Team 1: Marine and Climate System

Team Members

Manitoba Hydro
Kevin Sydor: Team co-lead

Academic team

David Barber (Prof.)	Project PI, sea ice geophysics, remote sensing
Jens Ehn (Associate Prof.)	Team lead, physical oceanography, sea ice geophysics, optics.
Greg McCullough (Researcher)	Limnology, oceanography, optics.
Jennifer Lukovich (Researcher)	NEMO model team coordinator, Arctic climatology, sea ice drift patterns.
Igor Dmitrenko (R. Prof.)	Physical oceanography.
Simon Bélanger (Prof.)	Ocean color remote sensing, CDOM
Sergei Kirillov (Researcher)	Mooring design and deployment, physical oceanography
David Babb (Researcher)	Sea ice dynamics and mass balance.
Jennifer Bruneau (RA)	Remote sensing of polynyas in NW Hudson Bay
Atreya Basu (PhD)	Freshwater tracing, sediment dynamics, and remote sensing
Vlad Petrusevich (PhD)	Physical oceanography, acoustics, mooring operations
Madison Harasyn (MSc, RA)	Microwave remote sensing of ice, Unmanned aerial vehicles (UAV).
Yanique Campbell (MSc)	Surface wave development in sea ice fields
Kaushik Gupta (PhD)	Coastal geomorphology, landfast sea ice climatology
Anirban Mukhopadhyay (PDF)	Satellite remote sensing, sediment dynamics, SST climatology and trends
Christopher Peck (PhD)	River plume dynamics in James Bay and impacts on eelgrass beds
(Nathalie Theriault (Researcher)	Investigating climate-ice relationships using remote sensing)
(Masayo Ogi (RA Prof.)	Teleconnections between Arctic and temperate climate)

Team 1: Objectives from proposal

GENERAL OBJECTIVE:

- **CLIMATE VS. REGULATION**: Understand and differentiate between how changes in climate variability and regulation affect processes related to mass and energy exchange between the freshwater, marine, sea ice and atmosphere systems.

HYPOTHESIS:

- ***H1.1:*** *The **spatial and temporal pattern of Bay-wide sea ice** growth and decay is a dominant factor forcing freshwater-marine coupling processes in Hudson Bay.*

- ***H1.2:*** *The **seasonality and magnitude of river runoff** is a dominant factor controlling freshwater-marine coupling processes in Hudson Bay.*

- ***H1.3:*** ***Climate variability and change** directly affect the vertical mixing and horizontal distribution of fresh and marine waters in Hudson Bay.*

More specific objectives of Team 1

- **PROCESS UNDERSTANDING**: Advance the understanding of the physical processes (related to mass and energy exchange between the land, marine, sea ice and atmosphere) in the climate and marine system that control the input and distribution of freshwater in Hudson Bay.
- **FRESHWATER TRACING**: Determine the distribution (horizontal and vertical) and origin (**Arctic inflow, sea ice melt, or river runoff**) of freshwater in Hudson Bay <u>over the seasonal cycle</u>. Various tracers are used: salinity, CDOM, oxygen isotope ratios, and remote sensing.
- **DOCUMENT CHANGES**: Collect new data and use available observational records (such as remote sensing products, climate reanalysis products, oceanographic mooring and survey data, weather station data) to characterize changes and variability in the Hudson Bay climate, marine and sea ice systems.
- **MODEL VALIDATION and UTILIZATION**: Contribute to NEMO ocean modelling efforts by Team 6 to address questions related to interannual, bay-wide scale changes caused by climate variability, trends, and hydroelectric regulation.
- **CONTRIBUTE DATA:** Contribute baseline oceanographic data for Teams 3 to 5.

Team 1: Results and updates

Task 1.1	**Winter Estuary Survey**
Task 1.2	**Spring/Summer Survey**
Task 1.3	**Moorings**
Task 1.4	**Remote Sensing**
Task 1.5	NEMO modelling → Team 6

The research of Team 1 involve the study of the
i) estuarine and coastal hydrographic regime,
ii) trends and dynamics of the sea ice cover, and
iii) offshore bay-wide hydrographic regime.

This is done through four tasks: 1.1-1.4. Results from all tasks are used to address each objective of Team 1.

Team 1: Results and updates

Task 1.1

Task 1.2

Task 1.3

Task 1.4

Winter Estuary Survey

The goal of Team 1

(i) characterize the ice cover in the two estuaries: e.g., morphology, growth/decay, physical properties…

(ii) study sub-ice freshwater-marine mixing and circulation processes in the estuaries of Nelson River and Churchill River.

Field work COMPLETED

Manuscripts

- Ice dynamics and drift using beacons and satellite products (Lukovich, Babb et al, in prep).
- Sea ice thickness distributions in Nelson and off Churchill (also includes past data (Babb et al, planned)
- Storm-induced landfast ice extent increase, tidal dampening and hydrography in Nelson Estuary (Gupta, Kirillov et al, planned)

Team 1: Results and updates

Task 1.1

Task 1.2

Task 1.3

Task 1.4

Spring/Summer Survey

Objective of Team 1 is to study processes governing

(i) the mixing of freshwater with seawater (offshore and estuaries)

(ii) the horizontal distribution of freshwater content throughout Hudson Bay and Hudson Strait, and in greater detail in coastal waters near river estuaries surrounding the Bay. Include distinguishing between sea ice melt and river runoff sources of freshwater.

(iii) Sea ice physical and electromagnetic properties during the melt.

(iv) Mooring operations

Field work COMPLETED

Manuscripts

- Influence of surface sediment on passive microwave signatures of first year sea ice (Harasyn et al., 2019, published)
- Characteristics of thick, fresh sediment-laden ice (Barber, draft)
- Algorithm validation and remote sensing of CDOM/TSS to evaluate Nelson/Hayes R. plume dynamics (Basu, draft)
- In-situ data (S, CDOM, O18) + remote sensing of CDOM/TSS to trace river runoff in Hudson Bay (Basu, in prep.)
- Study of wave characteristics in Hudson Bay/Nelson Estuary during ice covered and open water periods (Campbell, prep.)

Team 1: Results and updates

- Task 1.1
- Task 1.2
- **Task 1.3**
- Task 1.4

Moorings

i. to complement and extend ice- and data collected during field campaigns
ii. Understand temporal variations in ice and ocean properties
iii. to assist in comparing fluvial-marine mixing and sediment transport processes in open water and sub-ice conditions.

<u>Field work COMPLETED with recovery of 4/5 moorings</u>. Baysys mooring components redeployed in Belcher Islands and Southampton Island.

<u>Manuscripts</u>

- Ice thickness E-W asymmetry across HB (Kirillov et al., Submitted)
- DVM of zooplankton controlled by light and tides (Petrusevich, submitted)
- Wind-driven ocean dynamics at AN01 (Dmitrenko, draft in prep)
- Evidence of freshening and increased stratification from year-long timeseries (Ehn, in prep)
- Dynamic properties of of sea ice: a view from below (Babb, in prep)
- Wave characteristics in HB/NE during ice-covered and open water periods (Campbell, planned)
- Temporal changes in hydrography and sedimentation at mouth of JB compared to HB wide and LG estuary (Peck, planned)

Team 1: Results and updates

Task 1.1	Winter Estuary Survey
Task 1.2	Spring/Summer Survey
Task 1.3	Moorings
Task 1.4	**Remote Sensing** (i) Microwave satellite data for the timing and extent of sea ice formation and decay (*Hochheim and Barber, 2014; Andrews et al 2017*). (ii) Ice thickness using satellite altimetry (Landy et al., 2017, published). (iii) Identification and characterization of the polynya in NW Hudson Bay (Bruneau, Babb et al., Manuscript in prep.) (iv) Optical satellite data will be used to map seasonal and inter-annual patterns of the river plume (Basu et al., Draft) (v) SST pattern and trends over 2008-2018 (Mukhopadhyay, Manuscript in prep.) (vi) Landfast sea ice patterns and trends using CIS ice charts (Gupta, Manuscript in prep.)

3.1.5 Gaps and Recommendations

- To accurately estimate the sea ice transport within HBS, reliable data on ice thickness and drift is required. However, **ice drift products in the Hudson Bay derived from satellite data need to be additionally qualified**. We found that NSIDC 25-km Polar Pathfinder sea ice motion vectors tend to underestimate the ice drift speeds, while the EUMETSAT OSI-405-c ice drift product has low spatial resolution of 62.5 km.
- From intercomparison of NEMO model and in-situ mooring data, it was found that the **NEMO model tends to overestimate the rate of vertical mixing**. This leads to considerably deeper penetration of seasonal signal of both temperature and salinity, and shift of seasonal maximum at depth to earlier dates. As a result, the freshwater cycle in surface and bottom layers might be not represented well in the model results. Further work is needed to evaluate the vertical mixing in the model.
- We gained **limited observational understanding of Hudson Bay deep water** properties, ventilation, renewal during Baysys field programs. Still cannot say % of Pacific vs Atlantic source with more certainty.
- **Satellite estimates** of freshwater-marine interactions in estuaries and offshore **limited by few data points** with coincident measurements of all needed variables: remote sensing reflectance, apparent optical properties, and the inherent optical properties of the optically active substances (CDOM, sediment, phytoplankton). Majority of past field experiments have focused on subsets of the required data. Future fieldwork should emphasize the collection of complete optical datasets across the coastal continuum spanning the river mouth, across the estuary to the offshore marine waters.

