HIGH-LATITUDE DYNAMICS OF ATMOSPHERE–ICE–OCEAN INTERACTIONS

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The workshop on Dynamics of Atmosphere–Ice–Ocean Interactions in the High Latitudes attracted 90 scientists who met to 1) identify challenges in polar prediction, 2) explore our understanding of the coupled climate system in the high latitudes, and 3) identify research priorities to improve our knowledge and predictive capabilities. We summarize the workshop discussions for four main themes.

DYNAMICS OF ATMOSPHERE–ICE–OCEAN INTERACTIONS IN THE HIGH LATITUDES

WHAT: Scientists from 13 countries involved with modeling and observing the coupled high-latitude weather and climate system discussed our current understanding and challenges in polar prediction, extreme events, and coupled processes on scales ranging from cloud and turbulent processes, from micrometers and a few hundred meters to processes on synoptic-scale weather phenomena and pan-Arctic energy budgets of hundreds to thousands of kilometers. Workshop participants also evaluated research needs to improve numerical models with usages spanning from uncoupled to fully coupled models used for weather and climate prediction (http://highlatdynamics.b.uib.no/).
WHEN: 23–27 March 2015
WHERE: Rosendal, Norway

POLAR PREDICTION. The World Weather Research Program's Polar Prediction Project (PPP; 2013–22) has been launched in response to our relative lack, compared to mid and low latitudes, of weather and environmental prediction capacity in polar regions. Predictability limits for various polar phenomena and numerous critical processes are still not well understood. Thomas Jung explained how the PPP promotes "cooperative international research to improve weather and environmental prediction in the polar regions by strengthening the collaboration between academia, research institutes, operational forecasting centers, and stakeholders" (http://polarprediction.net/). The Year of Polar Prediction (mid-2017 to mid-2019) is an intensive observational and modeling period and a key vehicle for delivery of the PPP (Jung et al. 2016).

By employing Observing System Experiments (OSE) and Observing System Simulation Experiments (OSSEs), Roger Randriamampianina showed that enhanced frequency of radiosonde observations in polar regions can improve the moisture and geopotential height forecasts and that additional buoy observations increase skill of near-surface fields. Jun Inoue further emphasized the essential role of additional radiosonde observations for forecast improvements. For mesoscale forecasting (e.g., for polar lows), Teresa Valkonen showed that assimilation of scatterometer wind observations can have a beneficial impact on forecast quality. During discussions, it was pointed out that Arctic observations could be utilized to derive information specifically needed for societal and practical applications—for example, visibility for transportation. Furthermore, a recommendation was made to organize a workshop on OSE for the polar regions as well as the need to engage with stakeholders.

James Doyle stressed that the impact of observations on forecasts in high latitudes is weather regime dependent and has varying importance. Predictability of polar phenomena such as polar lows is critically dependent on mesoscale regions of low- and mid-level moisture in the model initial state. These results also suggest that diabatic processes introduce inherent uncertainties that motivate the need for ensembles for high-impact polar weather forecasting. Jørn Kristiansen and Hanneke Luijting presented MET Norway's new ensemble capabilities, highlighting polar low probability strike density maps to quantify forecast uncertainty.

THE COUPLED WEATHER AND CLIMATE SYSTEM. Sarah Keeley demonstrated improved European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric forecast skill at weeks 3 and 4, especially along the sea ice edge, when the ECMWF ensemble forecast system was coupled with the dynamic–thermodynamic Louvain-la-Neuve Sea Ice Model. Christoffer Horvat presented examples of advances in sea ice modeling on interactions between waves and floe sizes, and Einar Olason introduced the new next generation Sea Ice Model. Andreas Preußer and Sasha Willmes derived new satellite observations of lead size and distribution that could be used for model validation. On the basis of new aircraft measurements, Amelie Tetzlaff found that present internal boundary layer growth parameterizations do not work across all scales over leads. Christof Lüpkes presented a new theoretically based parameterization for drag as a function of ice fraction, thickness, and stability, which performs well, though further work is required to constrain surface roughness.

Francois Massonnet showed that increasing the horizontal resolution of an atmospheric model improves the forecast skill for low-level temperatures, while sea ice predictive skill increases with higher ocean resolution. Andrew Roberts highlighted that high-resolution fully coupled regional models can enable evaluation of coupled dynamics using short measurement records in a way that is often prohibitive for global simulations. For longer model integration times, Steffen Tietsche showed that subsurface oceanic processes are important for polar prediction. For experiments with the Max Planck Institute Earth System Model, the heat flux from the atmosphere dominates the ensemble spread the first year while ocean fluxes dominate after two years and onward.

