

solas event report

Report 04 | July 2017

Community workshop on:

“Cryosphere and Atmospheric Chemistry (CATCH)”

19 - 21 April, 2017

Guyancourt, France



The first workshop of the “Cryosphere and Atmospheric Chemistry” (CATCH), a new IGAC activity, took place at the Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS) in Guyancourt, France from 19 to 21 April 2017. CATCH aims to build a network of scientists to facilitate atmospheric chemistry research within the international community with a focus on the chemistry, biology and physics of the natural environment in cold regions. The two main workshop objectives were 1) to foster future collaborative work by highlighting cross-disciplinary research questions and 2) to identify future research needs and opportunities.

In total, 48 scientists from 14 countries from a wide range of disciplines and all career stages, including many graduate students and postdocs, came together to present over two days their science related to CATCH in short talks or posters and to discuss ways of how to develop this new initiative. The themes of the eight sessions were each introduced with a general overview talk accessible to non-specialists, followed by shorter science talks on a specific topic and then a general discussion. Poster sessions during lunchtime

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Figure 1: Participants of the 2017 CATCH workshop at LATMOS, Guyancourt, France.

Left to right - Back row: Thorsten Bartels-Rausch, Pablo Corrochano, Manuel Dall'Osto, Jochen Stutz, Gesa Eirund, Audra McClure, Aurelien Dommergue, Catherine Larose, Markus Frey, Martine Lizotte, Jennifer Murphy, Didier Voisin, Paul Griffiths, Kenjiro Toyota, Louis Marelle, John Burkhart, Alfonso Saiz-Lopez.

Middle row: Dominik Heger, Niels Bohse Hendriksen, Anna Jones, Niccolò Maffezzoli, Björn-Martin Sinnhuber, Wes Halfacre, Jo Browse, Megan Melamed, Samantha Tremblay, Valérie Gros, Becky Alexander, Roberto Grilli, Kathy Law, Taneil Uttal, Lei Geng, Jennie Thomas.

Front row: James France, Jacinta Edebeli, Xin Yang, Stefanie Falk, Kitae Kim, Kerri Pratt, Megan Willis, Michael Giordano, Kirpa Ram, Marcelo Guzman, Ben Murray, Tuija Jokinen, Xucheng He.

Missing: Claudia Di Biagio and Solène Turquet. © Jennie Thomas

provided opportunities for informal discussions and networking. After the workshop, members of the CATCH implementation team (for information on team members, see box below the summary) and some participants met for an extra day to plan the future of CATCH.

Background - The cold and polar regions are currently undergoing significant changes with implications for regional and global climate, ecosystems and society. The underlying natural chemical, biological and physical processes and feedbacks, which control the Earth system in the cold regions, are still poorly understood. However, reliable predictions of environmental change require a quantitative understanding of processes and feedback mechanisms, which can only be achieved through trans-disciplinary and international collaboration. Thus, workshop session themes included: aerosol and clouds; biogeo-

chemistry and biology; halogens, ozone, and mercury; surface processes and ice, fundamentals of chemistry in cold regions; as well as project overviews and facilities. The discussions were used to brainstorm and identify issues and open questions, a selection of which is briefly summarised below.

Aerosol and clouds - Atmospheric aerosol and associated climate impacts, particularly in cold regions have one of the largest model uncertainties (Flato *et al.*, 2013), which need to be resolved. In particular, origin, fate and cloud forming capability of particles formed at or near the surface in the Arctic and Antarctic are not well understood. However, a quantitative understanding of natural processes is needed, e.g. to reduce the model bias above the Southern Ocean linked to errors in representation of clouds and precursors (Flato *et al.*, 2013) or to assess and

mitigate the anthropogenic impacts from increased ship emissions in the high Arctic. Furthermore, fundamental aspects of the ability of aerosol to form clouds such as the difference in importance as cloud condensation nuclei or ice nuclei are still unresolved. It became clear that better links to the aerosol and cloud microphysics community, facilitated by CATCH, would likely enable a step change for answering some of the open questions.

