Atmos. Chem. Phys., 15, 5377–5379, 2015
www.atmos-chem-phys.net/15/5377/2015/
doi:10.5194/acp-15-5377-2015

Atmospheric Chemistry and Physics
Open Access

General introduction to the DAMOCLES special issue

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DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies) aimed at reducing the uncertainties in our understanding, modeling and forecasting of climate changes in the Arctic. Over the last 2–3 decades the Arctic has warmed more than other regions of the world and the Arctic sea-ice cover has decreased significantly in the same period. DAMOCLES was especially concerned with a significantly reduced sea-ice cover and the impact this drastic sea-ice retreat might have on the environment and on human activities both regionally and globally.

A first-order scientific and societal question is whether the Arctic perennial sea-ice will disappear in a few decades (or even faster as predicted by some state-of-the-art models). The changing Arctic climate has and will continue to have a wide range of impacts on human activities such as fisheries, shipping, as well as offshore oil and gas development at local, regional, national and international levels. DAMOCLES aimed at analyzing the adaptation to and vulnerability of human activities in the context of physical changes such as a sea-ice extent and concentration decrease, an ice free ocean and elevated air temperature. Through its regional, multidisciplinary approach, DAMOCLES intended to provide a broad perspective for decision-makers and stakeholders in considering future policies for adaptation. Adaptation and mitigation requires specific information, preferably early information. The coordinated analysis of observations and model simulations achieved during DAMOCLES, aims at facilitating the design of a future cost-effective and sustainable Arctic observing and forecasting system. The Arctic is a harsh environment and the sea-ice cover prohibits the use of many conventional instruments, data transfer methods and calibration schemes. DAMOCLES developed new technology to get observations of key variables in the atmosphere, sea-ice and in the ocean.

DAMOCLES brought together experts on polar research and a broad range of environmental modelers through an integrated research effort. The effort complemented other major research programs on climate variability and predictability. At a time when the International Polar Year focused on the science of the polar regions and on the human dimension of climate change, DAMOCLES provided a contribution reflecting both the skills of European scientists and the importance of European interests for the Arctic.

The EU DAMOCLES project lasted for 54 months from 1 December 2005 until 30 May 2010. It involved 51 partners including 8 small and medium enterprises spread over 10 European countries and coordinated with the United States, the Russian Federation, Canada and Japan. During the course of the project 152 peer-reviewed scientific papers were published, 302 deliverables were submitted to the EU Commission, 52 workshops and 8 summer schools were organized. 30 students passed their PhD examination. In addition to DAMOCLES, a Scientific Supported Action (SSA) "SEARCH for DAMOCLES" (S4D) gathering European and US scientists, a Third Targeted Countries (TTC) initiative bringing scientists from Russia and Belarus together with DAMOCLES partners and a MoU (Memorandum of Understanding) with China, were established. The DAMOCLES activity culminated during the International Polar Year (2007–2008) at a time of a phenomenal sea ice retreat in the summer of 2007 when the French schooner Tara accomplished a transpolar Arctic drift in about 500 days compared to a 3 year drift (approximately 1000 days) of Nansen's Fram more than a century ago. The Tara transpolar drift that started on September 2006 in the Laptev Sea and ended on January 2008 in the Greenland Sea, stimulated a number of peer-reviewed outstanding scientific papers. Twenty papers were selected for a book specially dedicated to the Tara DAMOCLES enterprise. The SSA S4D launched the first initiative for the so-called September Sea Ice Outlook consisting in

Published by Copernicus Publications on behalf of the European Geosciences Union.

predicting several months in advance (up to 6 months) the September minimum sea-ice extent. It allows scientists to share predictions and forecasts to explore and test the reliability of the best prediction models for sea ice. The MoU with China allowed DAMOCLES scientists to participate in two Chinese Arctic expeditions (CHINARE 2008 and 2010) on board the Chinese icebreaker Xuelong.

