameters during ZEPTER-2	
Scientific payload	1000 kg
Max. flight speed	50 km/h
Max. operating height	1000 m (AGL)
Max. horizontal reach	340 km
Max. endurance	6 h

3. THE ZEPTER-2 FIELD CAMPAIGN

The airborne field campaign ZEPTER-2 took place in late Oct. / early Nov. 2008 in Southern Germany in the region of Lake Constance. The measurements were aiming at a quantitative understanding of the distribution of OH and HO_2 radicals based on measurements of their precursors (ozone, nitrous acid, formaldehyde), the corresponding photolysis frequencies, and their main reactants (nitrogen oxides, carbon monoxide, volatile organic compounds) across the PBL in vertical as well as in horizontal direction. The airship was equipped with several in-situ instruments including a laser-induced fluorescence (LIF) instrument for the measurements of free radicals (OH and HO_2, [2]) which was mounted on the top platform. An overview of the measured parameters, the measurement technique and time resolution of the data is provided in Table 2.

A total number of 18 flights all starting from Friedrichshafen, the headquarter of ZLT, resulted in 58 hours of data. A projection of the flight tracks onto a Goggle Earth Map in Figure 2 shows that the majority of the flights were performed either over Lake Constance or over the city of Ravensburg and a nearby forest. A few flights captured the trace gas distribution in a larger area in the hinterland of the lake.

Table 2. *Instrumentation of the Zeppelin NT during ZEPTER-2*

Species / Parameter	**Technique**	**Time resolution**
OH, HO_2 radicals	Laser-induced fluorescence†	90 s
Ozone (O_3)	uv photometry	60 s
Carbon monoxide (CO)	uv fluorescence	1 s
Nitrogen oxides (NO, NO_2)	Chemiluminescence	60 s
NO_2 column	MaxDOAS†	-
Formaldehyde	Hantzsch fluorometry	3 s
Nitrous acid	LOPAP	240 s
Volatile organic compounds	Online GC and canisters	600 s
Aerosol size and number distribution	SMPS, CPC	1 s
j-values	Actinic spectroradiometry†	5s
Water vapour, temperature	Humicap sensor, Pt100	1s
3d-Wind, pressure	5-hole probe	0.1 s
Altitude	GPS	1 s
Positional data	GPS	1 s

† Instrument mounted on the top platform

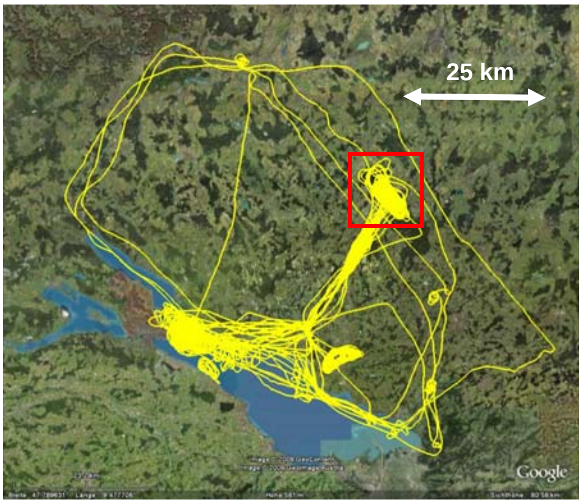

Figure 2. *Projection of the flight tracks of all 18 flights onto Google Earth Map. The red square marks the "Altdorfer Wald" region depicted in Figure 3*