Biogeochemistry and biology - Changes in the cryosphere, such as those observed in seasonality, extent and thickness of sea ice have profound impacts on biogeochemistry and biology. These changes include impacts on ecosystems, feedbacks on greenhouse gas emissions, and changes in the cycling of elements. Therefore, the engagement of scientists investigating the biology of the surface ocean and sea ice is crucial to CATCH. Workshop participants who are also involved in the projects “Biogeochemical exchange processes at Sea Ice Interfaces” (BEPSII) and SOLAS highlighted that many areas of research at the air-sea ice-ocean interface would benefit tremendously from collaboration and joint activities with CATCH.

Halogens, ozone, and mercury - Even though the atmospheric chemistry of halogens, ozone, and mercury above snow and ice covered regions has been the subject of research for the last 30 years, the relevant processes are not yet systematically integrated into regional and global models. A recent report evaluated air pollution in the Arctic, focusing on short-lived climate forcers such as ozone and black carbon (AMAP Assessment, 2015). But associated wider impacts of natural air-snow processes on climate and air quality have not been evaluated systematically. It was also pointed out that in some areas the fundamental process understanding is not yet mature enough to be included in general circulation models. Another issue raised, was that the interpretation of atmospheric observations needs to integrate better available information and exper-

tise from the fields of atmospheric boundary layer physics, as well as snow physics and chemistry. Better integration of the science community can be achieved by network initiatives such as CATCH. And finally, it was recognised that results from laboratory experiments, e.g. reaction rates, need to be evaluated critically before they are transferred to the real world.

Surface processes and ice, fundamentals of chemistry in cold regions - An on-going debate related to surface processes and ice, and fundamentals in chemistry, revolves around the nature of the air-ice interface and how it affects uptake, release and chemical reaction rates (Bartels-Rausch *et al.*, 2016). A challenge researchers are facing is to identify the origin of model errors. Knowing the source of uncertainties would allow to better target relevant and important processes in field and laboratory experiments. In order to realise these experiments, field and modelling communities need to work together to develop hypotheses, which are then tested in the laboratory. It is recognised that scale matters, i.e. global models may not be sensitive to some parameters (e.g. reaction rate constants) and therefore reducing their uncertainty would not result in much improved model performance.

Project overviews and facilities - The study of natural processes in the cold and polar regions is highly inter-disciplinary, logistically challenging and expensive. It therefore relies heavily on international collaboration, which enables shared access to research facilities and collaborative research projects. Workshop presentations highlighted existing opportunities for field work at research stations in the Arctic (e.g. Villum Station North or Summit Station, Greenland), in the Antarctic (e.g. Halley Station), at terrestrial snow sites (e.g. Finse Research Station, Norway, and Joseph Fourier Alpine Station, France), on research ice breakers, but also in mesocosms (e.g. the Roland von Glasow Air-Sea-Ice Chamber, University of East Anglia, United Kingdom). Existing network activities and projects such as “Air

Pollution in the Arctic: Climate, Environment and Societies” (PACES), BEPSII or “Network on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environments” (NETCARE) have overlaps with CATCH and a liaison with some of them would clearly enhance CATCH research and impact.

Next steps of CATCH - There was consensus that the focus in the next two years will need to be on identifying key research questions, which CATCH will then address through a number of activities. Such activities can include developing a white paper, scientific reviews, research proposals, a summer school, and coordinated field campaigns (Fig. 2).

Workshop feedback - Overall, 23 responses were received from a post-workshop survey, which rated the workshop as excellent regarding overall quality (60%) and organisation (74%), range of scientific topics covered (52%), and the quality of scientific discussions (39%). The latter may be due to the lack of time for in-depth discussions (48%), which is probably characteristic

for inter-disciplinary workshops covering such a large range of topics. The workshop objectives were met (87%), in particular enough time was given for networking and informal discussions (91%). Thus, a majority of participants recognised either many opportunities (30%) or at least some chance for collaborations and future work (52%). An important challenge CATCH is facing based on various comments is that on the one hand CATCH needs to find the right balance of being focused and define research questions, which allow distinction from other initiatives and on the other hand remain inclusive and not too narrow in scope.

