

Twenty years of experiments with the "M-55 Geophysica" on aerosols and clouds in the UTLS: results, discussions, controversies

By

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In 1993 a Russian high altitude reconnaissance aircraft of type "M-55" was displayed for the first time to the West on an airport in Italy near Rome. In the following years the aircraft was converted into the M-55 "Geophysica" high altitude research aircraft, and the development of scientific instrumentation began. The M-55 reaches maximum altitudes around 20 km with a payload of up to 1.5 tons. Since it is a single seated aircraft, all scientific instrumentation on board needs to be fully automated, capable of operating autonomously while enduring extreme environmental conditions like temperature changes from + 50 °C to -90 °C in 20 minutes; significant challenges for any developer. The first instrumented "Geophysica" flight was conducted out of Pratica di Mare (Rome) on November 13, 1996; the last research flight so far took place on August 10, 2017, from Kathmandu, Nepal. In between 17 field campaigns comprising nearly 140 flights were performed with different scientific goals and increasingly complex instrument payloads.

Polar Stratospheric Clouds (PSCs) and aerosols, arctic ozone loss, and the polar vortex were at the center of four field missions from Rovaniemi, Finland (1996/1997), and Kiruna, Sweden (2003, 2010, 2011). Other campaigns were designed for in-situ and near range remote sensing observations of tropical cirrus, subvisual cirrus, and the tropical pipe in the area of the Seychelles (1999). Or field missions were performed to probe deep convective cloud anvils and outflows in Brazil (2005) and Northern Australia (2005), as well as for Mesoscale Convective Systems in West Africa (2006). The recent two StratoClim field campaigns in 2016 and 2017 were dedicated to sampling the upper troposphere and lower stratosphere in the Asian Monsoon Anticyclone (AMA), and the Tropical Transition Layer (TTL) above the Himalayans, India, and Bangladesh. Almost all of these projects had in common that both, Thomas Peter and Stephan Borrmann, were deeply involved, albeit on the "different sides" of theory and experiment.

In the presentation several of the scientific issues, questions (some of which are still open), and controversies encountered in the course of time are revisited. Then the most recent results from the in-situ measurements of aerosol abundance and chemical composition in the tropical TTL of the AMA are discussed in more detail.

In hindsight, this European – Russian scientific and technological cooperation around the M-55 "Geophysica" can be considered as a prime example for an outcome of the "peace dividend" from the early Nineties. Also, clearly, in the past 21 years the "Geophysica" flights and the engaged scientists contributed a veritable piece to the history of atmospheric science in Europe and beyond.

Stephan Fueglistaler, Princeton University, USA

TITLE: "A mechanistic understanding of the temperature response to CO₂ radiative forcing"

ABSTRACT:

Radiative forcing at the top of the atmosphere (TOA) from changes in atmospheric CO₂ is only partially balanced by radiative forcing at the bottom of the atmosphere. About 2/3 of the TOA forcing remain as change in the atmosphere's radiative budget. Consequently, the atmospheric circulation must adjust in such a way that changes in sensible and latent heat fluxes from the ground to the atmosphere balance the perturbation in the atmosphere's radiative budget. We use a General Circulation Model in an idealized aquaplanet setup to study the mechanism that allows the atmosphere to transform the atmospheric radiative forcing to a forcing of the surface by sensible and latent heat fluxes. The GCM calculations show an ultra-fast response (time scale: days) in the atmospheric circulation in parallel with the atmospheric temperature response directly connected to the local radiative cooling rate change. While the temperature change in the near surface layers accounts for a negative Planck feedback (which increases the fraction of radiative surface forcing somewhat) and change in sensible heat flux (which is proportional to the ground-air temperature difference), about half of the forcing results from the circulation change inducing a change in atmospheric condensing water flux. This in turn leads to an adjustment in boundary layer specific humidity until the balance between evaporation and precipitation is restored.

Environmental ice crystals: to freeze, or not to freeze

Thomas Koop, Bielefeld University

The formation of ice crystals is a widespread environmental process with beneficial effects such as initiating atmospheric precipitation as well as adverse consequences such as biological frost damage. Nature has developed means to either promote or inhibit ice crystal formation, for example ice-nucleating proteins in bacteria or ice-binding antifreeze proteins in polar fish. This presentation will focus on different mechanisms that influence the kinetics of ice crystal formation and growth. Such processes include homogeneous and heterogeneous ice nucleation, with implications for atmospheric ice cloud formation, as well as ice growth inhibition through diffusion limitations or via adsorption of antifreeze molecules to ice crystal surfaces, with implications for cryobiology.