3.1.5 Gaps and Recommendations

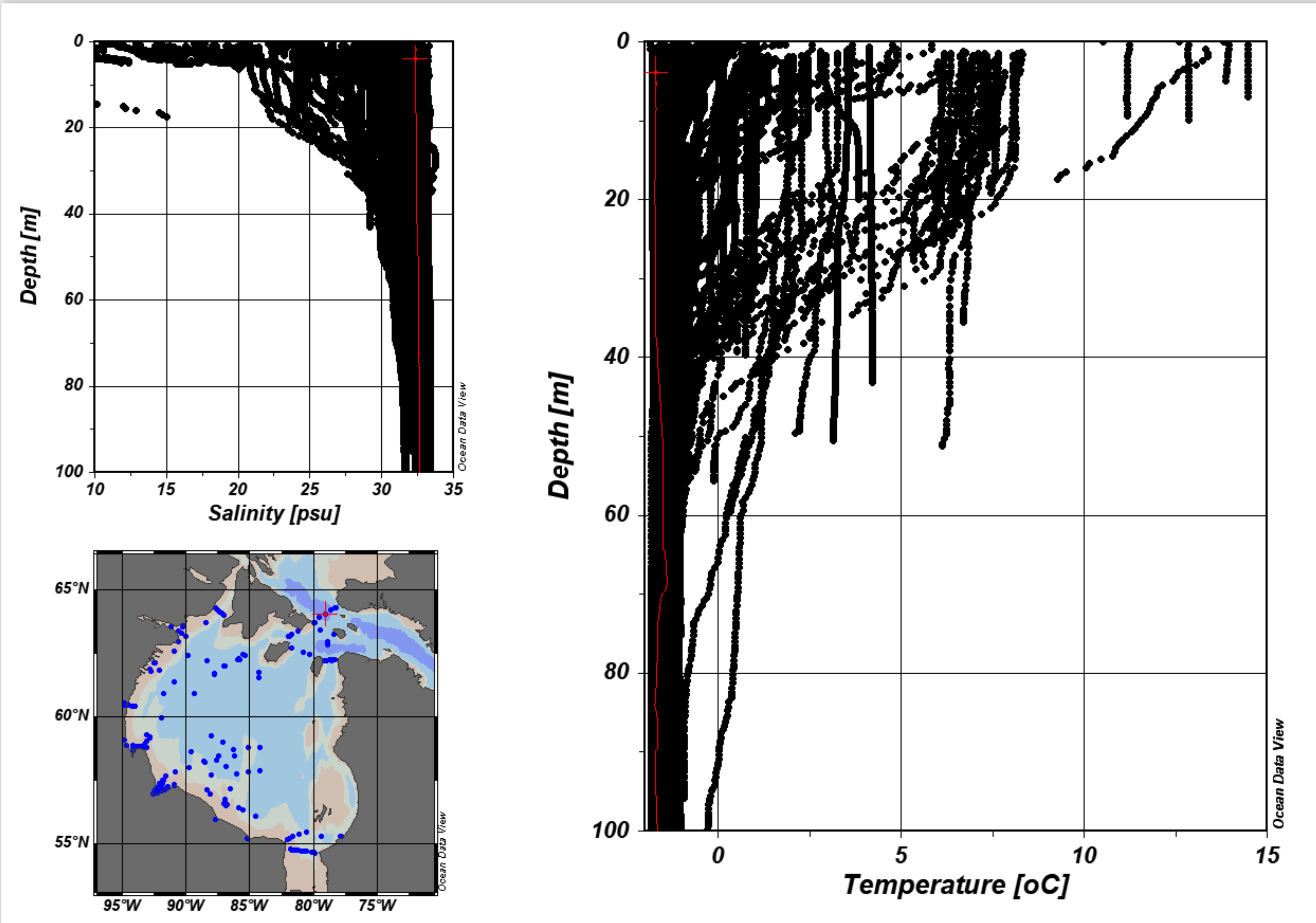
- Due to a **lack of match-ups between satellite imagery and in-situ observations** (due to clouds and limited field work opportunities), future work would benefit from the development of a high-resolution numerical model for the Nelson-Hayes estuary. Manitoba Hydro has conducted such modelling using MIKE by DMI, however, open source models such as Delft3D or FVCOM would promote broader scientific studies of plume spreading and dispersion during various conditions.
- Volume and freshwater transport in and out of the Hudson Bay through Hudson Strait and Fury and Hecla Strait are based on very limited data, that are decades old. Considering changes to Arctic-wide freshwater content, **new monitoring of gateways** seems necessary.
- The tidal flaw leads along the landfast ice edge in Hudson Bay are dynamic areas where open water form semi-diurnally and sites of frequent, rapid ice growth. Ice within the flaw lead becomes heavily deformed, often forming grounded ridges on the tidal flats, that may enter the mobile pack ice and drift through the melt season. The **formation and deformation of deformed ice within the flaw leads** has not been directly studied and would be of both regional and broader interest.
- On a broader scale, **in-situ observations of ice thickness are still a limitation** in Hudson Bay and would be beneficial to validate the spatial variability identified in the remotely sensed fields of ice thickness. Satellite altimeter sea ice products will need field validation.

RESULTS

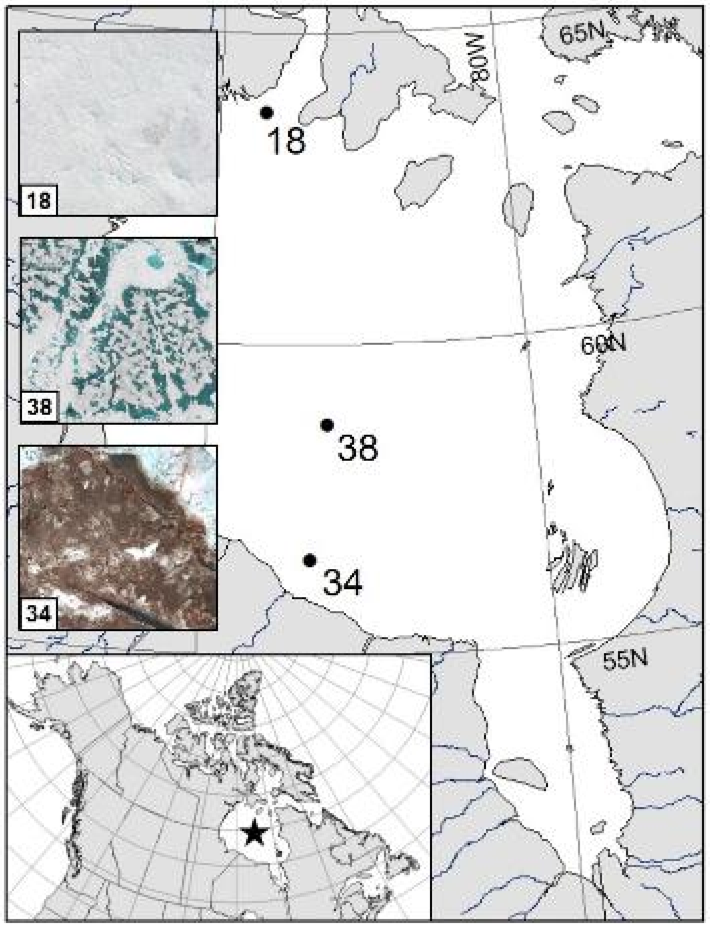
Tasks 1.1-1.2 – Ship-based surveys

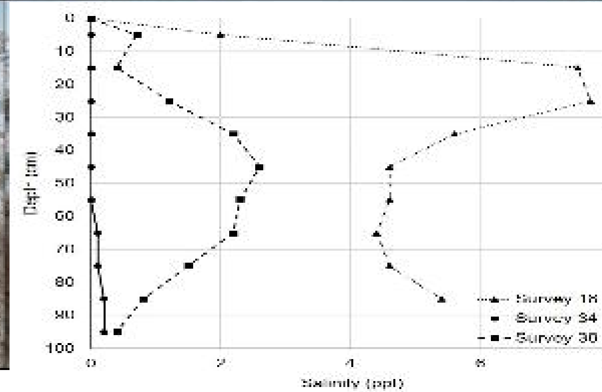
Task 1.1-1.2: All CTD data retrieved during BaySys

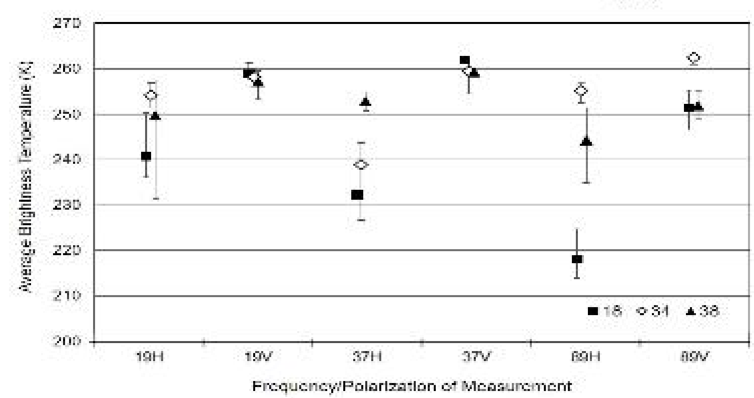
(Des Groseilliers, Henry Larsen, Nanuk, Churchill helicopter, Amundsen)



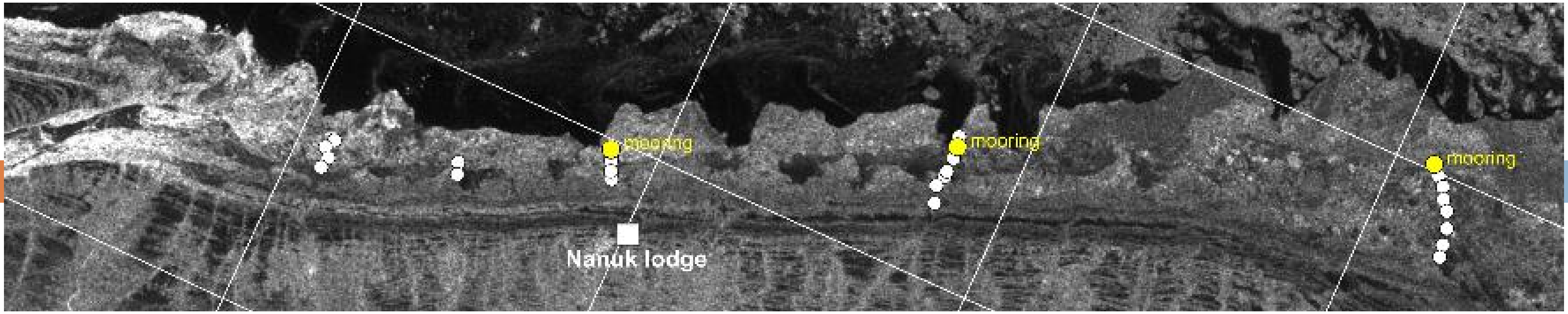
Published paper: Harasyn et al 2019: **The influence of surface sediment presence on observed passive microwave brightness temperatures of first year sea ice during the summer melt period**