Timo Vihma presented the Arctic Freshwater Synthesis (CliC/AMAP/IASC 2016), illustrating how transport of moist air into the Arctic contributes to changes in the hydrological cycle, precipitation, and clouds, and Rune Graversen also commented on the associated poleward energy transport from lower latitudes and its impact on Arctic climate. Harald Sodemann emphasized the importance of extreme moisture transport events to the total atmospheric energy transport into the Arctic, and Heini Wernli presented evidence that moist airstreams embedded within extratropical cyclones can strengthen the anticyclonic circulation over the Arctic due to import of low potential-vorticity air. Michael Tjernström

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pointed out that enhanced moisture transport in the spring is often followed by low September sea ice extent. This transport appears to be rather episodic and pinpoints the need to move beyond analyzing energy fluxes across a latitudinal belt or corresponding small-scale processes and to focus on coupling during air-mass transformation. Ola Persson further argued that the onset of surface melt and freeze often corresponds with the arrival of warm-air intrusions and that sea ice formation over the open ocean also depends on upper-ocean mixing and hence the wind forcing. Igor Esau demonstrated that any heat forcing leads to an amplified temperature response in climates with frequent shallow stably stratified boundary layers.

Tjernström also showed how clouds impact the energy budget at both the surface and the top of the atmosphere. Clouds in warm-air intrusions warm the surface while simultaneously increasing outgoing longwave radiation, thereby cooling the earth–atmosphere system. Both Joseph Sedlar and Tjernström emphasized that cloud-top moisture inversions affect cloud water as moisture is entrained across the cloud top, enhancing cloud-top cooling and generating turbulence. The resulting mixing determines the depth of the cloud–mixed layer and coupling with the surface. Georgia Sotiropoulou also discussed cloud–surface decoupling and the inadequate model representation of these processes.

John Cassano presented developments and advantages of unmanned autonomous vehicles to probe the lower atmosphere and atmospheric turbulence. Chris Fairall and Ian Brooks discussed how turbulent fluxes mediate atmosphere–ocean–ice coupling and that our understanding is compromised by surface heterogeneity—open ocean, sea ice, snow, melt ponds, leads, and ridges—and that parameterizations of other fluxes—heat, water vapor, and trace gases—are less developed owing to the paucity of process-level observations in polar regions.

Related to these shortcomings, Matthew Shupe presented the plans for the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC; www.mosaicobservatory.org/). MOSAiC will be a once-in-a-generation opportunity to study coupled atmosphere–ocean–ice processes in the Arctic over a full annual cycle expected to begin in fall 2019.

EXTREME EVENTS. Ian Renfrew pointed out that the highest wind speed events near the coast are associated with orography and are a climatological feature of polar regions. Both Renfrew and Günther Heinemann indicated that the occurrence of these winds is considerably influenced by the synoptic situation, though Heinemann, Svenja Kohnemann, and Alice DuVivier stressed that topographic effects dominate the acceleration of the atmospheric flow. Renfrew also commented on the importance of appropriate resolution and parameterizations, particularly of the stable boundary layer, thereby stressing that surface exchange processes are imperative for realistic numerical simulations of orographic flows. Andy Elvidge presented case studies of foehn events over the Antarctic Peninsula indicating that foehn wind extends farther downstream during linear flow regimes than during nonlinear flow regimes, which in turn has implications for ice shelf melting. Dmitry Chechin added that air-mass modifications, including the formation of low-level jets, by differential boundary layer heating at the ice edge are estimated to extend 400–800 km downstream.

Erik Kolstad attributed the most extreme wind events over the open ocean in the Nordic Seas to polar lows where, according to Maxence Rojo, the highest occurrence coincides with the region of warm ocean currents in the Norwegian Sea and west of Svalbard, which was also emphasized by Thor Erik Nordeng and exemplified by a polar low case study by Denis Sergeev. Marie Vicomte indicated that the considerable interannual variability of polar lows can partially be explained by the sea ice cover over the Barents Sea, where a reduction during midwinter culminates in more favorable conditions for polar low development toward the end of the winter season. Annick Terpstra and Thomas Spengler pointed out that polar low genesis environments can be classified as either a polar version of classical midlatitude baroclinic environments or resemble secondary development associated with frontal instability. Christopher Fairless added that both environments are conducive for the deep warm-core polar low formation, which is characteristic of intense polar lows. Spengler and Richard Moore also pinpointed the prominent role of moisture and associated latent heat release for polar low development. Andrew Carleton showed that understanding the teleconnection-related interannual variability of mesoscale cyclones in the Southern Ocean might provide insight into their role in modifying deep-water formation. Similarly, Tsubasa Kohyama indicated that Antarctic sea ice and meridional wind are coherent intraseasonally.