Overall, everyone left the workshop after two full days of intense discussions invigorated and with the positive feeling of having learned about neighbouring science disciplines and having met new collaborators and colleagues. We thank the workshop sponsors and all the participants to have come from near and far to join CATCH, to engage in truly cross-disciplinary and international dialogue and scientific discussions which often require a lot more patience than talking to your specialist colleague. We are also thankful to

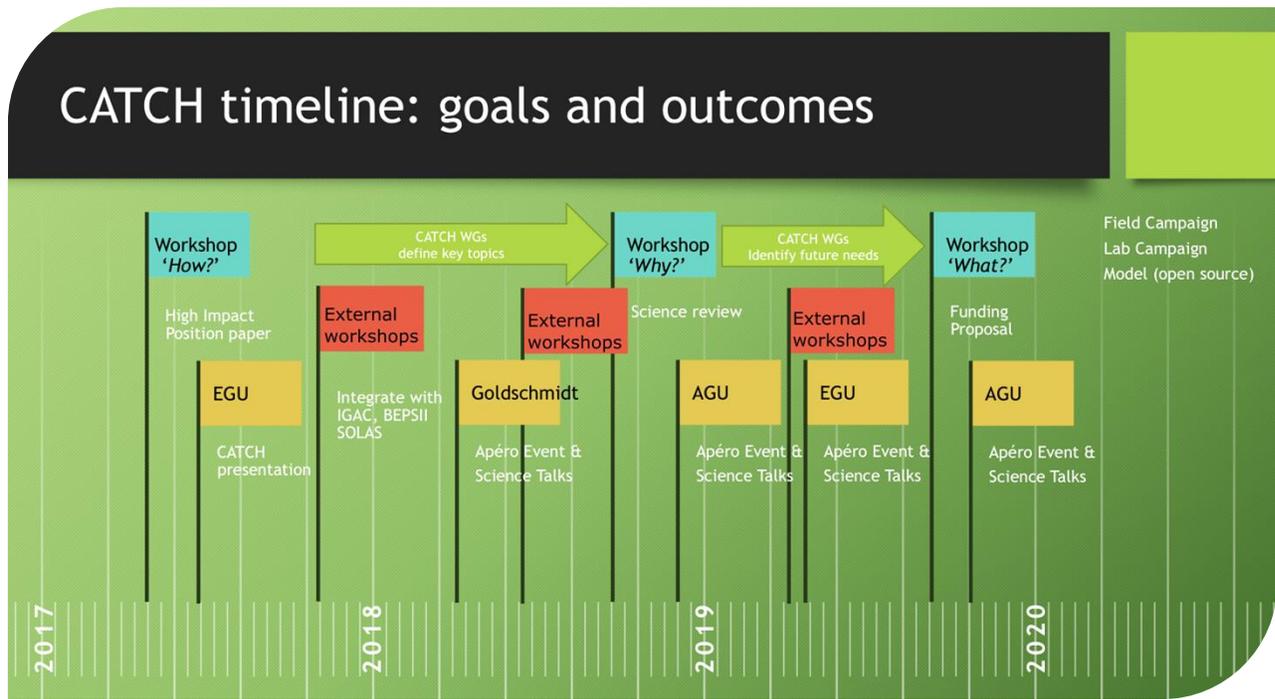


Figure 2: A potential timeline for the development of goals and anticipated outcomes of CATCH. © Thorsten Bartels-Rausch

IGAC executive officer Megan Melamed who moderated the science strategy discussions. We are looking forward to taking the next steps in the development of CATCH.

Markus Frey, British Antarctic Survey, Cambridge, United Kingdom
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Link to the event website: <http://bit.ly/2rpJXII>

The outcomes of this workshop contribute to advance our knowledge of the Core Theme 4 “Interconnections between aerosols, clouds, and marine ecosystems” and Cross-Cutting Theme “Integrated Topics” of the SOLAS 2015-2025 Science Plan and Organisation.

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Event sponsors





Martine Lizotte obtained her PhD at Laval University, Canada, investigating the oceanic cycling of dimethylsulfide (DMS). Since 2010, she has been working on the impact of various environmental stressors (ocean acidification, iron depletion, light) on the biogeochemistry of DMS, with a more recent focus on Arctic regions.