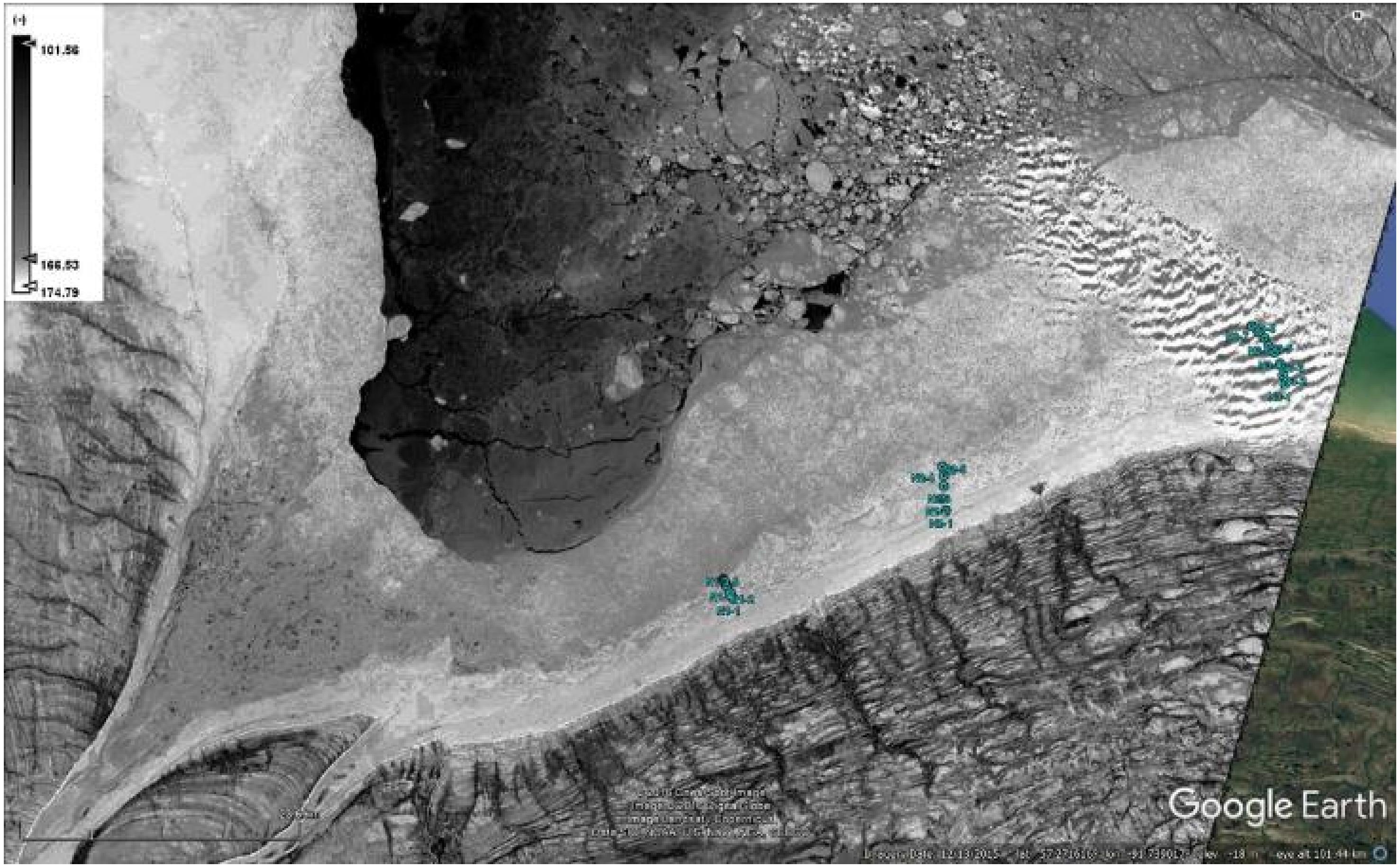




12 Feb 2017

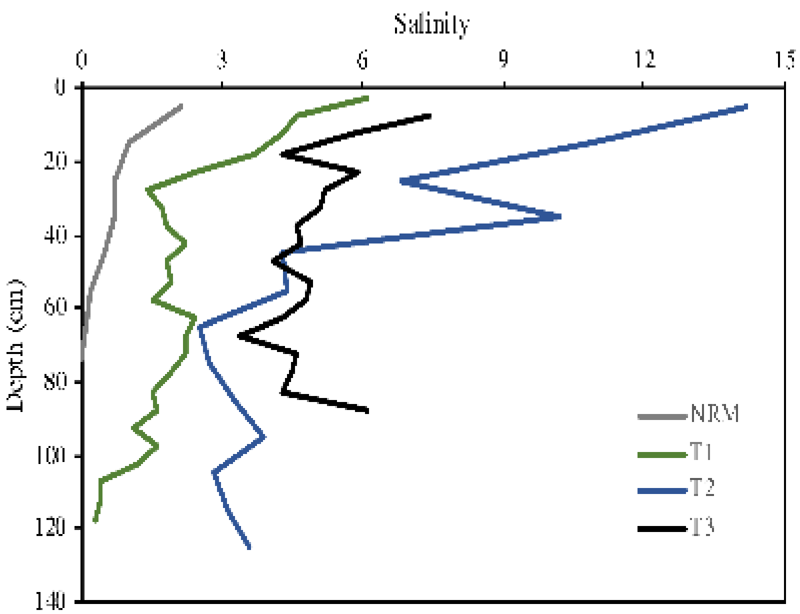


24 Mar 2017
(Landsat)



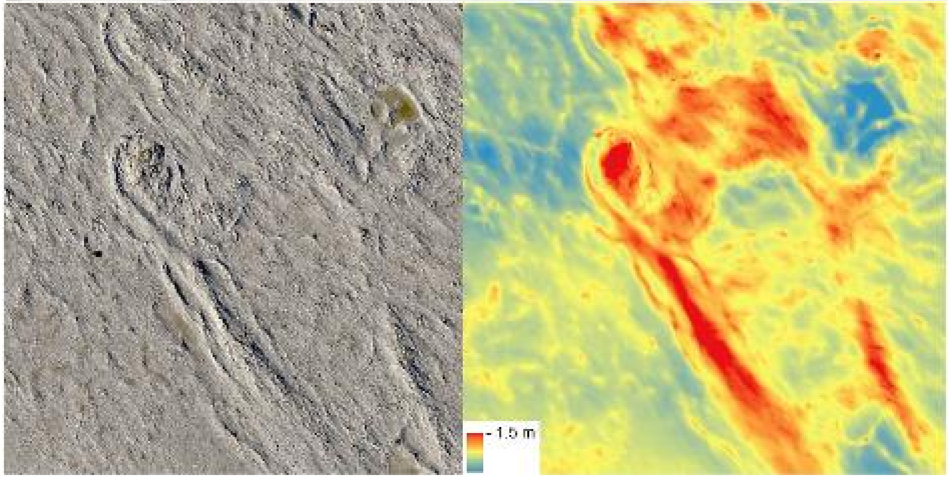
Ice packed in after storm on ~ 8 March

Physical properties & surface topography



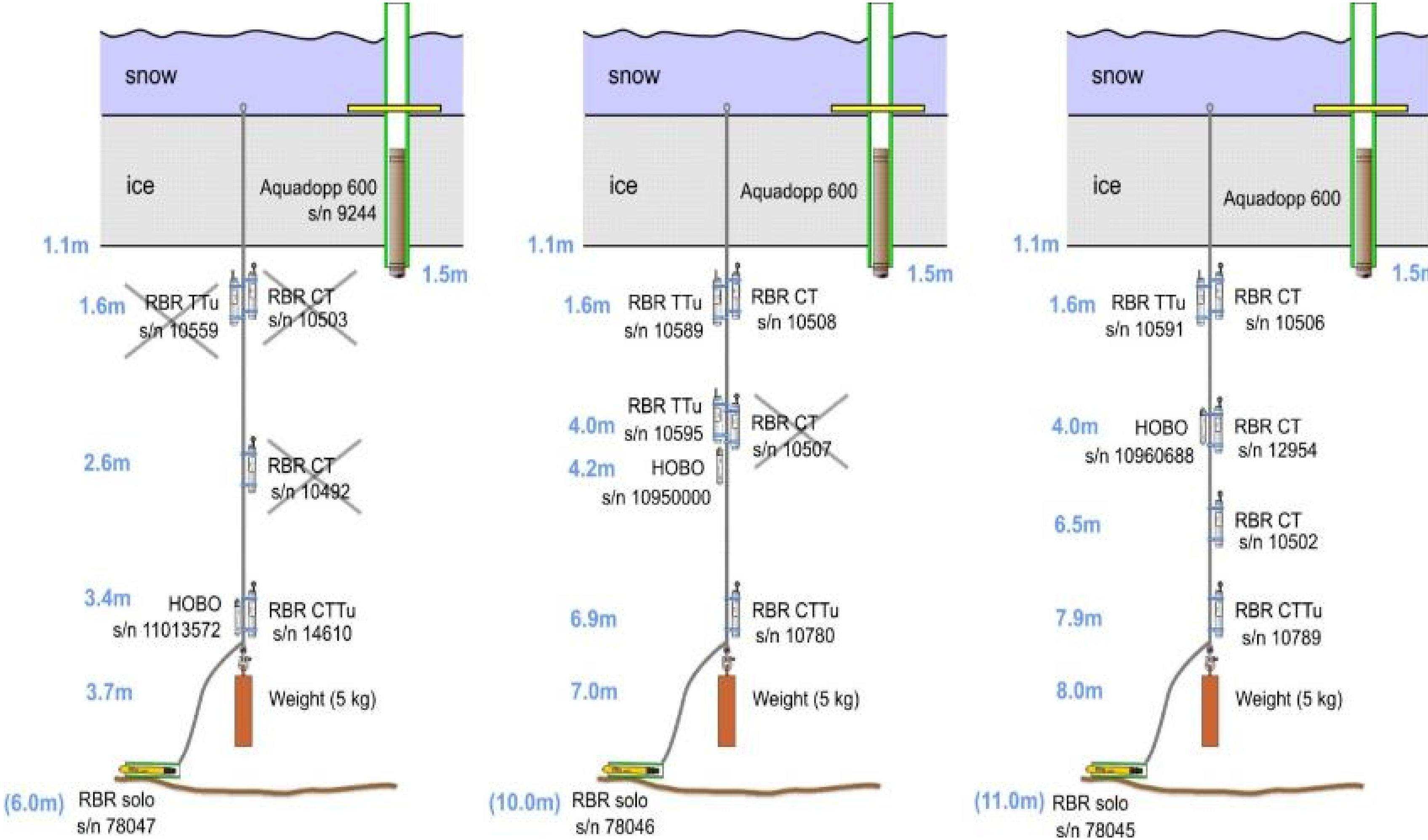
Sea ice salinity profiles from 4 locations on the landfast ice cover collected during Leg 3 (April). NRM is the Nelson River Mouth. Samples were sectioned at 10 cm intervals.

