Unendorsed (not funded) Using Complex Networks to Advance Sea Ice Forecast Models

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Areas of contribution

Polar atmospheric processes
Oceanic processes
Modelling and forecasting
Sea ice processes

Summary

Overall objectives are to (1) improve our understanding of the functioning of the climate system and (2) its predictability by investigating relevant underlying physical processes and their interactions. This will be explored using innovative statistical techniques, namely Complex Networks (CN) analysis, that can move the field forward by identifying mechanisms that provide potential predictability at a variety of timescales, with a focus on the sub-seasonal to annual time-scales. While Complex Networks have been gaining traction in Earth science studies, they have yet to be applied to the problem of sea ice predictability. Yet they are powerful tools for studying the structure of statistical interrelationships between multiple time series in various scientific disciplines. The focus of the study is to search for predictive power amongst key climate variables within the Arctic climate system and use the knowledge gained to improve seasonal ice forecasting. Through our collaborations the UK Met Office, we will assess these processes within the Met Office seasonal prediction model GloSea5 and climate model HadGEM3.
Specific objectives include:
1. Compile datasets from observations and CMIP5 of key Arctic climate variables that may hold predictive power.
2. Develop Complex Network analysis suitable to extract meaningful spatio-temporal connections in the polar climate climate system.
3. Apply Complex Network methodology to identified factors controlling sea ice variability and predictability.
4. Test the observed teleconnections within a subset of CMIP5 models. Feed in new understanding in development version of HadGEM.
5. Use increased understanding of processes and machine learning methods to offer operational statistical forecasts with increased skill.

Description

A large number of factors drive the seasonal evolution of Arctic sea ice and potential hold predictive power. These include atmosphere-ice, ocean-ice, land-ice and ice-ice (or preconditioning) interactions. In this study, we will focus on three target interactions that our initial research has shown to offer promise in holding predictive skill for Arctic sea ice and are well-suited for Complex Network (CN) analysis.

Land-Ice:
The potential influence of snow extent upon minimum sea ice was noted some 20 years ago when in 1990 the annual minimum sea ice extent (SIE) was preceded by the lowest spring time northern hemisphere snow extent. In a similar vein, there may be links between snow extent and recent shifts in June atmospheric geopotential height patterns, which in turn are related to atmospheric circulation patterns that lead to greater ice dispersal; with a distinct change since 2007. Geographically based features, such as changes in snow amount and subsequent soil moisture anomalies, temperature changes or albedo alterations can favor blocking patterns and extremes. Our preliminary analysis finds a strong correlation between detrended spring snow extent and September sea ice extent linked to specific regions of Siberia and Russia, and to a lesser extent, Alaska. One hypothesis is that earlier Eurasian snowmelt lowers the albedo, enhances land warming and atmospheric moisture content that is transported over the sea ice. This may also promote amplified Rossby waves to push warmth further north. Another hypothesis is that runoff from early snowmelt provides heat to the ice shelves, which accelerates fast ice decay. River discharge may also contain high values of chromophoric dissolved organic carbon, which absorb solar radiation, leading to enhanced surface warming and lateral ice melt. In our recent study we found river runoff to be positively correlated with the timing of sea ice retreat for the Lena River and the Laptev Sea, but not for the Yenesei/Kara Sea. This supports previous results that runoff has localized impacts.

Ocean-Ice:
Sea ice and ocean mixed layer temperatures in the Arctic are intimately coupled, and upper-ocean temperatures have been used as predictors of sea ice concentration (SIC). Oceanic heat advection in the marginal ice zones drives, for example, clear relationships between summer temperature of Atlantic Water in the Barents Sea Opening and winter sea ice extent in the Greenland-Iceland-Norwegian (GIN) Seas. In the Pacific sector, the Bering Sea heat inflow is driven by the mean wind field in that region and correlates highly with the minimum SIE. Nevertheless, predictability is limited by the chaotic nature of the winds over the summer. On the other hand, the timing of ice retreat combined with Bering Sea heat inflow provides good predictability of timing of ice advance. In our new analysis, we found that the timing of when ice retreats provides predictive skill in the timing of fall ice advance in Baffin Bay, the Laptev and East Siberian Seas as a result of increased ocean mixed layer temperatures. Combining Bering Strait heat influx with the timing of retreat provides further predictability in the Chukchi Sea. Through our CN approach, we will be better able to elucidate the exact processes responsible for the observed relationship, and what additional variables (runoff, oceanic heat flux, atmospheric circulation) can improve the predictive skill. Following this line of investigation and linked with the snow cover analysis discussed above, we can also ask whether the appearance of humid conditions in the Arctic in late May,
which in part drives early ice retreat, is connected to changes in snow cover and and subsequent land surface forcing.