High-frequency profiling of oceanic dimethylsulfide in a fast changing Arctic

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There is mounting evidence that marine dimethylsulfide (DMS)-derived aerosols may significantly contribute to cloud albedo forcing in the pristine atmosphere of the Arctic during summer (Leitch *et al.*, 2013). At a time when the top of the Earth is unremittably turning from white to blue, due to reductions in sea-ice extent, understanding what drives the cycling of DMS within the hydrosphere-cryosphere complex, has become a pressing matter. Localised hotspots of DMS have been observed in association with sea-ice habitats such as brine channels in bottom-ice and melt ponds at the ice's surface (Levasseur, 2013). With expanses of sea-ice being extremely dynamic, i.e. subject to pronounced freeze-melt cycles and advective processes giving rise to fractures, leads and drifting floes, DMS-producing communities are often exposed to large fluctuations in temperature, salinity, and light. Autotrophic organisms, both pelagic and sympagic, may cope with these strong environmental gradients by synthesising the compatible solute and precursor of DMS, dimethylsulfoniopropionate (DMSP), known for its roles in osmoregulation, cryoprotection, and scavenging

of free radicals (Stefels *et al.*, 2007). Beyond the potential direct enzymatic conversion of DMSP into DMS by autotrophic organisms themselves, heterotrophic bacteria's use of DMSP as a source of carbon also leads to the production of DMS. Zooplankton grazing and viral attacks on phytoplankton may further contribute to the community DMSP-to-DMS yield; undoubtedly making the cycling of DMS a "food web affair". As the Arctic continues to change, thinning and retreating of sea-ice allows for the earlier onset of phytoplankton blooms potentially rich in DMS, even under the ice itself, as many autotrophic organisms possess low light adapted photosystems. Increasing amounts of protons (H⁺) and decreasing reservoirs of carbonates ensuing from ocean acidification, may impact DMS-producing communities (Hussherr *et al.*, 2017). And what of increasing temperatures, changes in nutrient availability, potential shifts in community dominance and successions, as well as other fast-pace changes that lie in wait? As of yet, establishing large-scale empirical relationships among oceanic DMS pools, changes in sea-ice extent, and phytoplankton productivity has prov-

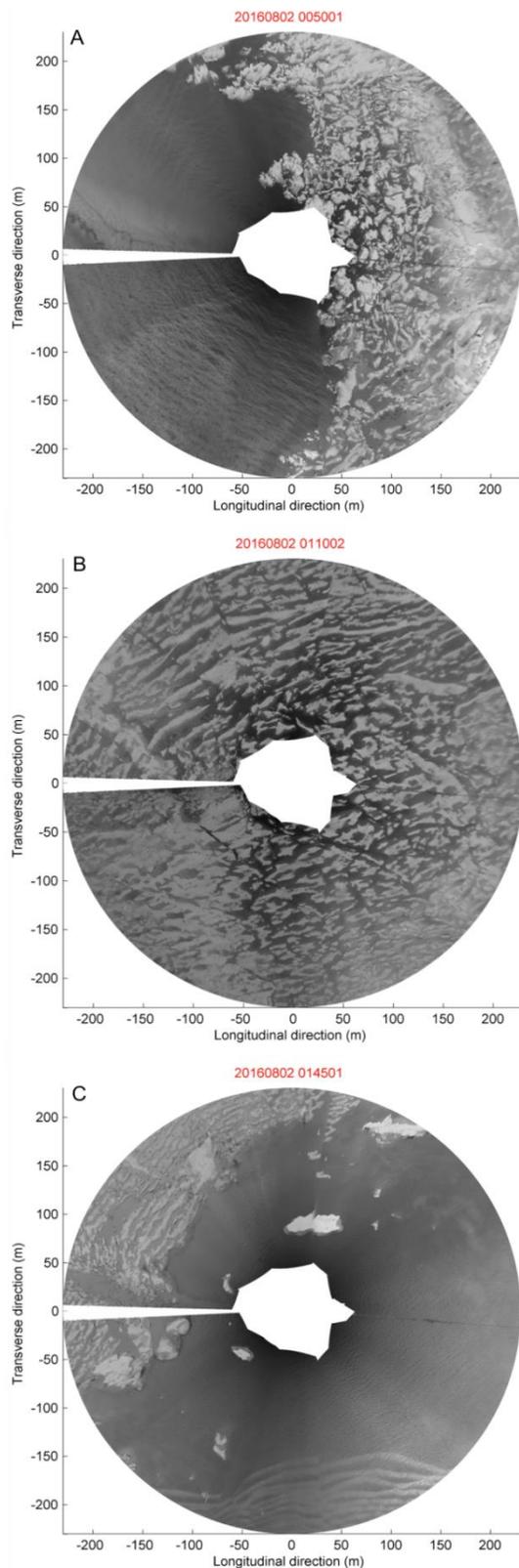


Figure 3: A 360° landscape imagery collected by the Canadian Coast Guard Ship ‘CCGS Amundsen’ in the Canadian Arctic in 2016. Processed data, composite image of a 12-lenses array of cameras located above the bridge. Version 1. Accessed in mid-August 2016. (A) Icebreaker entering a giant ice floe in Northern Baffin Bay; (B) Icebreaker passing through the ice floe exhibiting significant melt pond cover; (C) Icebreaker exiting the ice floe.