Drone survey locations



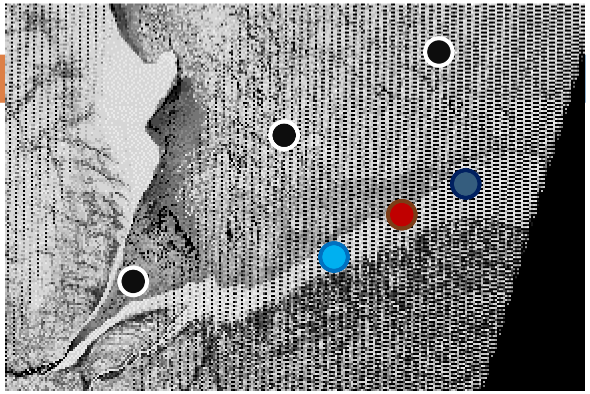
A sample photo mosaic and DEM derived from survey #27 over a ridge in the landfast ice cover near Nanuk.

Tasks 1.1 & 1.3 – Winter estuarine survey + moorings

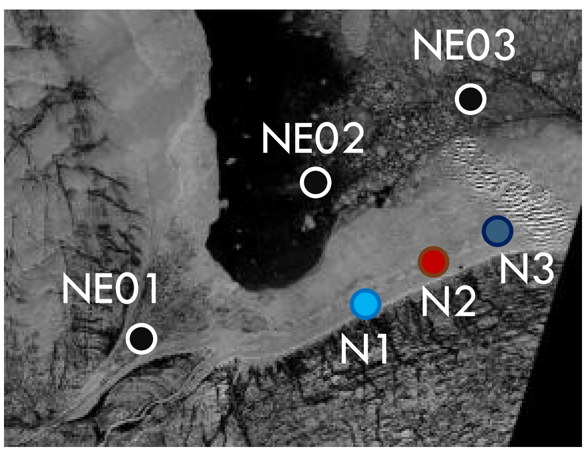


The scheme of ice-tethered moorings. The crossed out sensors indicate units that do not contain reliable records.

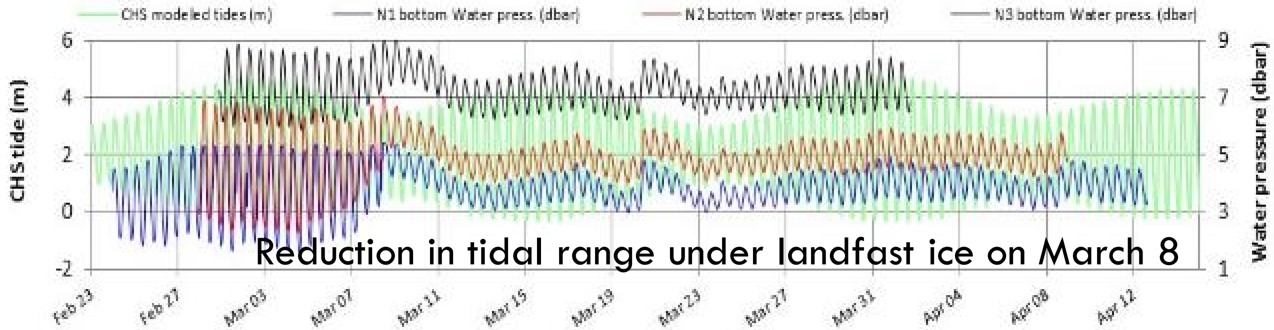
Tasks 1.1 & 1.3 – Winter estuarine survey + moorings

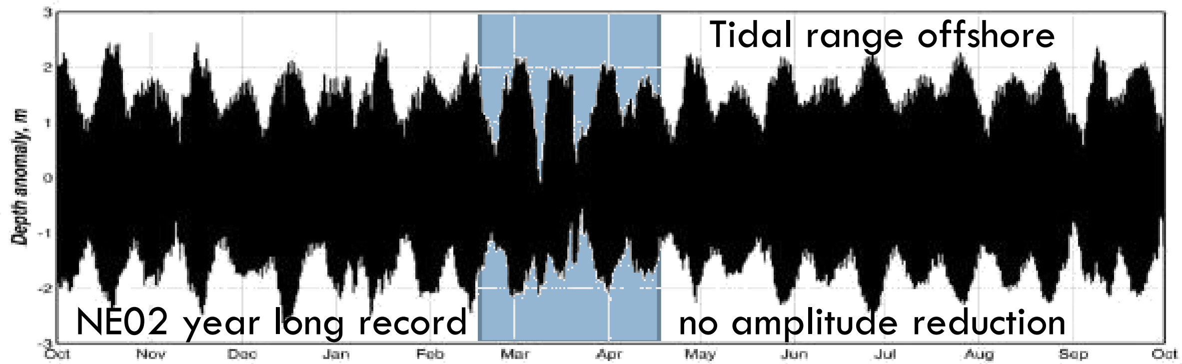


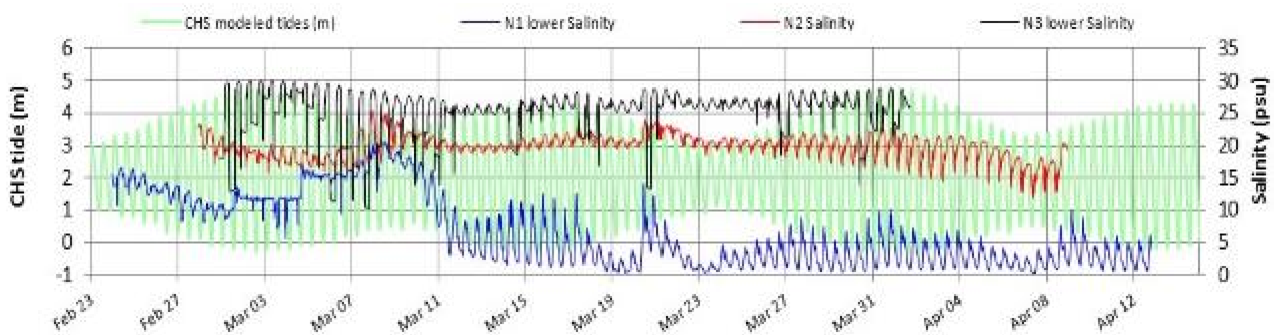
20 Feb 2017



24 Mar 2017

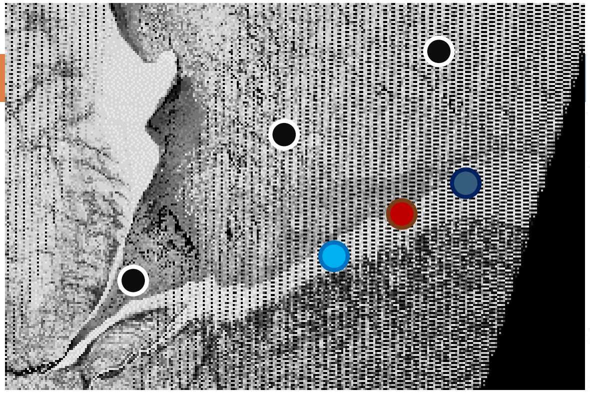




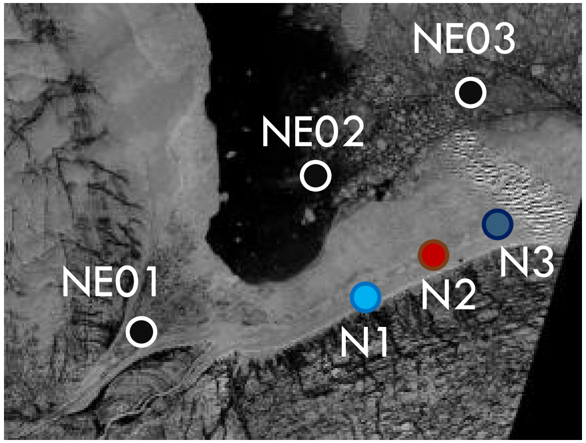


Salinity record under landfast ice fringe

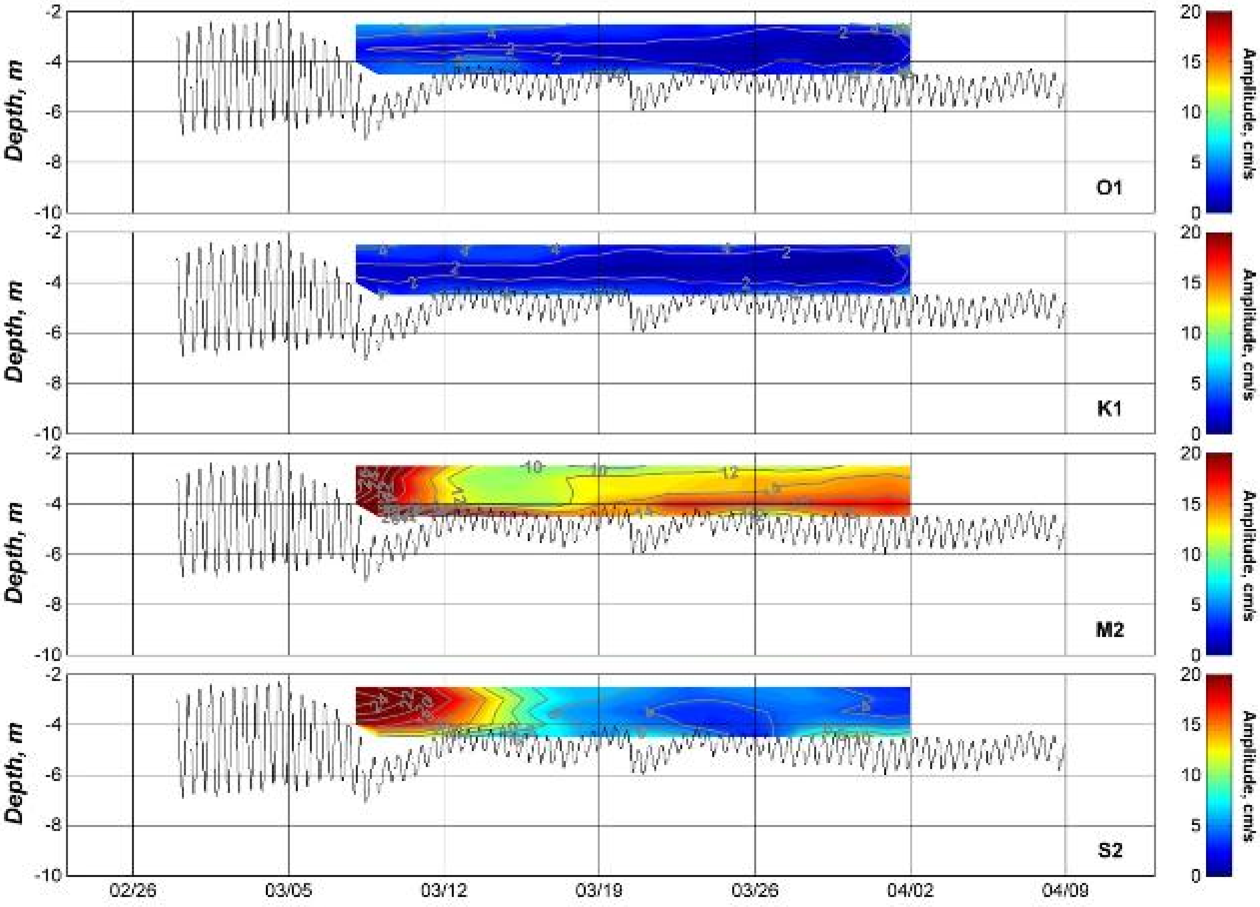
Tasks 1.1 & 1.3 – Winter estuarine survey + moorings



