Probabilistic Approach for Mapping Landfast and Sea Ice Extent in the Canadian Arctic Archipelago From MODIS at 250m Spatial Resolution

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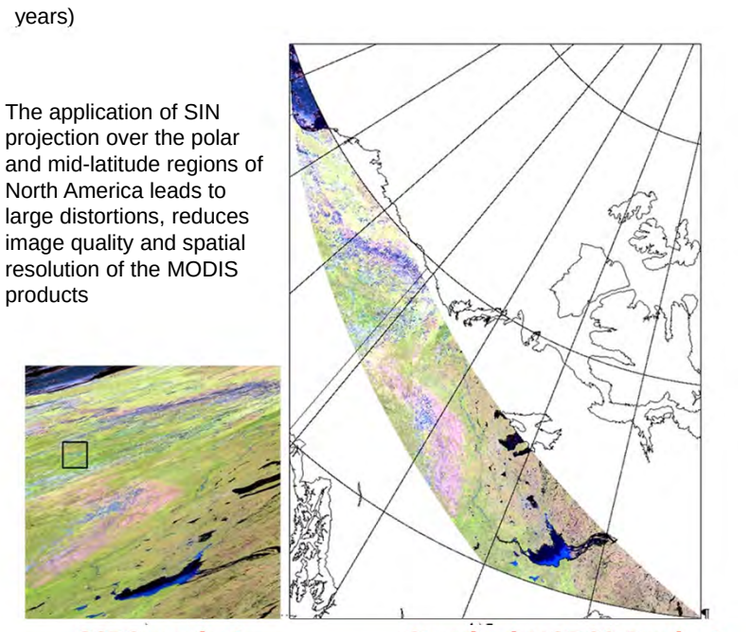
Introduction

- The landfast and sea ice are very important phenomena in the Canadian Arctic Archipelago. It can influence coastline dynamics by changing the effective rate and intensity of the wave and wind erosion during open water periods. It is widely understood that climate changes will alter the current ice regime and lead to significant changes to nearshore and coastline dynamics, the accessibility of remote Arctic communities, subsistence hunting activities and marine transportation routes through the Canadian Archipelago and Arctic Ocean.
- Xia et al. (2014) reported that for summer months (July–October), there was a 34-year (1979–2012) declining trend in sea-ice extent at most regions, except for the Canadian Arctic Archipelago. We took a closer look at this region using our recent MODIS datasets to assess trends for the last 17 years, i.e. since 2000.
- The possibility of using The Long Term Satellite Data Records (LTSDR) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) 250-m imagery at the Canada Centre for Remote Sensing (CCRS) for mapping the sea and landfast ice was investigated. Successful application of the MODIS LTSDR for mapping perennial snow and ice over land has been recently demonstrated by Trishchenko et al (2016). We propose to augment this methodology for characterization of the sea ice features in the Canadian Arctic Archipelago.
- The technique is based on multi-temporal analysis of clear-sky composites produced from MODIS imagery using technology developed at CCRS. The CCRS processing system downscales imagery for MODIS 500m bands B3-B7 to 250m spatial resolution compatible with bands B1 and B2. The clear-sky composites are generated for each 10-day interval (3 per month, 36 per year). The temporal sequence of data for each pixel during the warm season (April-September) is analyzed to produce the snow/ice ID flag. The sequence of flags is then converted into the probability of snow or ice presence over the warm season. This probability map is then used to identify the landfast and sea ice and its year-to-year variability.

CCRS procedure for MODIS 250m downscaling

- Product is generated from original swath (L1B level) i.e. no multiple re-projection steps;
- Employs the correlation between 500m bands B3-B7 and B1,B2 and NDVI at 500m and applies it at 250m;
- Generates bands B3-B7 at 250m resolution using B1, B2 and NDVI with 250m using Adaptive Regression and Normalization;
- 10-day compositing intervals instead of 16-day as in MODIS standard processing chain;
- Two-value (Forward & Backward scattering geometry) composites;
- Instead on MODIS Sinusoidal (SIN) projection, we use
  - Lambert Conic Conformal projection (LCC) for Canada
  - Lambert Azimuthal Equal Area (LAEA) projection for circumpolar Arctic
  - Lambert Azimuthal Equal Area (LAEA) projection for North America (selected years)

The application of SIN projection over the polar and mid-latitude regions of North America leads to large distortions, reduces image quality and spatial resolution of the MODIS products



Some definitions

Landfast ice is the defining feature of the Arctic coast. Barry et al. (1979) provided the following comprehensive description, defining landfast ice as ice that

(i) ‘‘remains relatively immobile near the shore for a specified time interval,’’