en to be challenging. This is partly because concurrent measurements of those parameters at relevant time and spatial scales are scarce. However, the advent of high-frequency underway measuring systems, coupled with satellite and 360° landscape imagery (Fig. 3) now provide remarkable frame of reference to tackle these issues. During the joint Arctic Network of Centres of Excellence of Canada/Network on Climate and Aerosols (ArcticNet/Netcare) campaign in 2016, our team explored SOLAS-relevant DMS topics through the deployment of automated underway systems, acquiring unique datasets, which would be otherwise industrious to collect. Transiting through a giant drifting ice floe (Fig. 3) revealed elevated DMS concentrations associated with an abrupt freshening of sub-ice waters suggesting a potential up-regulation of DMS production under salinity downshock or under increased doses of solar radiation. Further work is needed to explore large-scale relationships within the extensive dataset collected, but already this information has started to feed into Netcare modelling products that will further our predictive capabilities of the potential impact of DMS on climate.

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Kitae Kim completed his doctorate in environmental science, focussing on enhanced inorganic redox reactions in ice and their environmental implications, at the Pohang University of Science and Technology, Korea. In 2012, he started his career at the Korea Polar Research Institute, where he is investigating intrinsic chemical reactions in ice and its impacts on polar regions.

Abiotic production of reactive iodine species in ice and its implication

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Reactive halogens (including chlorine, bromine, and iodine) play a significant role in ozone depletion events, oxidizing capacity in the atmosphere, mercury depletion events, the perturbation of the hydroxide/nitrogen oxide cycles, and in dimethylsulfid oxidation to form cloud condensation nuclei. Compared to chlorine and bromine compounds, the fate of iodine species in polar region has been less investigated; although, iodine has a key role in forming ultrafine aerosols which may influence solar radiative force and finally also the climate (Abbatt *et al.*, 2012; Saiz-Lopez *et al.*, 2012; Simpson *et al.*, 2015). While the high concentration of atmospheric active iodine monoxides during the Antarctic spring season have been observed by ground and satellite based techniques, sources and mechanisms of this large iodine burden are not yet fully understood (Saiz-Lopez *et al.*, 2007). Especially abiotic sources of atmospheric iodine from the Antarctic are less understood when compared to biological iodine sources from micro- or macro algae. In general, chemical reactions are slow when temperature drops according to Arrhenius equation (IUPAC, 1997); however, some processes are accelerated by freezing (Takenaka *et al.*, 1992; Kim *et al.*, 2010). The oxidation of nitrite to ni-

trate, which is a very slow reaction, was significantly accelerated by freezing. When a solution solidifies, the organic/inorganic compounds are being concentrated in unfrozen parts of the ice. This so called freeze concentration effect affects chemical variables such as protons, dissolved gases and the concentration of reactants. Therefore, this effect is regarded as the main driving force for the enhanced processes in sea ice (Fig. 4). Our experimental results show that the production of tri-iodide via iodide oxidation, which occurs negligibly in aqueous solution, was signif-

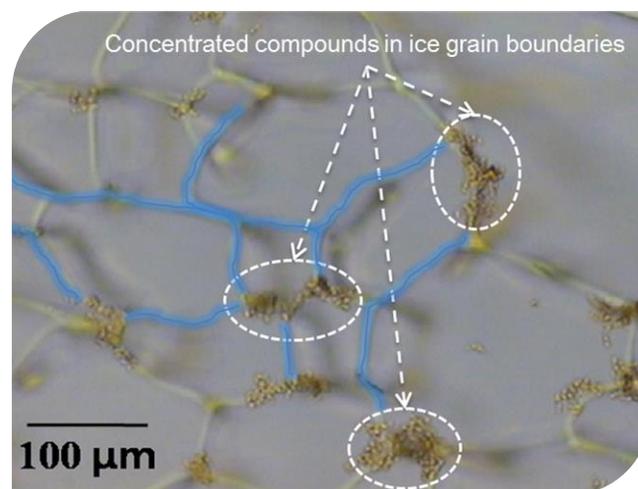


Figure 4: Microscopic image showing the freeze concentration phenomena of the concentrated compounds (circled) by freezing in ice grain boundaries (blue).