LARGE-SCALE PROCESSES AND INTERACTIONS BETWEEN HIGH AND LOWER LATITUDES. Jennifer Francis hypothesized that a weakening of the near-surface meridional temperature gradient associated with

Arctic amplification may cause a slowdown of the westerly winds and larger amplitudes of waves in the midlatitude jet stream, leading to more persistent weather regimes. James Screen discussed how certain aspects of this hypothesis were hard to verify with observations because of short time series, metric dependence, and large natural variability and cautioned that model projections do not support an increase in waviness in the future.

Ocean heat transport into the Arctic was shown by Ingrid Onarheim to be a critical driver of Barents sea ice variability. Martin King proposed that the stratosphere is important to an observed lagged relationship between autumn Barents–Kara sea ice and wintertime tropospheric circulation. Kelly McCusker spoke about the dramatic cooling over continental Eurasia in the last decade and attributed this cooling to internal variability rather than a forced response to sea ice loss. Stephen Outten showed that many models in the fifth phase of the Coupled Model Intercomparison Project (CMIP5) fail to correctly capture the observed covariability between sea ice and Eurasian temperatures. Model experiments presented by Yvan Orsolini and Ruth Petrie showed a sensitivity of the winter North Atlantic Oscillation (NAO) to Eurasian snow cover and summer NAO to observed sea ice loss, respectively.

Turning to the Southern Hemisphere, Sharon Stammerjohn discussed the seasonally and regionally varying trends in Antarctic sea ice and emphasized their close connection to wind and wind-driven ocean heat transport changes. Scott Hoskins linked the recent warming of West Antarctica to a shift in the Amundsen Sea low, which the CMIP5 models suggest is a manifestation of internal variability. Fumiaki Ogawa proposed that ozone-driven changes in the Southern Annular Mode are sensitive to model representation of oceanic fronts, with larger sea surface temperature gradients enhancing the vertical connectivity between the surface and the stratospheric polar vortex.

SUMMARY. There was recognition that including coupling between atmosphere, sea ice, and ocean can improve forecast skill across a range of time scales. Coupling must therefore be considered across a range of scales appropriate to the time scale of the forecast, from planetary-scale dynamics to subgrid-scale processes in models. It was pointed out that better knowledge is needed as to the dominant causal direction of atmosphere–ocean–ice coupling and polar–midlatitude–tropical interactions and of their physical mechanisms, including the role of the stratosphere. In addition, the effects of model biases on projections for many of the phenomena discussed are still poorly understood.

Participants pointed out that further work is required to elucidate the anthropogenic contribution to sea ice trends and to better understand the character of anthropogenic changes in the large-scale atmospheric circulation. Another key message emanating from the discussion was that Arctic–midlatitude interactions are clearly two way, which complicates attribution of cause and effect. For example, Arctic amplification is itself partially a response to lower-latitude forcing.

Participants suggested that future research with respect to extreme events at high latitudes should be extended to oceanography, biology, avalanches, and visibility. Furthermore, there was a general agreement to enhance stakeholder involvement with respect to polar predictability. Last, workshop participants pinpointed the importance of process-based studies to make progress on research questions where insufficient observations and/or inadequate models hamper assessment of larger temporal- and spatial-scale processes.

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REFERENCES

CliC/AMAP/IASC, 2016: The Arctic freshwater system in a changing climate. WCRP Climate and Cryosphere (CliC) Project, Arctic Monitoring and Assessment Programme (AMAP), International Arctic Science Committee (IASC) Summary Rep., 24 pp. [Available online at http://iasc.info/images/news/2016/AFS_Report.pdf.]

Jung, T., and Coauthors, 2016: Advancing polar prediction capabilities on daily to seasonal time scales. *Bull. Amer. Meteor. Soc.*, **97**, 1631–1647, doi:10.1175/BAMS-D-14-00246.1.