Analyzing Mid-Latitude and Arctic Cirrus Clouds by means of the large scale Lagrangian model CLaMS-Ice

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CLaMS-Ice is a newly developed large-scale Lagrangian cirrus forecast and analysis tool. The CLaMS-Ice model consists of a detailed microphysical cirrus cloud box model (Spichtinger and Gierens, 2009) which can be operated along atmospheric trajectories of the global Lagrangian model CLaMS (Chemical LAGrangian Model of the Stratosphere). The two-moment bulk microphysics scheme includes the main mechanisms of cirrus forming directly from the gas phase (in-situ origin cirrus, Krämer et al., 2016): heterogeneous ice nucleation on ice nucleating particles, and homogeneous nucleation of liquid solution particles of sulphuric acid. Further, depositional growth and sublimation as well as sedimentation of ice crystals are treated in the model. In addition to in-situ origin cirrus clouds, CLaMS-Ice also represents cirrus originating from uplifted frozen liquid drops (liquid origin cirrus, Krämer et al., 2016) by transferring liquid and ice water content from ECMWF meteorological fields into the cirrus temperature regime (< 238 K) by assuming that all liquid water freezes as soon as a trajectory crosses the temperature threshold of 238 K.

Based on CLaMS-Ice simulations, it is possible to track the origin of cirrus clouds, their formation mechanisms together with the frequency of occurrence of the respective cloud types. Thus, from CLaMS-Ice simulations, new insights on cirrus clouds microphysical and thus radiative properties are expected. As a first, important step, CLaMS-Ice is evaluated based on in-situ observations from the HALO campaign ML-CIRRUS 2014 in mid-latitude spring (Rolf et al., 2016).

Here, we apply CLaMS-Ice to mid-latitude in comparison to Arctic regions. We analyze in-situ and liquid origin cirrus: overall, in-situ cirrus are more frequent than liquid origin cirrus. Nevertheless, liquid origin cirrus occur more often at mid-latitudes than in the Arctic, which we attribute to the generally slower updraft velocities in this region. In line with this, in the Arctic thin cirrus are more common.

Analysis of the freezing mechanisms of in-situ and liquid origin cirrus yields that the formation mechanism of in-situ cirrus is divided into two regions for the complete temperature range: heterogeneous freezing prevails in lower updrafts where thin cirrus are formed, while homogeneous freezing as second freezing event occurs most frequently in higher updrafts that form thick cirrus. Differently, in liquid origin cirrus heterogeneous and homogeneous ice nucleation occurs in different temperature ranges: heterogeneous freezing prevails at higher cirrus temperatures, while at colder temperatures additional homogeneous freezing occurs more often on top of the heterogeneous freezing, especially in the Arctic. In summary, neither heterogeneous nor homogeneous freezing is dominating the formation of the total ensemble of cirrus clouds.

References

- Krämer et al. (2016): A microphysics guide to cirrus clouds – Part 1: Cirrus types, *Atmos. Chem. Phys.*, **16**, 3463–3483, doi:10.5194/acp-16-3463-2016.
- Rolf et al. (2016): Reconciliation of in-situ observations and large-scale simulations of mid-latitude cirrus clouds, *17th ICCP Conference*, Manchester, July 25–29.
- Spichtinger and Gierens (2009): Modelling of cirrus clouds - Part 1a: Model description and validation, *Atmospheric Chemistry and Physics*, **9**, 685–706, 2009.

Rolf Müller, Forschungszentrum Jülich, D: "Ozone loss caused by heterogeneous chlorine activation: from the poles to mid-latitudes"

Polar ozone destruction is driven by elevated levels of ozone destroying ("active") chlorine in spring. These elevated levels of active chlorine are formed at low temperatures on the surfaces of cold binary sulphate aerosol and polar stratospheric clouds. A similar type of chemistry has recently been suggested to occur also in the mid-latitude lowermost stratosphere over continents. Regarding ozone loss in Antarctica (the ozone hole), it is a matter of debate, how the maintenance of active chlorine is brought about in spring, when the rate of formation of HCl (considered to be the main chlorine deactivation mechanism in Antarctica) is extremely high. It will be discussed, how in the heart of the ozone hole (16–18 km or 100–70 hPa, in the core of the vortex), high levels of active chlorine are maintained by effective chemical cycles (referred to as HCl null-cycles). In these cycles, the formation of HCl is balanced by immediate reactivation, i.e. by immediate reformation of active chlorine. Under these conditions, polar stratospheric clouds sequester HNO₃ and thereby cause NO₂ concentrations to be low. These HCl null-cycles allow active chlorine levels to be maintained in the Antarctic lower stratosphere and thus rapid ozone destruction to occur. These arguments imply that, in the lower stratosphere, future increased methane concentrations will not lead to enhanced chlorine deactivation (through the reaction $\text{CH}_4 + \text{Cl} \rightarrow \text{HCl} + \text{CH}_3$) and that extreme ozone destruction to levels below ≈ 0.1 ppm will occur until mid-century. Regarding mid-latitude ozone loss in the lowermost stratosphere, a major question is the sensitivity of the proposed mechanism on enhanced water vapour (caused by continental deep convection), on the chlorine levels prevailing in the lowermost stratosphere and on the stratospheric aerosol loading (which varies with volcanic eruptions and, possibly, with climate engineering measures). These sensitivities will be explored in model simulations.