icantly accelerated in the ice phase, in the presence and absence of irradiation (Kim *et al.*, 2016). The produced tri-iodide is converted into iodine molecules and iodide ions (Fig. 5). Once the iodine molecule is released into the atmosphere, it forms iodine oxides via photolysis and then affects the formation of ultrafine aerosol particles. Field experiments carried out under ambient conditions for the Antarctic region (King George Island, 62°13'S 58°47'W, sea level), confirmed that the formation of tri-iodide via photo-oxidation is enhanced when iodide is trapped in the ice media. An enhanced release of gaseous iodine molecules and iodine monoxide radical was observed by Cavity Ring Down Spectroscopy. The enhanced oxidation of iodide and iodine molecules formation in ice is largely owing to the freeze concentration of iodide, protons, and dissolved oxygen in the ice crystal grain boundaries. This result shows that the intrinsic chemical reaction of iodide and the following release of gaseous iodine molecules can be accelerated in ice media and consequently may contribute to ozone depletion events and new particle formation in cold environments.

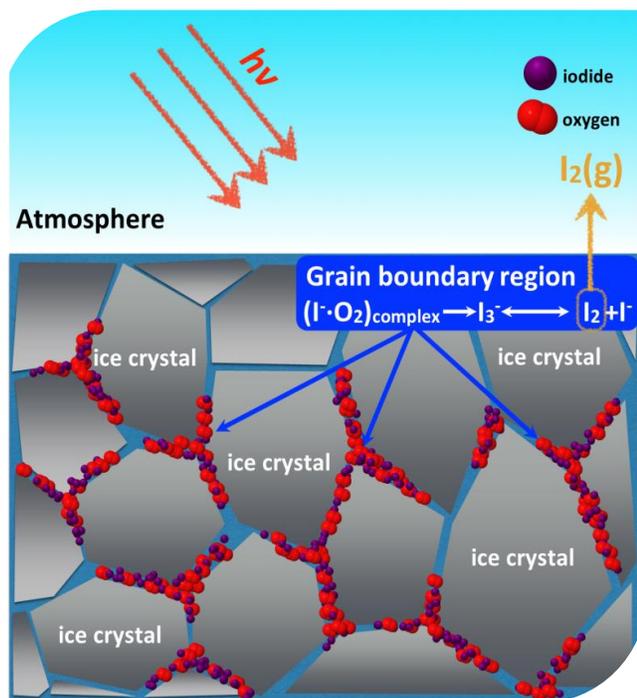


Figure 5: Schematic diagram for the enhanced production of reactive iodine compounds in ice (iodide I⁻, iodine molecules I₂, tri-iodide I₃⁻).

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Jo Browse studied Physics at the University of Edinburgh, United Kingdom, before moving to Leeds in 2008 to start her PhD. In 2016, Jo started as a lecturer in physical geography at the University of Exeter, United Kingdom. She develops complex models to forecast the evolving Arctic environment.

The problem with Arctic clouds

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Modelling studies have suggested that the Arctic cloud response to sea-ice retreat may mitigate the ice-albedo feedback (Struthers *et al.*, 2011). However, the response of Arctic clouds to increasing temperatures (in particular with respect to aerosol interactions) is uncertain (Browse *et al.*, 2014). This uncertainty derives from multiple factors, most significantly, from our lack of understanding of the source of high-latitude cloud condensation nuclei, to which Arctic clouds are peculiarly sensitive (Birch *et al.*, 2012). Observations suggest a combination of primary and secondary sources ranging from ammonia induced nucleation of dimethylsulphide derived sulphur dioxide (Croft *et al.*, 2016) to organic (microgel) emissions from sea-ice leads and polynyas (Orellana *et al.*, 2011). However, models struggle to reproduce observed Arctic cloud condensation nuclei (Fig. 6) and cloud droplet concentration using existing nucleation parameters or scavenging processes. Indeed, the introduction of sophisticated aerosol nucleation schemes has in many cases reduced the skill of our models in the Arctic (Fig. 6). Furthermore, while it is possible to ‘fill the gap’ in modelled cloud condensation nuclei with numerous

tuned emission fluxes or processes, the response of Arctic cloud albedo to sea-ice retreat is likely predicated on the assumed dominant aerosol source (Browse *et al.*, 2014).

