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A Practical Guide to Atmospheric Simulation Chambers

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This book is dedicated to Dr. Ian Barnes and to Prof. Astrid Kiendler-Scharr

Preface

The ability to predict the evolution of the atmosphere over a wide range of time scales (hours to decades) brings great benefits to society. Examples include short-term public warnings of hazardous air quality and the long-term evaluation of climate warming and policy effectiveness. Atmospheric predictions use complex models that are underpinned by observations and a sound understanding of the underlying processes, which include the interactions between atmospheric components and their environment. Atmospheric simulation chambers are among the most advanced tools for studying and quantifying atmospheric processes and are used to provide many of the parameters incorporated in air quality and climate models. Without chamber-derived parameters to constrain predictive models, any physico-chemical forecasts of the atmosphere are highly unreliable, both in the short- and long-term.

The largest uncertainties in our current knowledge of atmospheric processes and their impact on air quality and climate change are associated with complex feedback mechanisms in the Earth System. Understanding and quantifying those mechanisms that are just becoming measurable are only possible through a synergistic approach that combines atmospheric observations, detailed simulation experiments and modelling. This methodology is the most efficient means of obtaining a quantitative understanding of physico-chemical transformations in the atmosphere and chamber studies are a key component of that approach.

The level of scientific understanding of climate drivers, the health impacts of complex mixtures of air pollutants, and the interaction between the two is still evolving. Simulation chambers were originally created to study the impact of atmospheric processes on regional photochemistry. This approach has since been extended to understand particles formation, cloud microphysics and global warming. More recently, atmospheric simulation chambers have been applied to a wider range of research areas such as human health and cultural heritage. In all cases, a key objective is to work under conditions that are as realistic as possible.

In the real atmosphere, it is difficult to separate chemistry from meteorology, emissions, transport and other variables. Since the late 1960s, closed systems have been developed to provide a controlled atmosphere to study the formation and the evolution of air pollutants by isolating specific compounds of interest and controlling the oxidizing environment.

Initially, chamber experiments were mainly focused on understanding the chemical processes governing the formation of photochemical smog. These “smog chamber” experiments enabled investigations into the formation of secondary pollutants such as ozone and oxygenated reactive nitrate species, as well as the associated atmospheric oxidation mechanisms. This approach has been extremely useful in producing gas-phase kinetic data, branching ratios and product distributions of chemical reactions. Together with data arising from flow tubes and flash photolysis experiments, this knowledge allowed the scientific community to develop numerical chemical models that are used to predict the chemical evolution of the atmosphere. Nowadays, chambers are also essential tools for evaluating these chemistry modules and for predicting the formation of secondary pollutants in the absence of uncertainties associated with emissions, meteorology and mixing effects.

Over the past few decades, simulation chamber studies have been extended to include processes related to the formation, chemical aging and physico-chemical properties of secondary organic aerosol (SOA). This research has compelled the atmospheric science community to pay even more attention to the design of simulation chambers, e.g. their size or wall material, and the experiments carried out in them. Nevertheless, the general aim of chamber experiments remains focused on the simulation of processes occurring in ambient air and under controlled conditions.

Our understanding of atmospheric chemical and physical processes has evolved considerably over the last two decades, but new challenges are expected to arise from responses of the Earth System to changes in the climate due to anthropogenic activities.

To respond to such challenges, the atmospheric simulation chamber community in Europe has organized itself within the EUROCHAMP consortium. Three consecutive EU funded projects—EUROCHAMP, EUROCHAMP-2 and EUROCHAMP-2020—spanning the period 2004–2021, have enabled most of the European research groups involved in experimental atmospheric simulations to adapt their research platforms to the emerging research needs. A wide range of topics have been addressed including unexpected gas-phase chemistry, understanding oxidative capacity, secondary organic aerosol formation and growth, along with studies of the cryosphere, air-sea exchange and real-world emissions. The integrated suite of state-of-the-art simulation chambers within the EUROCHAMP consortium provides unprecedented opportunities for atmospheric scientists to perform experiments that address the most important questions in air quality and climate research.

Innovative methodological research carried out in the EUROCHAMP projects, as well as best practices and standard protocols are reported in the present volume. With the production of the first-ever “Practical Guide to Atmospheric Simulation Chambers”, we are not only aiming at producing a key tool for knowledge transfer within the EUROCHAMP community, but also provide the global atmospheric science community with a unique resource that outlines best practice in the operation of simulation chambers and in related data exploitation.

Moreover, at a time when the provision of open data has become the standard approach in scientific publishing and reporting, EUROCHAMP provides a sustainable Data Center that includes results from thousands of simulation chamber experiments, as well as a range of advanced data products. As Europe looks to efficiently re-organize its atmospheric research infrastructures, many EUROCHAMP facilities and consortium members will become part of the Aerosols, Clouds and Trace Gases Research Infrastructure (ACTRIS). The Data Center will continue to grow and be available for access within the framework of the ACTRIS Research Infrastructure.

This guide is based on the work carried out in the EUROCHAMP community. Its scope, though, is much larger, as it aims to provide a broader scientific audience with the knowledge needed to analyze, reuse, review or combine simulation chamber data.

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