Ice-Ice (or preconditioning):
Sea ice reemergence, where anomalies in SIC or SIE recur at a 5 to 12 month time-lags, has been found to be related in part to sea ice thickness (SIT) anomalies between fall and spring. While SIT and volume may have long-term memory that could be exploited for prediction of SIE, pan-Arctic estimates of these quantities and their associated uncertainties (a necessary requirement for data assimilation) have only recently emerged. Other sea ice factors, such as melt pond fraction show promise in statistical forecasts of pan-Arctic SIE: a prediction based upon a regression of modeled integrated melt pond fraction demonstrated skill at a lead-time of three months. The underlying argument is that emergence of ponds during the early part of the melt season initiates an albedo feedback.

We will perform our Complex Network analysis in three steps. First, we will compute the ‘‘cell-level network’’ from the de-trended anomaly time series of each cell in the spatial grid. Second, we will apply an area identification algorithm on the cell-level network to identify the nodes of the final ‘‘area-level network’’; an area here represents a geographic region that is highly homogeneous in terms of the given climate field. Third, we will compute the weight of the links between areas, roughly corresponding to teleconnections, based on the covariance of the cumulative anomalies of the two corresponding areas. The strength of this methodology is that a global climate network emerges with statistically meaningful climate areas interconnected with links of varying strength. We will proceed in our CN analysis in stages of increasing complexity. We will first analyze single field patterns (e.g. SIC) with linear and zero-lag correlations. Applied to the Arctic, such synchronous link maps provide a direct visualization of SIC correlations between different regions. These correlations can in turn be related to known atmospheric teleconnection patterns.

Timeline

2017-09-01 - 2019-08-25

User relevant aspects

Building on the large group of Sea Ice Outlook (SIO) participants, YOPP initiatives and networking activities at the University College London Center for Polar Observation and Modelling (UCL CPOM) will facilitate the collaboration and communication required to advance the project goals. The “network” in this context is broadly defined as the project team: groups of scientists working on a specific objective within the UK and elsewhere, agency representatives, stakeholders, and the general public. This network will include a diverse range of disciplines and perspectives, and as such, will require a suite of networking activities:

1. Web Portal: A comprehensive and dynamic web portal will be developed to provide timely information on all project activities, products, and results developed at UCL CPOM, and will link to the resources and reports currently available through the SIO (http://acrus.org/sipn) and National Snow and Ice Data Center websites (http://nsidc.org/sipn). Different sections of the portal will be geared towards different user groups (e.g., modelers will find integrated datasets; the public will find information in accessible formats; industry stakeholders will find probability of sea ice conditions). The portal will contain multiple functionalities, including discussion forums, workspaces for dissemination of results, and ‘shared knowledge areas’ (i.e., wiki
and blogs), where the proposal team, outside members of the sea ice prediction and user communities can contribute content and knowledge directly to the website.

2. Activities will leverage other resources by partnering with the Sea Ice Prediction Network (SIPN) that is already partnering with research teams in Canada, the US, the EU, and Norway. Targeted international partners include YOPP and the World Meteorological Organization’s (WMO) Polar Prediction Project, and the CliC Sea Ice Working Group to ensure the broader research community is engaged in progress made by this project.

3. We will continue to participate in webinars hosted by ARCUS and SIPN, throughout the duration of this project and beyond. These webinars provide an open forum for presentation and discussion on targeted topics and project results.

4. The public and media are increasingly aware of changes occurring in the Arctic. This presents both opportunity and urgency for public engagement with scientific research. The visibility and reputation of SIPN, the SIO, and YOPP make these platforms ideal for more effective science communication through active public engagement.