20 Feb 2017



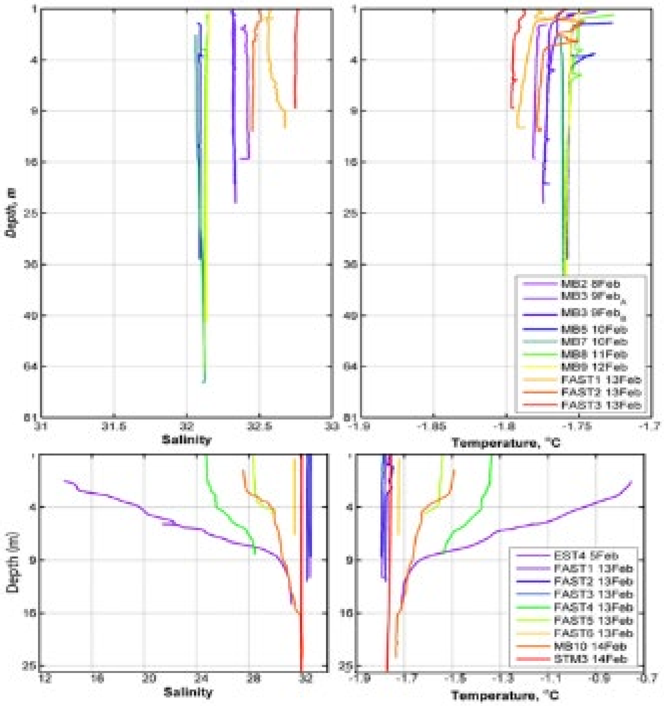
24 Mar 2017



Temporal evolution of the most energetic constituents of tidal currents as measured at N2 position.

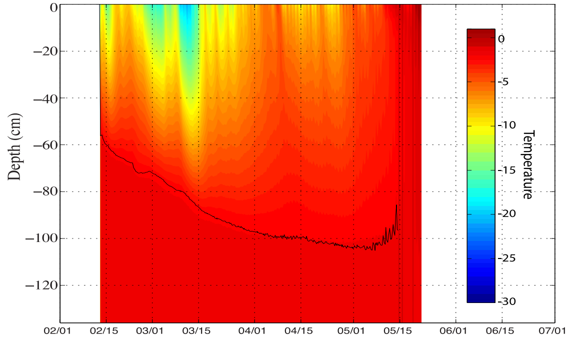
Task 1.1 –Winter helicopter survey

- February 1 – 15, 2017
- Team 1 – Dave B., Jack & Nic
- Team 1 objectives:
  - Collect in situ ice and water samples
  - 14 ice beacons + 3 IMB's deployed (two failed in late Feb) and transmitted position every hour.



Tidal driving drift

Thermodynamic growth



RESULTS

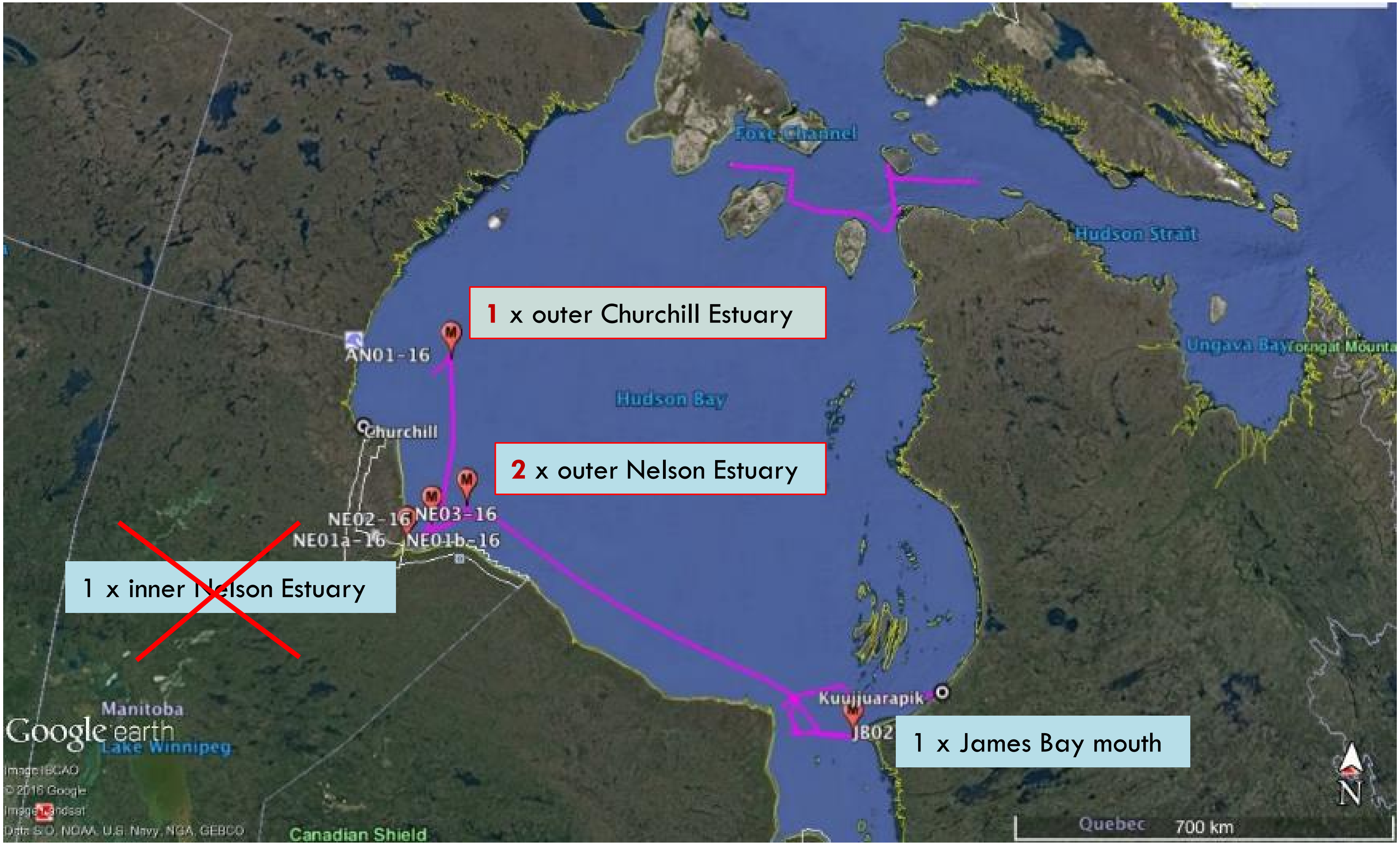
Tasks 1.3 – Moorings

Task 1.3 – Moorings

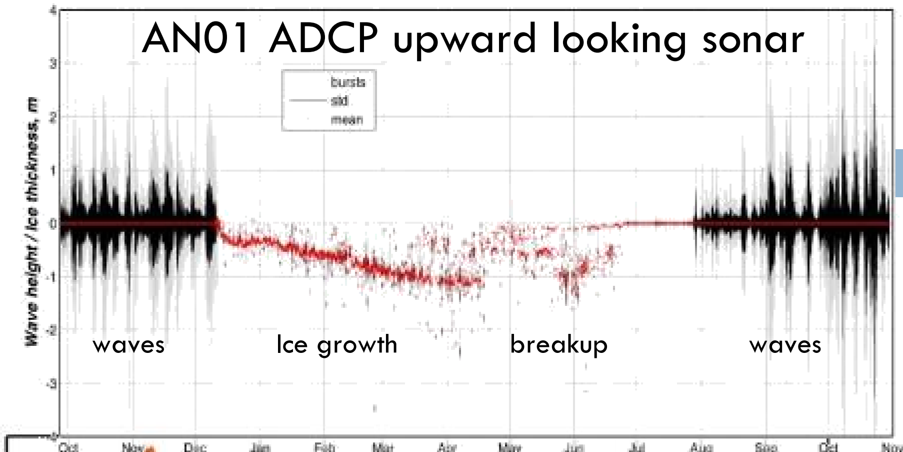
5 Deployed during Fall cruise in Oct 2016 from onboard CCGS *Des Groseilliers*