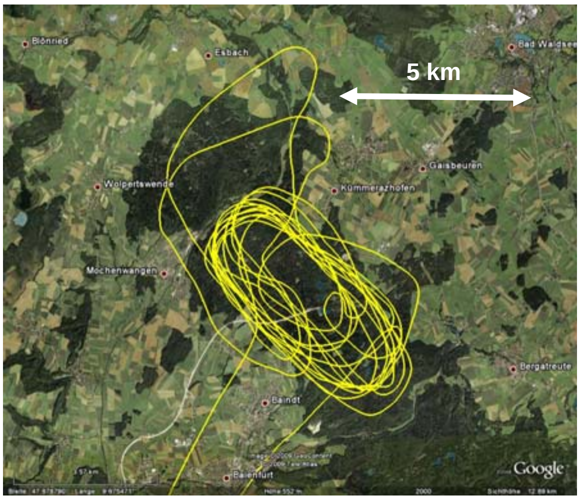

Figure 3. *Projection of the flight track of flight #10 on 26. Oct. onto Google Earth Map. The forest is the "Altdorfer Wald". The town of Ravensburg follows about 5 km SW of the forest.*

To demonstrate the capabilities of the Zeppelin NT as an airborne platform for investigations of the PBL and its transition into the overlying free troposphere data from flight #10 on 26. Oct. which led into a forested area close to Ravensburg are presented. The projection of the flight track onto Google Earth Map is shown in Figure 3. From 13:52 to 15:15 MEZ (local time) the airship cruised over the forested region in elliptical circles thereby descending at a slow rate from about 700 m down to 100 m above ground level. Some of the data obtained during this time period are depicted in Figure 4 which shows vertical profiles of the temperature and the concentrations of different chemical tracers above the forest. This time period was characterized by clear sky conditions and south-westerly winds between 2 and 10 m/s.

The left panel in Figure 4 shows a well developed temperature inversion at an altitude of about 900 m. Descending from the free troposphere into the PBL leads to a temperature drop from 14 °C to 8 °C within a layer 100 m thick. This temperature inversion is reflected by distinct concentration gradients for carbon monoxide (CO) and nitrogen oxides ($NO_x = NO + NO_2$) which are both markers for anthropogenic emission sources. These species exhibit high concentrations of 300 ppb for CO and 8 ppb for NO_x within the PBL which decrease to 100 ppb and less than 1 ppb above the inversion layer, respectively.

The opposite gradient is observed for the radical species HO_2. Due to its fast reaction with NO the concentration is low within the PBL but shows a very sharp