Role of aerosols in climate change and air quality in developing countries: India as a case study

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Aerosols are also known as particulate matter (PM). They play key roles in global climate forcing, because of their interaction with incoming light, and human health since they are air pollutants. It is generally accepted that the overall effect of aerosols is to offset the warming effect of greenhouse gases. Different countries and regions of the world have had different rates of emissions of greenhouse gases and precursors for aerosols/PM; thus, they have contributed differently to the global climate warming and air pollution in their own countries and regions. I will examine the time history of the net contributions of regions and countries to climate warming and of PM to air pollution, describe current levels of pollution over India (a major rapidly developing economy), and the tradeoffs between global warming and immediate human health. The information for this talk will be simple energy balance calculations, GEOS-Chem modeling of aerosols over India, and some preliminary measurements of PM_{2.5} in an Indian city.

Aldona Wiacek, Saint Mary's University, CAN: "Marine sector emissions, air quality and climate"

This talk will review trends in world shipping emissions, their regulation, and their effects on atmospheric chemistry, air quality and climate. Recent results from the literature will be highlighted before discussing the shipping context at the intermediate port of Halifax, Canada. Results from an open-path Fourier transform infrared (OP-FTIR) spectrometer measurement campaign will be presented, which characterized trace gas concentrations in the vicinity of marine vessels, in some cases with direct or near-direct marine combustion plume intercepts. This is the first application of the OP-FTIR technique to measurements of shipping emissions and we report on a number of non-criteria air contaminant gases, i.e., NH_3 , CH_3OH , HCHO , CH_4 , and N_2O . During periods of low wind speed we observed extended (~9 hr) emissions accumulations combined with near-complete O_3 titration, both in winter and in summer. Our results compare well with a government monitoring station ~1 km away, pointing to the extended spatial scale of this effect, commonly found in much larger European shipping channels. We also calculated total marine sector emissions in Halifax Harbour based on a one-year dataset of ship activity and will present a breakdown of results by ship type and season. Shipping emissions were found to be greater than or comparable to all vehicle NO_x emissions in the city, highlighting the need to accurately represent such emissions at intermediate ports integrated into urban environments

Symposium at ETH Zurich, Feb. 2, 2018: "Aerosols and Greenhouse Gases in a Changing World"

Presentation by Andreas Zuend

Title:

Modelling Organic-Inorganic Aerosol Thermodynamics – From Phase Separation to Cloud Droplet Activation

Abstract:

Aerosol particles are a ubiquitous component of ambient air with important impacts on air quality, visibility, atmospheric chemistry and the climate system on local, regional and global scales. Aerosol particles in the troposphere present great complexity and variability in size range, shape, chemical composition, scattering and absorption of light, water content, acidity, phases and their physical states. These properties evolve subject to chemical reactions and due to the partitioning of individual components between the gas phase and liquid or solid particle phases, all of which are driven by a progression towards thermodynamic equilibrium under present environmental conditions. Adequate consideration of these properties and their interplay in process-level and large-scale models presents a genuine challenge. One branch of development of aerosol models therefore aims at providing predictive tools for phase equilibria and related gas-particle, liquid-liquid and liquid-solid partitioning of organic and inorganic components. The presence of two or more liquid or solid phases in aerosol particles leads to internal structures that may impact the overall morphology as well as properties such as the surface tension of the air-particle interface. In combination with particle size, such morphology effects may influence substantially the ability of ultrafine particles to act as cloud condensation nuclei (CCN) under typical water vapor supersaturation in the early stages of cloud formation. In this presentation, I will introduce the origin of mixed organic-inorganic aerosol particles and discuss our recent advances in the development of predictive models for liquid-liquid phase equilibria and gas-particle partitioning. Furthermore, we will explore the distinct roles of organic matter, inorganic ions and liquid-liquid phase separation in ambient particles of various sizes, discuss potential consequences for the formation of cloud droplets and emerging questions in this field of atmospheric science.