(ii) ‘‘extends from the coast as a continuous sheet,’’ and

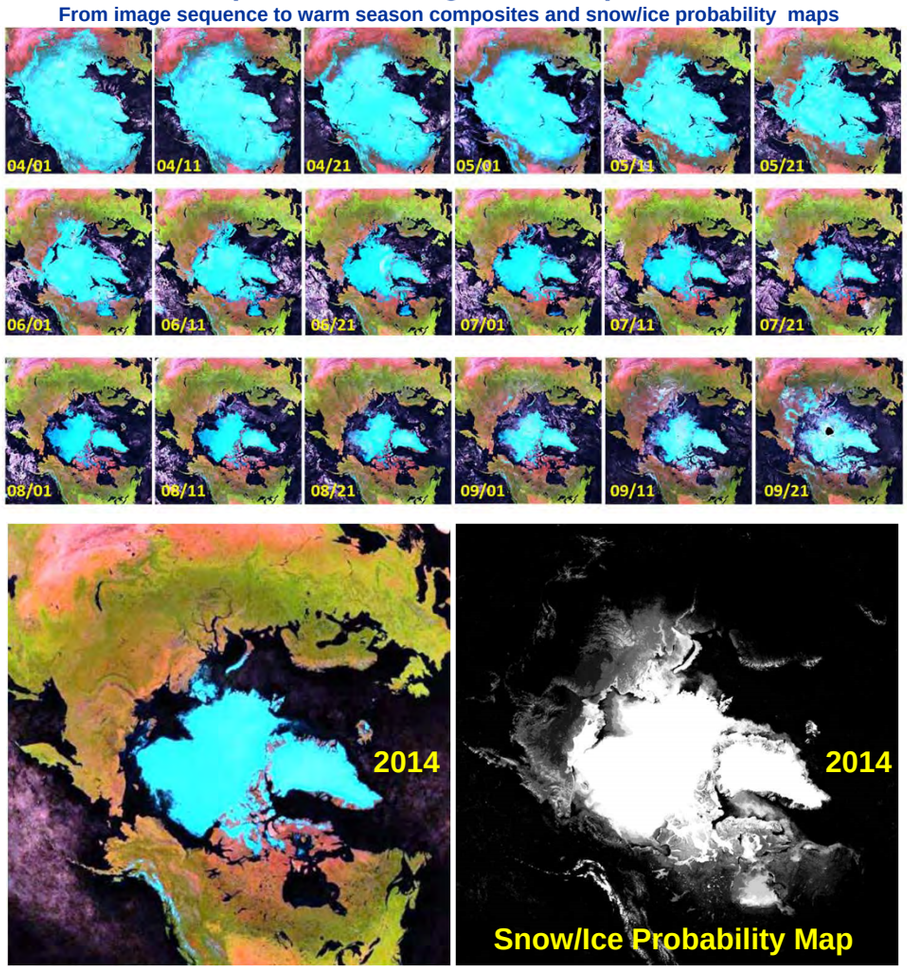
(iii) ‘‘is grounded or forms a continuous sheet which is bounded at the seaward edge by an intermittent or nearly continuous zone of grounded ridges.’’

Covering the shallow shelves and the narrow channels among high Arctic islands, landfast ice can extend offshore from a few kilometers to several hundred kilometers.

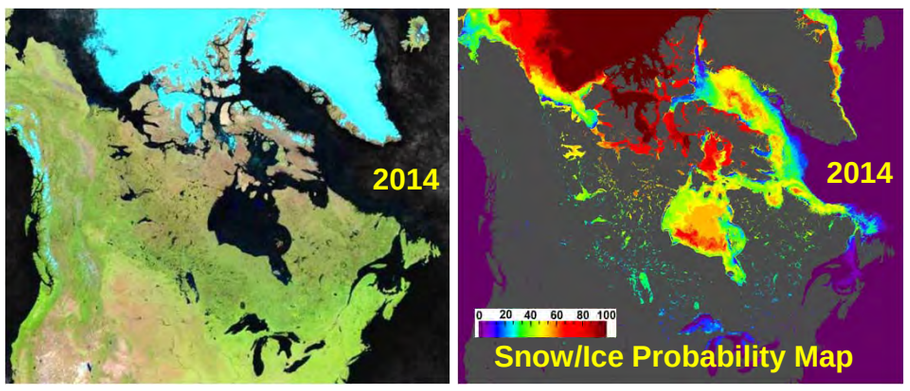
In our study we analyzed **the Summer Minimum Ice (SMI)** extent i.e. an sea ice that persists over the entre summer season from April to September. It includes significant amount of the landfast ice but also possibly some floating ice. The SMI extent is determined from the probability maps based on 10-day composites over period: Apr 1-Sept 20 (i.e. 17 intervals) and computed from sequence of satellite images: (Nsnow&ice)/MaxNumber*100%. Image examples from 2014 are shown below for the circumpolar Arctic, Canadian Arctic and Canadian Arctic Archipelago regions. There are some topological challenges in the accurate definition and delineation of landfast ice for a complex coastline structure in the Canadian Arctic Archipelago.