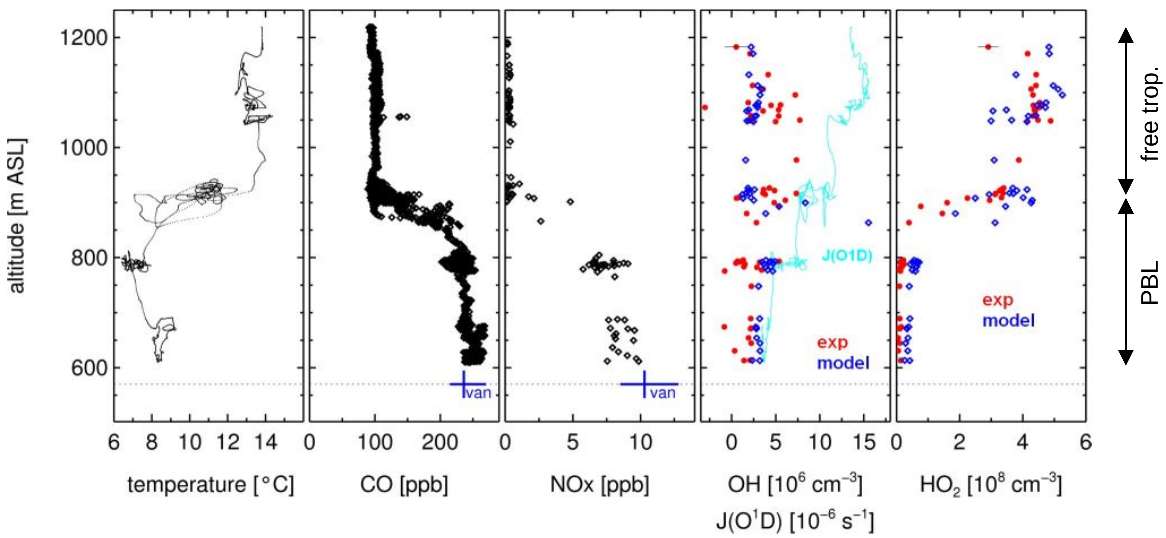

Figure 4. *Vertical profiles of radicals and trace gases measured on 26 Oct from 13:52 – 15:15 (local time) above Altdorfer Wald. Ground level is at 570 m (asl). The blue crosses (CO, NO_x) represent ground-based measurements below the Zeppelin (vertical bar: median values, horizontal bar: total range). All data are preliminary. HCHO was between 0.5 ppb (free trop.) and 1.5 ppb (PBL) and the total OH reactivity between 4 s^{-1} (free trop.) and 10 s^{-1} (PBL). All data are preliminary.*

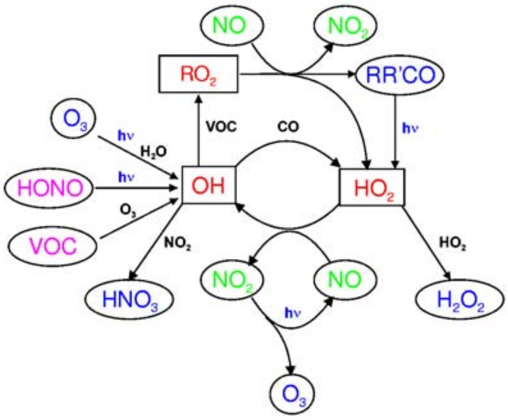

Figure 5. *Simplified scheme of tropospheric photochemistry. HO_x concentrations were modeled using the RACM2 ([3]) with modified isoprene mechanism ([4]). Measured trace gases and photolysis frequencies were used as model input.*

increase towards the free troposphere where NO concentrations are much smaller. The very short-lived OH radical shows a different behaviour. Its concentration is nearly independent of height which can be understood in terms of simultaneous changes of its sources and sinks when crossing the inversion layer from the clean free troposphere into the polluted PBL.

These more qualitative arguments to explain the observed radical measurements are supported by a zero-dimensional box-model calculation which takes into account most of the available measurements listed in Table 2. A simplified scheme of tropospheric chemistry is displayed in Figure 5. The model results obtained are included in Figure 4. While the model overpredicts the measured radical concentrations of OH and HO_2 within the PBL it nicely reproduces the observed effect on the concentrations of both radicals when entering the free troposphere.

4. SUMMARY

The airship Zeppelin NT has proven to be a unique platform to investigate the chemical and physical state of the PBL and its transition into the free troposphere using numerous in-situ instruments. Its ability to carry even large loads on a platform mounted on top of the airship providing an unobscured view into the sky makes it a valuable carrier for instruments probing fast photochemical processes in the PBL.

During the ZEPTER-2 field campaign in autumn 2008 in Southern Germany several vertical concentration profiles of short-lived HO_x radicals together with their longer lived precursor and reactant species were measured with an unparalleled vertical resolution. The transition from the PBL into the free troposphere was clearly identified in terms of strong gradients in temperature and chemical composition.

ACKNOWLEDGEMENTS

Financial support by BMBF (contract no. 01LG0602 and 01LP0803A) is gratefully acknowledged. The authors thank R. Wegener, R. Tillmann, and R. Häseler for providing measured data of VOCs, HCHO, and HONO, respectively, D. Klemp and S. Janson for groundbased CO and NOx data, the crew of ZLT Zeppelin Luftschifftechnik GmbH and Deutsche Zeppelin-Reederei GmbH for their helpful cooperation and logistical support of the field campaign, the Rhenish Institute for Environmental Research (Univ. Cologne) for chemical weather forecasts (EURAD) during the campaign and Univ. Wuppertal and Heidelberg for help and cooperation.

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