Thus, we will investigate the urgent ‘problem with Arctic clouds’ in global climate models. We will introduce novel modelling methods which could inform observation. These include the use of perturbed parameter ensembles (Fig. 7) and emula-

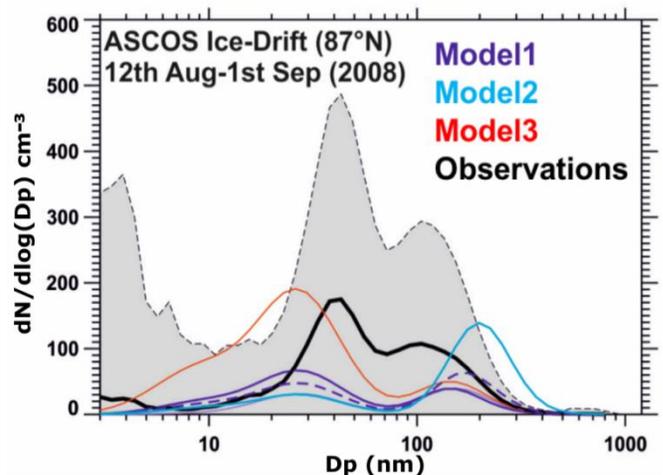


Figure 6: Arctic aerosol size distribution observed during the Arctic Summer Cloud Ocean Study (ASCOS) at 87°N (grey shading) and median of observations (black), compared to a model with a high wet scavenging rate (Model 1), a low wet scavenging rate (Model 2) and a model where boundary layer nucleation is linearly dependent on sulphur dioxide concentration only (Model 3).

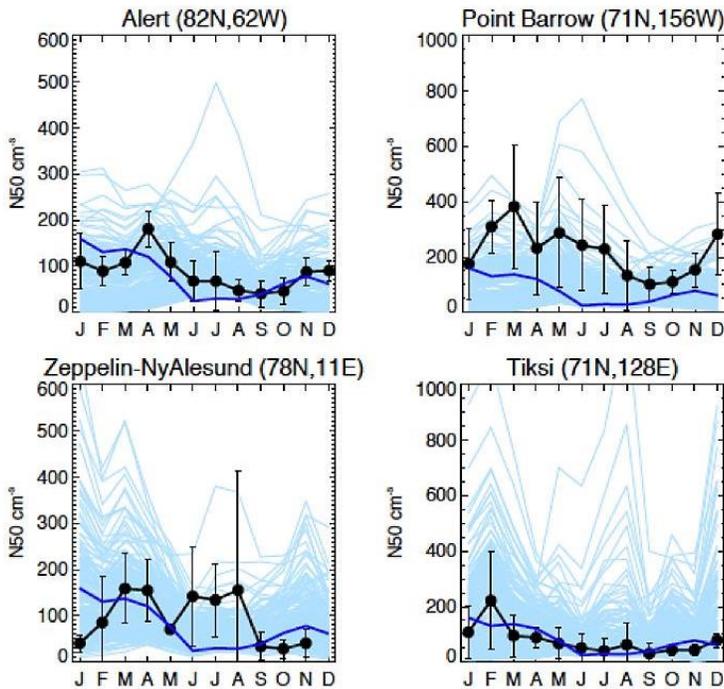


Figure 7: Example of a ‘particles with diameter >50 nm’ (PPE N50) output compared to observations at four Arctic ground stations. Model runs are shown in light blue and observations in black. Error bars indicate temporal error in monthly mean observation. The median (baseline) run is shown in dark blue. Acknowledgements: Original model runs completed by Pringle, K. and Yoshioka, M.

tion methods to quantify parametric model uncertainty and identify crucial yet poorly constrained parameters contributing to model error. Finally, we call for a combined use of modelling and observational techniques across diverse fields to address the following knowledge gaps:

- Understand the nucleation process in the Arctic boundary layer, including the likely significant but unconstrained role of biological sources.
- Determine the importance of primary biogenic emission in the Arctic to Arctic cloud condensation nuclei and cloud forcing.

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