Circumpolar Arctic Region: Example for 2014

From image sequence to warm season composites and snow/ice probability maps



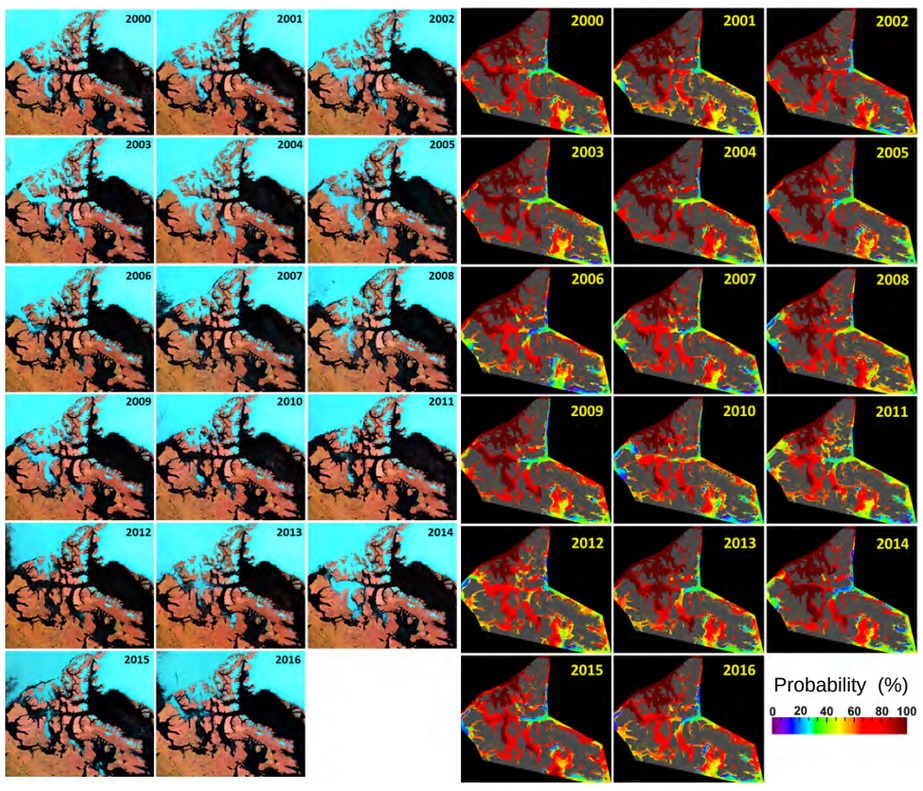
Canada, Northern US and Neighboring Regions