Almost five years later we are glad to publish a DAMOCLES special issue "Ice-Atmosphere-Ocean interactions during IPY: the DAMOCLES project" including 17 new peer-reviewed scientific papers in the Copernicus journals Ocean Sciences (6), The Cryosphere (6) and the Atmospheric Chemistry and Physics (5) of the European Geophysical Union (EGU). 15 out of 17 scientific papers were published in 2012 (8) and 2013 (7). One early paper was published in January 2011 and the most recent in April 2014. The even distribution of the 17 papers of the DAMOCLES special issue across the three Copernicus journals reflects a typical aspect of the DAMOCLES project, essentially dealing with interactions between the Arctic atmosphere, the cryosphere and the ocean.

Arctic meteorology was studied in DAMOCLES by the means of observations and model experiments. The research addressed three main topics: (1) Arctic cyclones, (2) atmospheric boundary layer, and (3) clouds and radiative transfer. In this Special Issue, five papers were published in Atmospheric Chemistry and Physics (ACP) and meteorological issues were addressed in three papers published in The Cryosphere (TC). Three of the papers published in ACP address the vertical structure of the atmosphere with respect to wind, air humidity and temperature. Jakobson et al. (2013) analyse low-level jets (LLJs), i.e., local maxima in the vertical profile of the wind speed. Roughly half of the tethersonde soundings of the wind profile over the central Arctic Ocean during the Tara drift in spring – summer 2007 included a LLJ. The most important generation mechanism for LLJs was baroclinicity associated with transient cyclones, but LLJs are also generated via inertial oscillations in the stable boundary layer. Nygård et al. (2014) investigated humidity inversions, i.e., layers where the air specific humidity increases with height. The study is based on radiosonde sounding data from 36 Arctic stations. Although rare at low latitudes, humidity inversions were present on multiple levels nearly all the time in the Arctic. Almost half of the humidity inversions were related to temperature inversions, whereas the others were related to an uneven vertical distribution of moisture transport from lower latitudes. A high atmospheric surface pressure and clear skies favored the occurrence of humidity inversions. Chung et al. (2013) evaluate the possibilities to use atmospheric re-analyses to study the vertical structure of the recent Arctic climate change. Four different re-analyses agreed on (a) a warming trend in all seasons in the lower and mid-troposphere in the period 1979–2011 and (b) an autumnal mid-tropospheric cooling trend in the subperiod 1998–2011. Due to data assimilation, the re-analyses agreed better with each other at the locations of radiosonde sounding stations, whereas surface weather stations did not have such an effect.

Two papers published in ACP are review papers. They both address the recent advances in understanding the Arctic climate system, Döscher et al. (2014) from the point of view of the system state and change and Vihma et al. (2014) from the point of view of small-scale physical processes and their parameterization. Döscher et al. (2014) conclude that the sea-ice decline is a result of the global atmospheric warming and its Arctic amplification due to positive feedback mechanisms. The amplification is also supported by the sea-ice reduction. Poleward heat transport in the ocean strongly affects the locations of the ice margin, particularly in the Atlantic sector. Uncertainties remain, e.g., in the magnitudes and variability of the atmospheric moisture transport into the Arctic, as well as in the future changes of the amount and phase of precipitation. All these strongly affect the sea-ice surface energy budget. Vihma et al. (2014) address the highly interactive small-scale physical processes in the atmosphere, sea ice, and ocean. Since the start of the International Polar Year, significant advances have been made in understanding the physical processes (e.g., cloud physics, radiative transfer, mesoscale cyclones, flow over fjords, and boundary layer processes), but challenges remain in parameterization of the processes in climate and numerical weather prediction models as well as in understanding and parameterizing the complex interactions between different processes. Uncertainty in the parameterizations continues to be one of the greatest challenges in modeling the Arctic climate system.

In addition to this special issue, DAMOCLES yielded several other papers on Arctic meteorology. During the Swedish Icebreaker Oden expedition in 2008, an unprecedented amount of detailed measurements on clouds and atmospheric boundary layer were made over the Arctic sea ice. Many of the results were published in the ACP special issue "Arctic Summer Cloud Ocean Study (ASCOS)" in 2011–2014. DAMOCLES papers were also published in various other journals. These addressed, among others, Arctic cyclones; atmospheric moisture budget; atmospheric forcing on sea-ice dynamics and thermodynamics; remote sensing of water vapor and clouds; radiative transfer in clear and cloudy atmosphere; evaluation of atmospheric re-analyses, regional climate models, and numerical weather prediction models; influence of leads in sea ice on the air temperature; surface energy budget, and the meteorological conditions responsible for the extensive Arctic sea-ice melt in summer 2007.