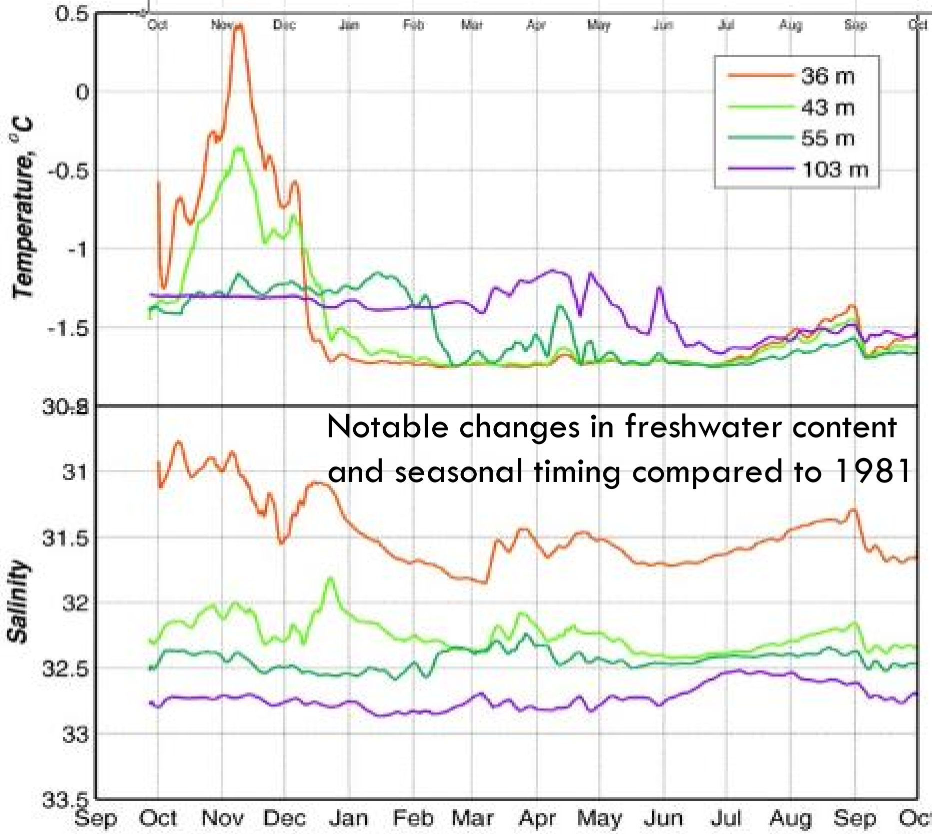
3 Recovered and redeployed during November 2017 (Sergei, Vlad, Chris)

4 recovered during September 2018 using R/V William Kennedy (Vlad, Keesha)

