WP2: Aerosol, water vapour, and ozone feedbacks in the Arctic climate system (Roland Neuber, Markus Rex)

We map and interpret feedbacks in key components of the Arctic atmosphere from the boundary layer to the stratosphere.

Objectives and challenges

The improvement of recently published climate models (see ANNEX) depends on the availability of high quality atmospheric measurements. For this purpose, high-resolution observations over long periods and over long distances are required. Regular long-term observations at selected stations and satellite data provide a general picture of the temporal atmospheric development, while detailed spatial measurements can be obtained by regular airborne measurements as demonstrated during the MARCOPOLI programme.

Atmospheric measurements of surface energy balance, heat and moisture fluxes, cloud and aerosol properties, aerological and water vapour and ozone profiles are essential for the understanding of key processes in the Arctic climate system (see research highlights in ANNEX). The interpretation of measurements with regional atmospheric and coupled regional climate models will expand and deepen our knowledge of Arctic change, and allow a system-approach to project changes into the future and to study options for response to changes.

Major gaps and uncertainties exist in our knowledge of processes governing the build-up of air pollution and aerosols in the Arctic and its role for climate change. Various anthropogenic and natural sources contribute, including new ones like increased tundra fires. Atmospheric aerosol and clouds have a mutual influence on each other. Aerosol particles modify many climatically important cloud properties, including the cloud reflectivity and lifetime. Aerosol optical properties enter radiation transfer calculations, and the aerosol - cloud interactions are important for the parameterization of cloud formation processes.

Strong ozone losses have been found in some of the Arctic winters. New results of detailed in-situ measurements of ozone loss rates and key chemical species indicate that the major fraction of the observed polar ozone loss is due to a currently unknown chemical process. Anthropogenic chemical loss of ozone and natural dynamically driven variability contribute each about half to the overall variability of total ozone in the Arctic in spring. To allow reliable predictions of ozone abundances over the Arctic for the next half-century, we need solid understanding of both factors and how they may change in a scenario of increasing greenhouse gas levels and decreasing halogen loading of the stratosphere. Observational results show that changes in the temperature conditions in the Arctic polar stratosphere have been a major driver of large Arctic ozone losses during the past decade. A strong cooling of the "cold" Arctic winters led to a steep increase in the geographical extent of conditions that allow polar ozone loss. The maximum values of this extent reached during the past decade are more than four times larger than values reached in the late 1960ies and early 1970ies. This change in temperature is qualitatively consistent with the direct irradiative effect of increasing greenhouse gases, including water vapour, but the magnitude of the trend is much larger.

The main challenges of this WP are…

- Understanding spatial and temporal patterns of Arctic changes in the coupled climate system and to development appropriate adaptation measures, improved Arctic observations, interpretation tools and more accurate predictions of the consequent changes of climate.
- Identification of key feedback processes concerning the coupling between the planetary boundary layer and the baroclinic cyclones over the Arctic sea ice cover and the cloud - water vapour - aerosol feedbacks.
- Quantification of the optical properties of aerosols and the aerosol - cloud interactions, as well as water vapour as a key parameter for cloud formation processes.
- Investigation of the reasons behind the Arctic stratospheric ozone layer variability as a function of ozone transport from the tropical source region to the Arctic and as result from changes in ozone chemistry.

Implementation

Aerosols, water vapour, and ozone measurements will be performed on three main platforms provided by TOPICS 5 and 6. Firstly, comprehensive ground-based measurements at the AWIPEV Arctic Research base on Spitsbergen form the back bone and allow determining a complete data set for the atmospheric column from the ground (including air – soil interactions) to the stratosphere. Secondly, regular aircraft measurements will connect the Spitsbergen data with other measurement sites on and around the Arctic Ocean, including drifting ice stations, which are established during and after IPY. Thirdly, satellite data will extend the local measurements on the temporal and spatial scale to cover the whole Arctic. Based on the synthesis and assimilation of this large amount of available data, we will provide comprehensive spatial and temporal aerosol and cloud fields. The obtained aerosol and cloud fields will be used in regional Arctic climate models for validation and to quantify their climatic impact that will be linked to model development in TOPIC 4. New, state-of-the-art measurement techniques for water vapour content will be applied to measure the atmospheric water content from ground based, balloon and air borne platforms. This includes tethered as well as free flying balloons and instrumentation onboard AWI's Polar 5 aircraft. Variations in water vapour profiles will be analysed and interpreted in relation to dynamical processes as well as aerosol and cloud formation processes. Detailed ozone data are collected from balloon and space borne platforms. By means of trajectory calculations and chemistry box models we will shed light on the seasonal and inter annual variation of the Arctic stratospheric ozone budget. The influence of such ozone variations on the Arctic climate will be investigated. We will carry out detailed model studies and field measurements to assess the problem of the differences in observations and model predictions of ozone loss and to identify the missing chemical processes.

Milestones

- Availability of collected, quality checked, and reliably stored data sets from the IPY period and beyond, particularly for aerosol, water vapour and ozone data (end of year 2).
- Investigation whether the continuous change in the temperature conditions in the Arctic winter over the past forty years is due to an unknown dynamical feedback mechanism or to long term internal variability of the climate system (until end of year 2).
- Characterization the dynamically induced variability of total ozone and stratospheric water vapour in the Arctic, which links to atmospheric circulation modes and external forcing factors (year 3).
- Completion of the analysis and interpretation of aerosol and water vapour data from IPY (year 3).
- Development of new measurement techniques of aerosol properties for ground based, air borne and balloon borne platforms (ready in year 4).

Deliverables

- A spatially and seasonally resolved aerosol data set for the Arctic, suitable for implementation into climate models
- Assessment of warming / cooling rates due to observed high aerosol load episodes in the Arctic
- Water vapour climatology for the Arctic from ground to the lower stratosphere
- Assessment of dynamical influences on water vapour and ozone profiles in troposphere and stratosphere
- Assessment of contributing factors to the observed ozone variability
- Determination of the importance of new chemical schemes and reaction constants for the ozone budget
- State of the art instruments for water vapour and aerosol measurements on air craft and balloon platforms, as well as for fixed and drifting ground stations