As DAMOCLES was a sea-ice centric project, a high number of scientific papers are related to the marine cryosphere. Within the DAMOCLES special issue one scientific paper (Heygster et al., 2012) is a review of the advances made during the International Polar Year for sea-ice remote sensing due to the importance of sea-ice extent, concentration and thickness for climate change issues both at regional and global scales. The first paper submitted to the DSI by Oikkonen and Haapala (2011), points out the shift between Multi Year Ice to First Year Ice observed all over the Arctic Ocean during the IPY. A paper by Gimbert et al. (2012) stresses attention to an amplification of inertial oscillations observed from Arctic sea-ice motions due to a reduction of sea-ice thickness, sea-ice concentration and spatial extent. The three remaining papers, part of the cryosphere component of the DSI, are mainly related to air-sea ice interactions (Haller et al., 2014), the impact of cyclones (mostly wind stress) on sea-ice divergence (Kriegsmann and Brümmer, 2014) and large amplitude inertial sea-ice motion. Finally Tetzlaff et al. (2013) investigate 2 m air temperature all over the Arctic Ocean under clear-sky conditions in spring time showing large differences mainly due to sea-ice concentration.

As DAMOCLES was a marine dedicated project, a high number of scientific publications all related to the ocean is an expected outcome. Within the DAMOCLES special issue, two papers are dedicated to large scale observations of water mass distributions in the Eurasian Basin over an extended period of time (Rudels et al., 2013) and in the upper Canadian basin during two contrasting years (2008 and 2010) characterized by a strong inversion of the Arctic Oscillation index (Bourgain and Gascard, 2013). Two other papers deal with water mass circulation around Svalbard and through Fram Strait (Walczowski, 2013; Marnela et al., 2013) reflecting the importance of water masses exchanges through the main gate connecting the Arctic Ocean to the World Ocean. A paper led by Korhonen et al. (2013) is related to the fresh water and heat contents observed from 1991 to 2011 with an increase in fresh water especially evident in the northern Canadian basin and a warming of the Atlantic water confined in the Nansen basin during recent years (2000s) indicative of a strong recirculation of the Atlantic inflow within the Nansen basin. Finally, a paper by Döscher and Koenigk (2013), based on regional coupled climate scenario experiments, looks at various mechanisms in order to explain the rapid sea-ice loss observed in the Arctic during the IPY and the DAMOCLES project. Major driving forces are related to atmospheric circulation changes and occasional long wave radiation effects. It does not seem like short-lived forcers such as soot (black carbon) were involved in the drastic sea-ice loss observed during IPY and DAMOCLES.

DAMOCLES represented the largest effort to assemble simultaneous observations of the entire Arctic atmosphere-ice-ocean system. The observational time period for DAMOCLES coincided with the 4th International Polar Year, providing yet additional information about the system at that time. DAMOCLES represented one of the main contributions from the European Community to the International Polar Year. The data set was and still is used to increase our understanding of the processes and mechanisms underpinning the Arctic climate system as well as to validate and to improve the suite of numerical models operated for DAMOCLES, to merge (assimilate) data in numerical models for quantitative estimates of circulation in the Arctic atmosphere and Ocean and to initialize ensemble forecasts of the future state of the Arctic.

Finally, we would like to honor and celebrate the memory of friends and DAMOCLES partners that passed away since the completion of the DAMOCLES project. Jan Piechura from the IOPAN Oceanographic Institute in Sopot (Poland), Eberhard Fahrbach from the Alfred Wegener Institute in Bremerhaven (Germany), Seymour Laxon and Catherine Giles from the University College of London (UK), contributed immensely to the success of the DAMOCLES project and their work is an integral part of the DAMOCLES legacy for future generations.