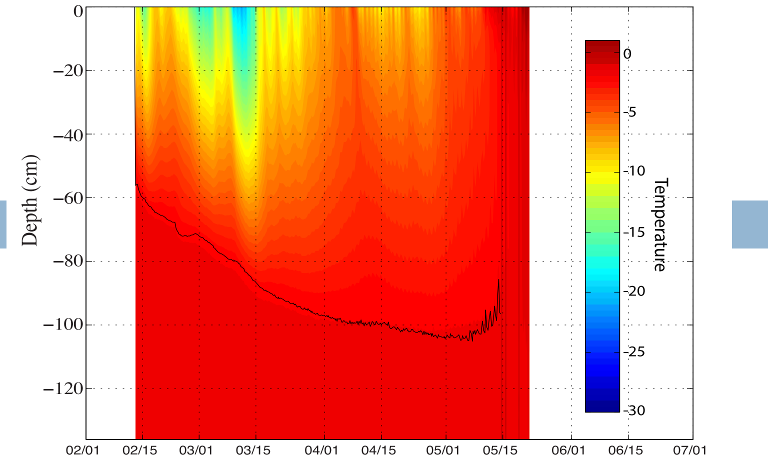


Task 1.3 – AN01 mooring results



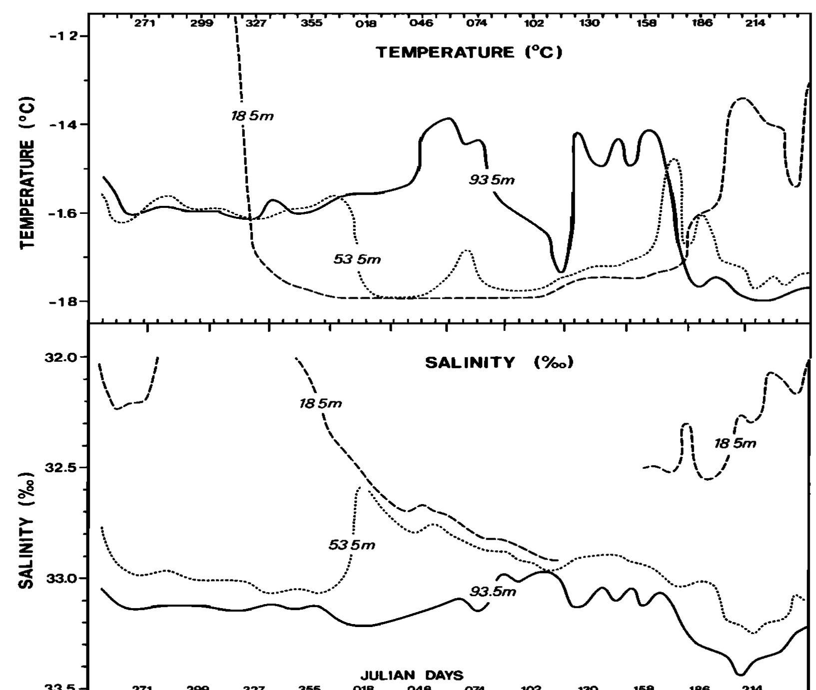


2016-2017



Concurrent SIMBA ice mass balance buoy

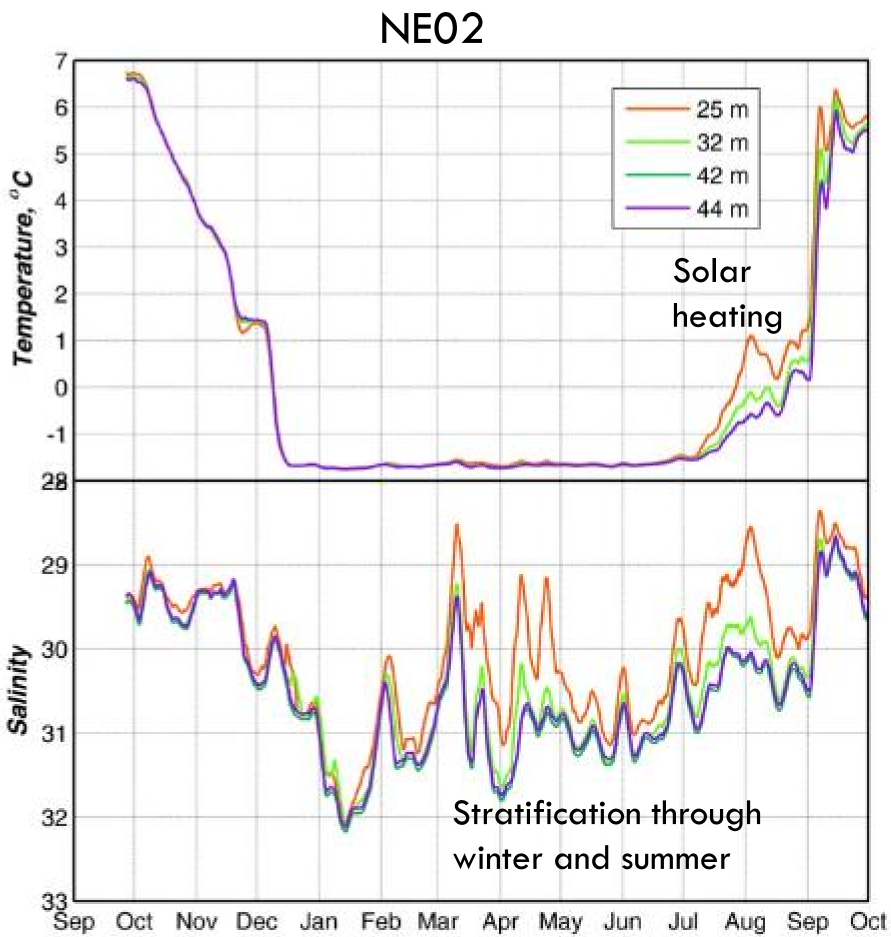
PRINSENBERG: SEASONAL CURRENT VARIATIONS OBSERVED IN WESTERN HUDSON BAY

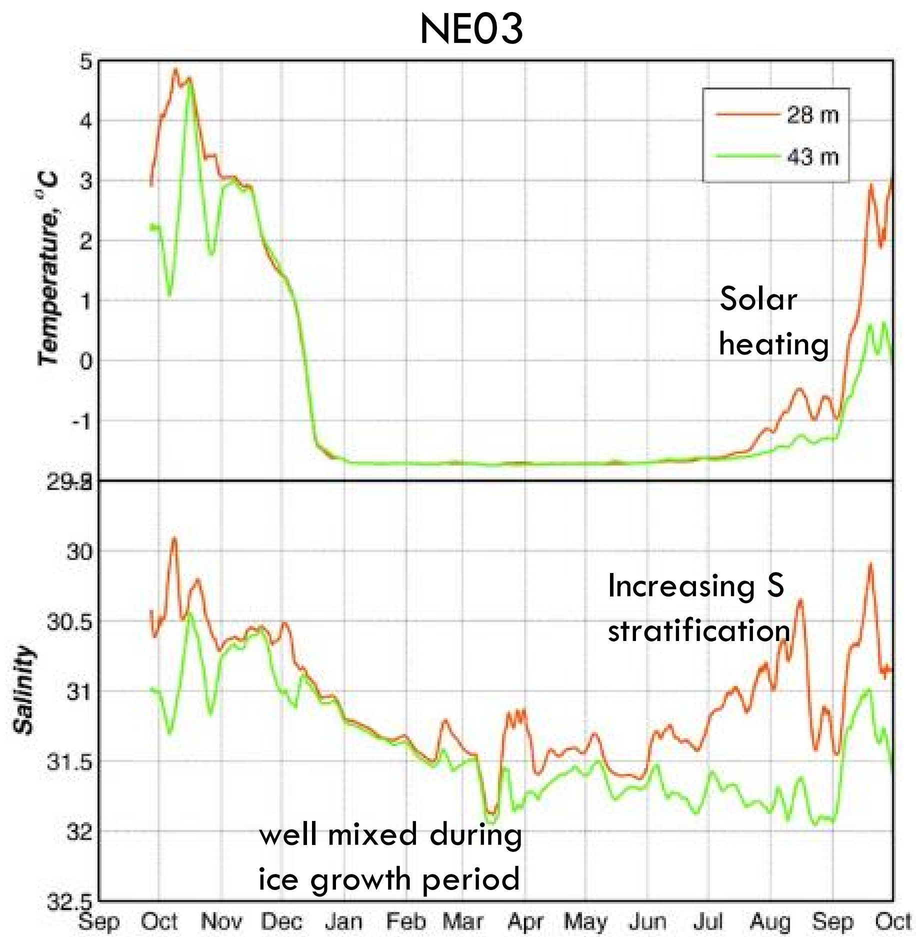


1981-1982 data from Prinsenberg 1984

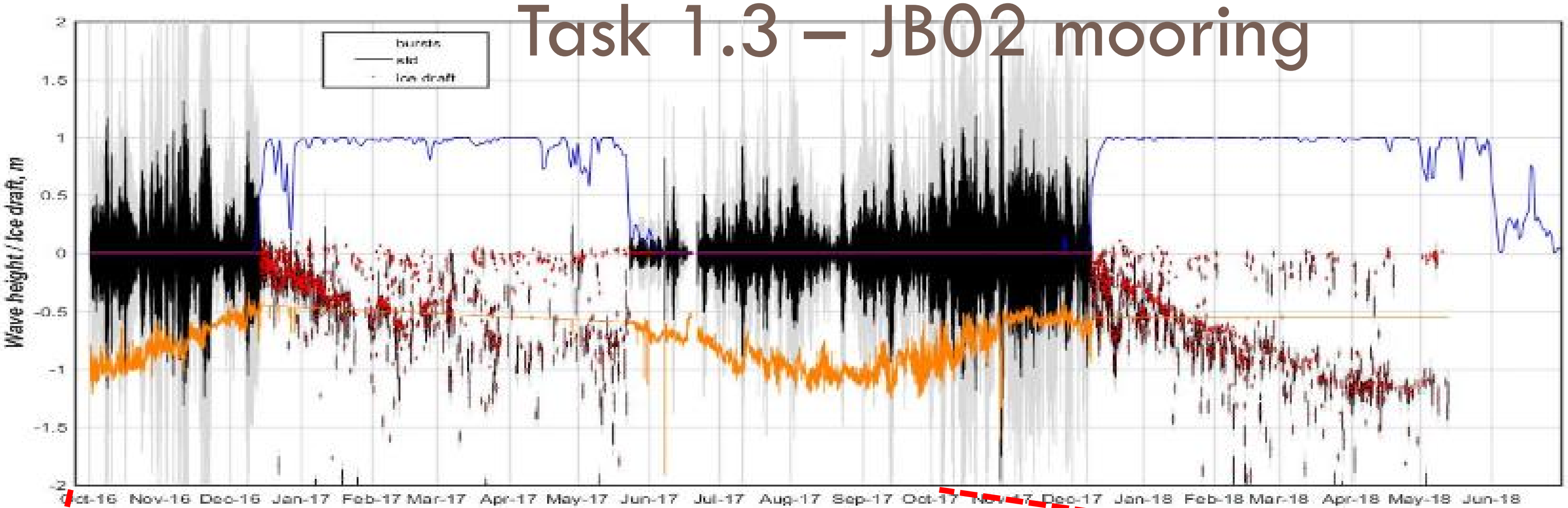
Task 1.3 – NE02 and NE03 mooring results