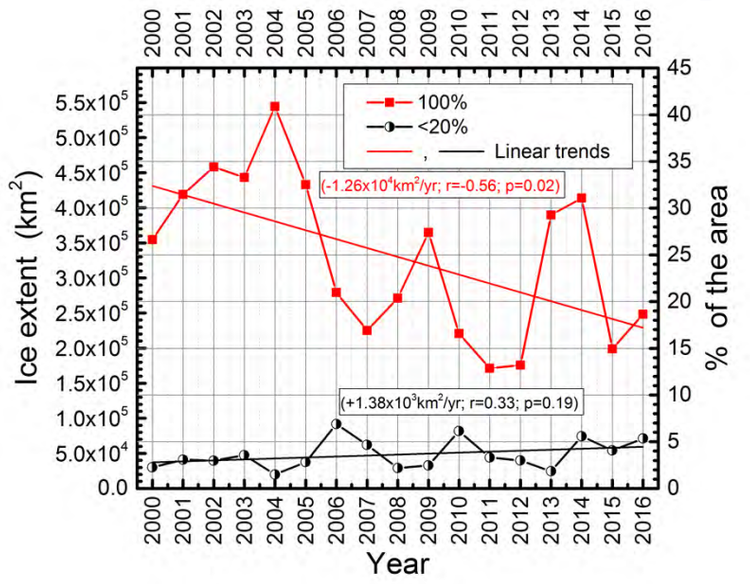
Canadian Arctic Archipelago: 2000-2016

Warm season clear-sky composites

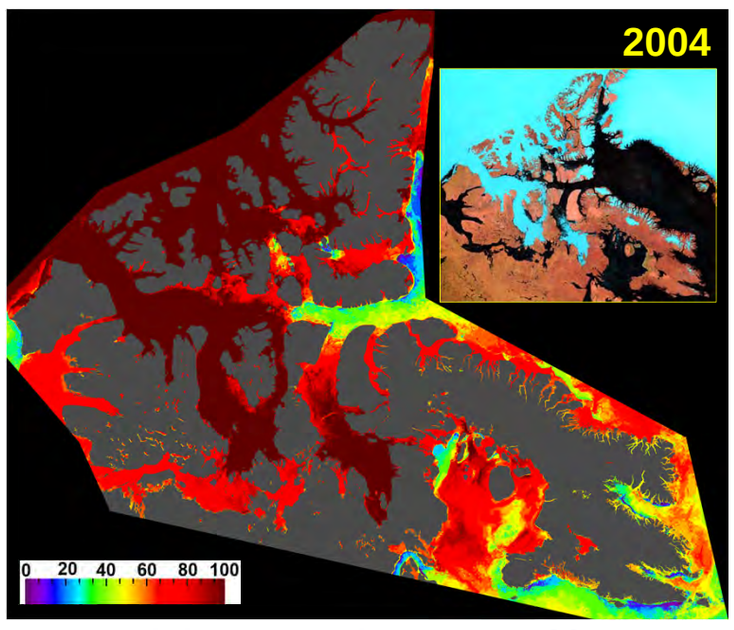
Warm season ice probability maps



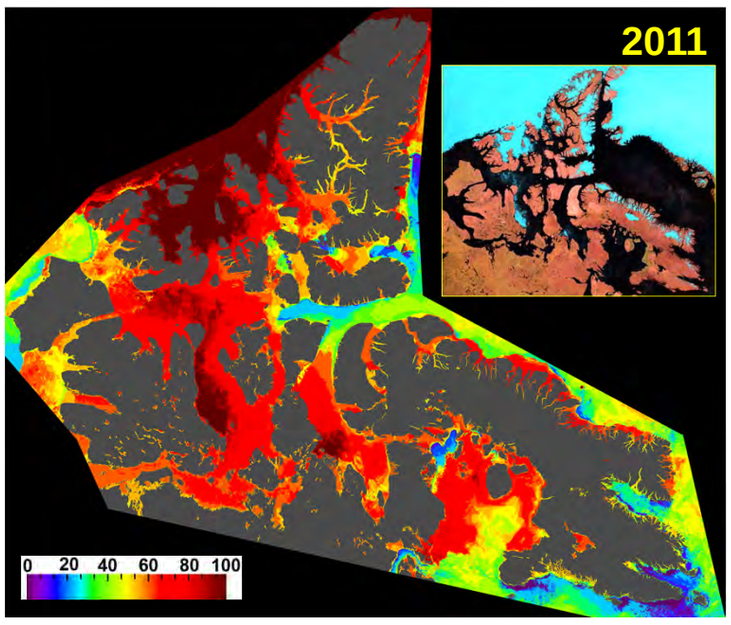
Interannual variations in landfast and sea ice extent in Canadian Arctic Archipelago



Maximum sea ice extent- 2004



Minimum sea ice extent- 2011



Conclusions

1) The extent of Summer Minimum Ice (SMI) (i.e. landfast and sea ice that persists over the entre summer season from April to September) was analyzed for period 2000-2016 in the Canadian Arctic Archipelago using CCRS-developed MODIS processing technique. It was derived from the warm season ice probability maps;
2) The average sea ice extent (100% probability) in the Canadian Arctic Archipelago region (as defined in this study) for 17-year period 2000-2016 was found to be 0.33×10^6 km^2 (24.8% of the water area) with minimum 0.17×10^6 km^2 (12.9%) in 2011 and maximum 0.544×10^6 km^2 (40.9%) in 2004. The open water (ice prob <20%) extent is on average 0.48×10^5 km^2 (or 3.6% of the total archipelago water area);
3) Analysis of sea ice probability over 17-year period revealed a significant (r=-0.56, p=0.02) negative trend (1.26×10^4 km^2 /yr decrease) for sea ice extent at 100% probability. A positive trend (increase 1.38×10^3 km^2 /yr) for areal ice extent with less than 20% probability was detected, although statistically less significant (p=0.19);
4) There are some topological challenges in the accurate definition and delineation of landfast ice for a complex coastline structure in the Canadian Arctic Archipelago;
5) Separating the landfast ice and floating sea ice remains a challenge due to significant ice drift that cannot be quantified from multi-day and seasonal composites.

Acknowledgments

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- MODIS data used for generating images and retrievals were acquired from the NASA archive.

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