5. Industry stakeholders already have access to predictions made by the SIO and operational agencies such as the Met Office. Through our collaborations with the Met Office, new insights gained by our investigations will be evaluated in the context of how well these models represent important processes and how the models can be improved further to reduce uncertainty in sea ice forecasts, a key objective of YOPP. Improving forecast skill is critical for industry operating in the Arctic, who often need to make million-dollar decisions on when to start and stop operations. Communication of uncertainty in the skill is equally important. Changing the way we present forecasts to industry stakeholders, in terms of probability maps will help them to make more informed decisions.

6. Stakeholder Questionnaire: In the final year of the project, a questionnaire will be distributed to a representative sample of the identified stakeholder community (list generated from collaborations with Adrienne Tivy at the National Research Council of Canada) to assess how well results from our project are currently meeting stakeholder needs for sea ice prediction. Questions will focus on ensuring that our indices, format, and skill of predictions are adequately communicated, and if needed, are refined to ensure predictions are meeting their needs.

**Regional emphasis**

Northern hemisphere: Yes

Southern hemisphere: No

**Key project deliverables**

The research team is committed to complying with our funding agency policies on the preservation, dissemination, and sharing of research data. Specific data generated through this project will be disseminated via the Sea Ice Prediction Network (SIPN) websites (http://acrus.org/sipn and http://nsidc.org/sipn), which is a hub for the sea ice community. PI Stroeve currently manages the SIPN data portal at the National Snow and Ice Data Center (NSIDC) and will ensure continued collaboration between this project and other sea ice prediction efforts. By archiving and distributing data through these existing institutional capabilities, we minimize overall costs. Another benefit to having project data archived at NSIDC is that the User Services staff responds to user requests for data, support, and information in a timely manner. NSIDC follows a team approach in which data
center staff with the appropriate expertise work to develop data sets, supporting web content, tools, and documentation. User Services’ role in this effort is to represent the broader community’s perspective and ensure that adequate information and resources exist to support user inquiries.

Most fields can be stored as 1- or 2-byte arrays, minimizing server space requirements. Since most of the data is in 12.5 km² or 25 km² spatial resolution, or larger (for reanalysis data and model output), the data set is a very manageable archive size given current storage capabilities. We plan to archive not only data fields generated by this project, but also complete metadata including collection and granule level metadata as well as ancillary data inputs, processing steps and source code. Collection level metadata will be compliant with the Content Standard for Digital Geospatial Metadata, Version 2 (FGDC-STD-001-1998) with remote sensing extensions and will be submitted to the Global Change Master Directory (GCMD) in Directory Interchange Format (DIF) for incorporation into the GCMD catalog and dissemination to a broad array of catalog systems including Geospatial One-Stop. Granule level metadata will be compliant with the Climate and Forecast (CF) metadata extensions.

Hindcast model output of sea ice, snow cover, atmospheric data can be hosted at UCL CPOM. We estimate the output will amount to just under 1TB. We arrived at this number assuming 20 models and 1 deg resolution, or 0.13MB for each field. Each model is assumed to provide 1400 runs of 60 months duration each. 1400 runs assumes 10 ensemble members in each of 4 different start times per year for 35 years. We anticipate we will adopt the Climate and Forecast (CF) metadata conventions (used by CMIP5 already) in the netCDF format. The full raw output will be kept at the individual modeling centers. If possible, additional variables and/or greater frequency than monthly will be attempted.

In addition, a comprehensive and dynamic web portal will be developed at UCL CPOM to provide timely information on all project activities, products, and results, and will link to the resources and reports currently available through the SIO and NSIDC websites. Different sections of the portal will be geared towards different user groups (e.g., modelers will find integrated datasets; the public will find information in accessible formats). The portal will contain multiple functionalities, including discussion forums, workspaces for action teams, and ‘shared knowledge areas’ (i.e., wiki and blogs), where members of the sea ice prediction and user communities can contribute content and knowledge directly to the website. A Sea Ice Prediction LinkedIn Group will further strengthen network communication and by building on an Arctic Maritime Transportation LinkedIn forum that includes some of the co-PIs as members will help establish links between stakeholders and the scientific community.

Data management

NSIDC

Is data provided to WMO Global Telecommunication System

No
Real-time provision

if needed, also at NSIDC