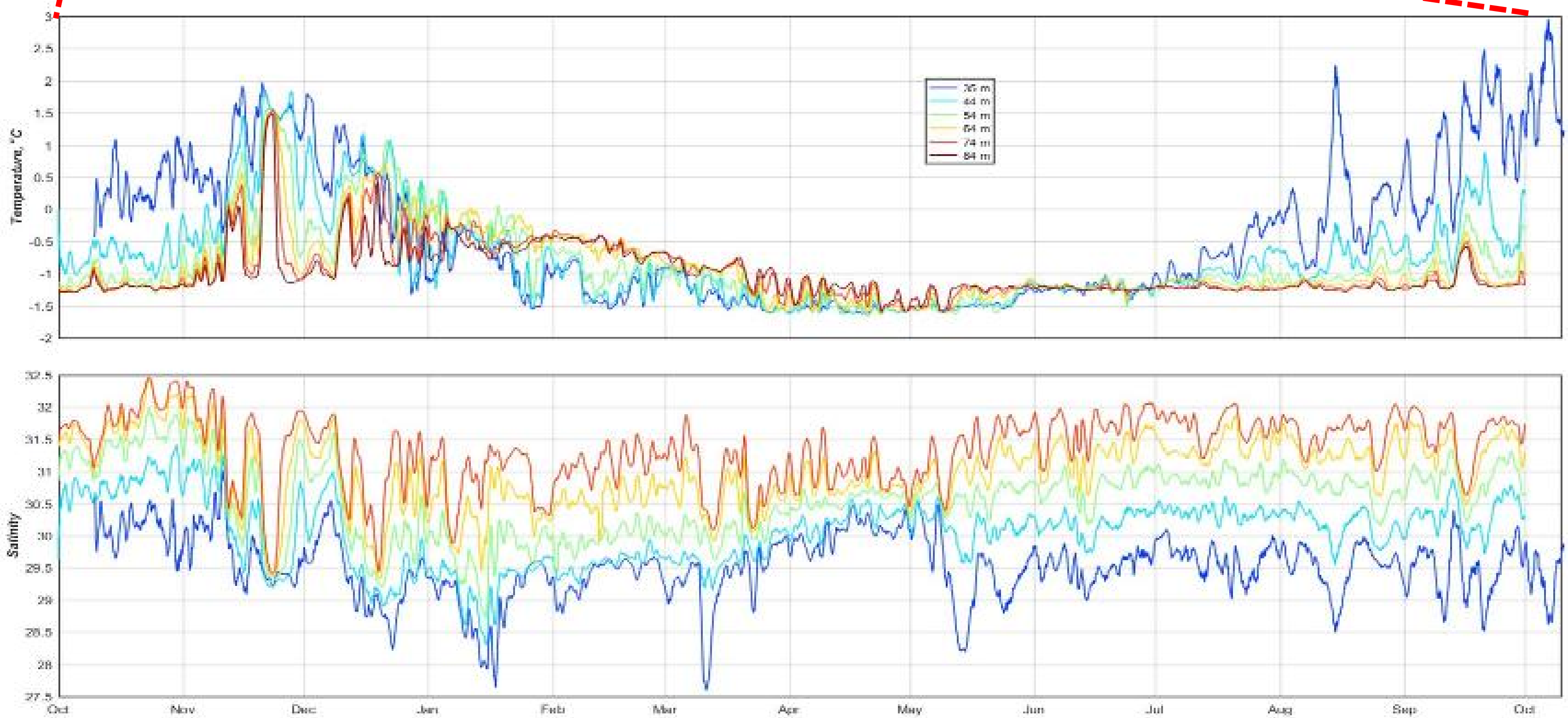
Temperature and Salinity





Task 1.3 – JB02 mooring

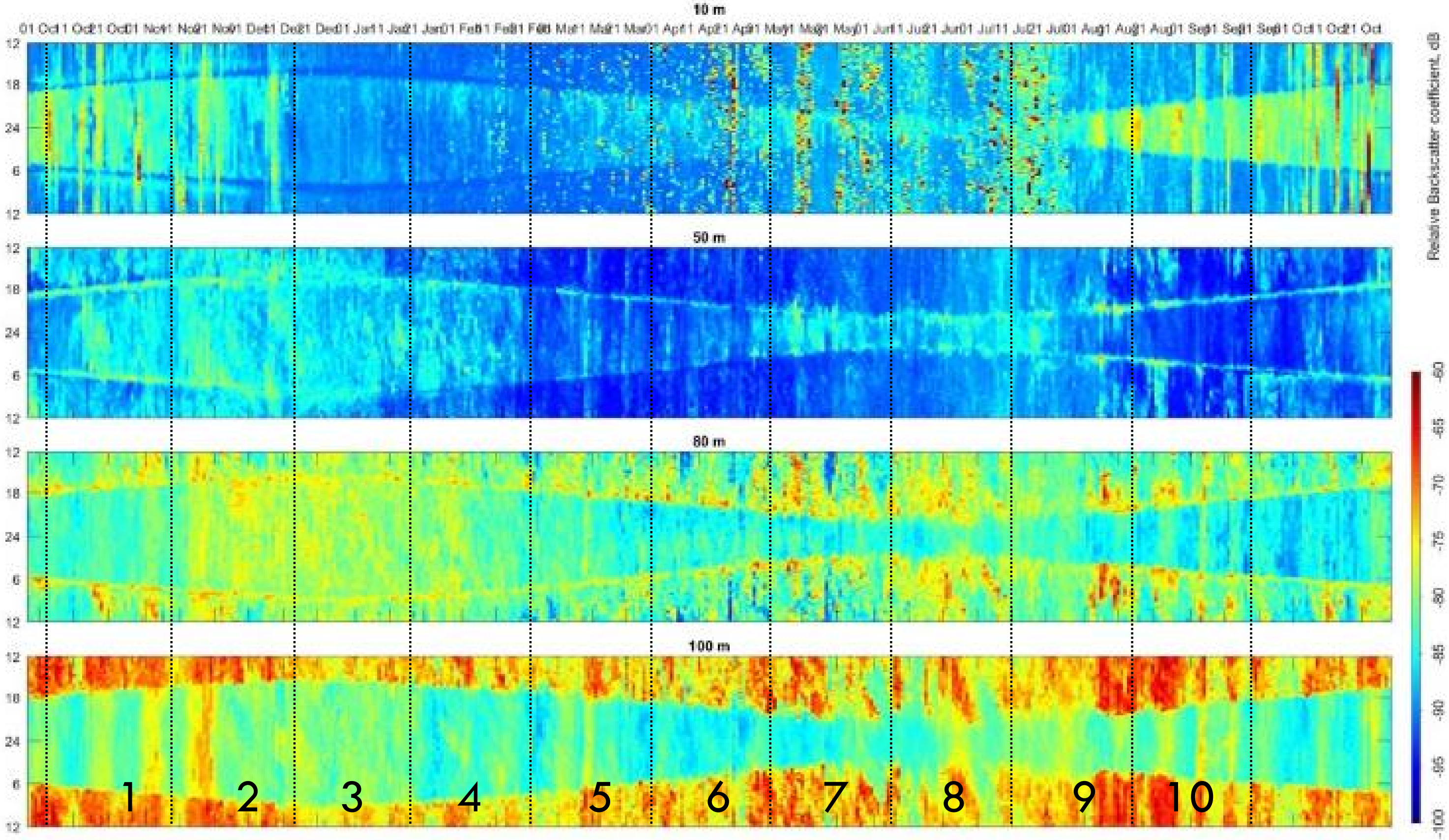




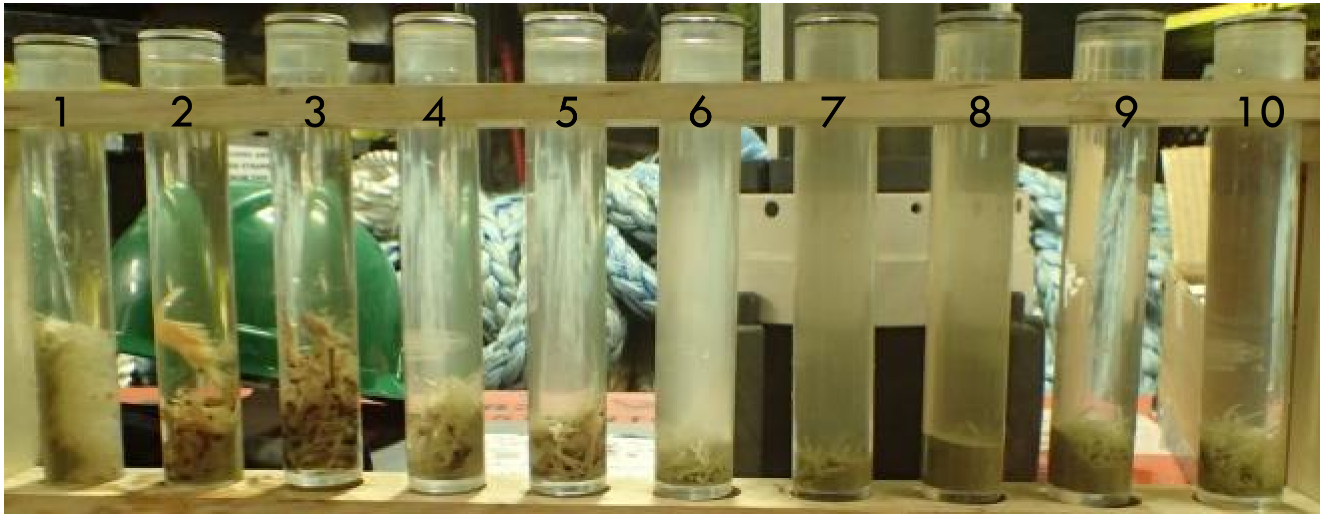
Acoustic Backscatter from ADCP at AN01

Petrusevich et al. Submitted

Reveals
- Diurnal vertical migration
- Settling of ice rafted sediment

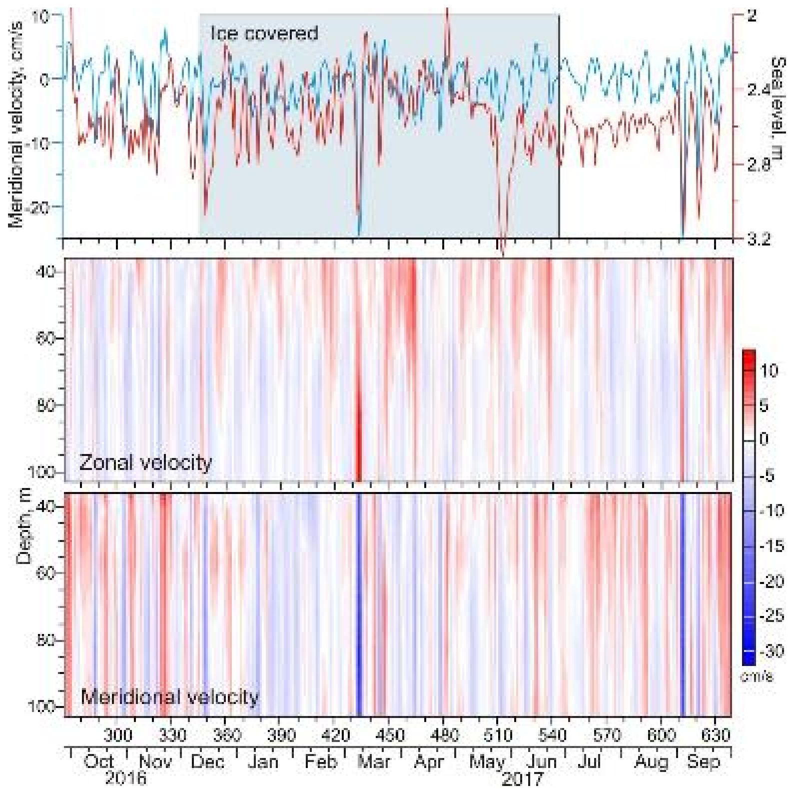


	Start date
1	4-Oct-16
2	8-Nov-16
3	13-Dec-16
4	17-Jan-17
5	21-Feb-17
6	28-Mar-17
7	2-May-17
8	6-Jun-17
9	11-Jul-17
10	15-Aug-17
end	19-Sep-17

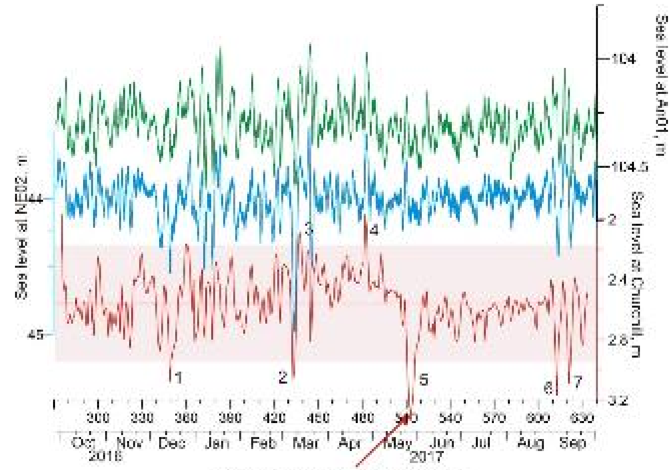


Manuscript in progress: Dmitrenko et al., **Wind forcing controls bay-scale circulation in Hudson Bay**

Sea level at Churchill, and NCEP meridional wind and velocity time series at mooring AN01



Sea level at Churchill, and at moorings AN01 and NE02

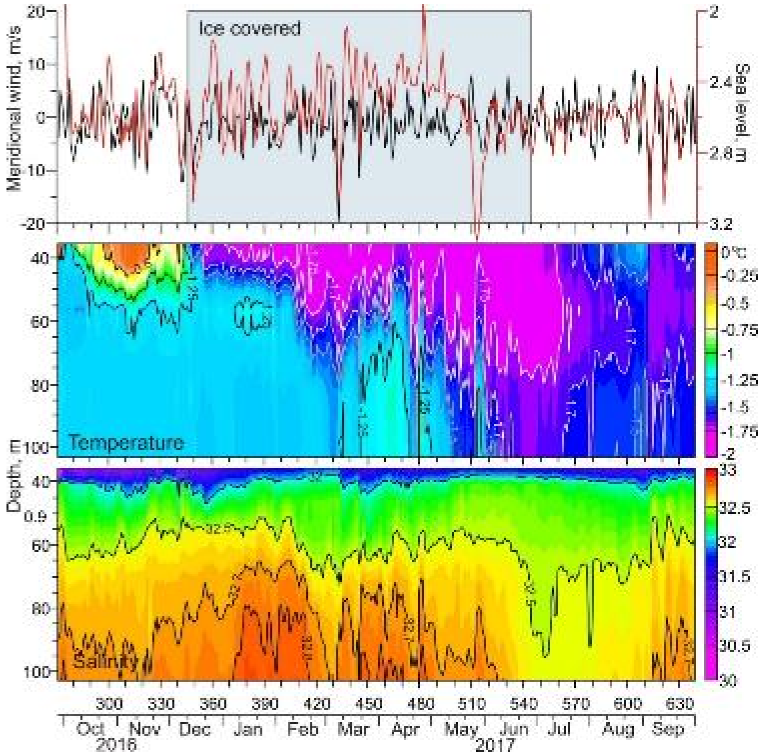


#5 is flood in Churchill, May 2017

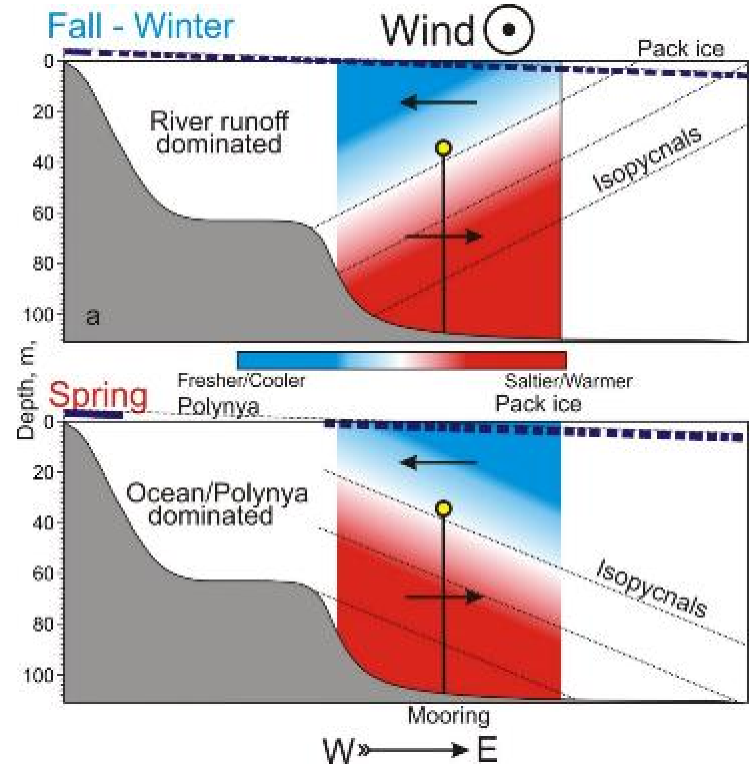
- In response to northerly wind, a surface Ekman on-shore transport and associated increase of the sea surface heights over the shelf produce a cross-slope pressure gradient that facilitates an along-slope southward flow

Manuscript in progress: Dmitrenko et al., **Atmospheric forcing facilitates cross-shelf exchange in Hudson Bay**

Sea level at Churchill, and NCEP meridional wind and temperature and salinity time series at mooring AN01



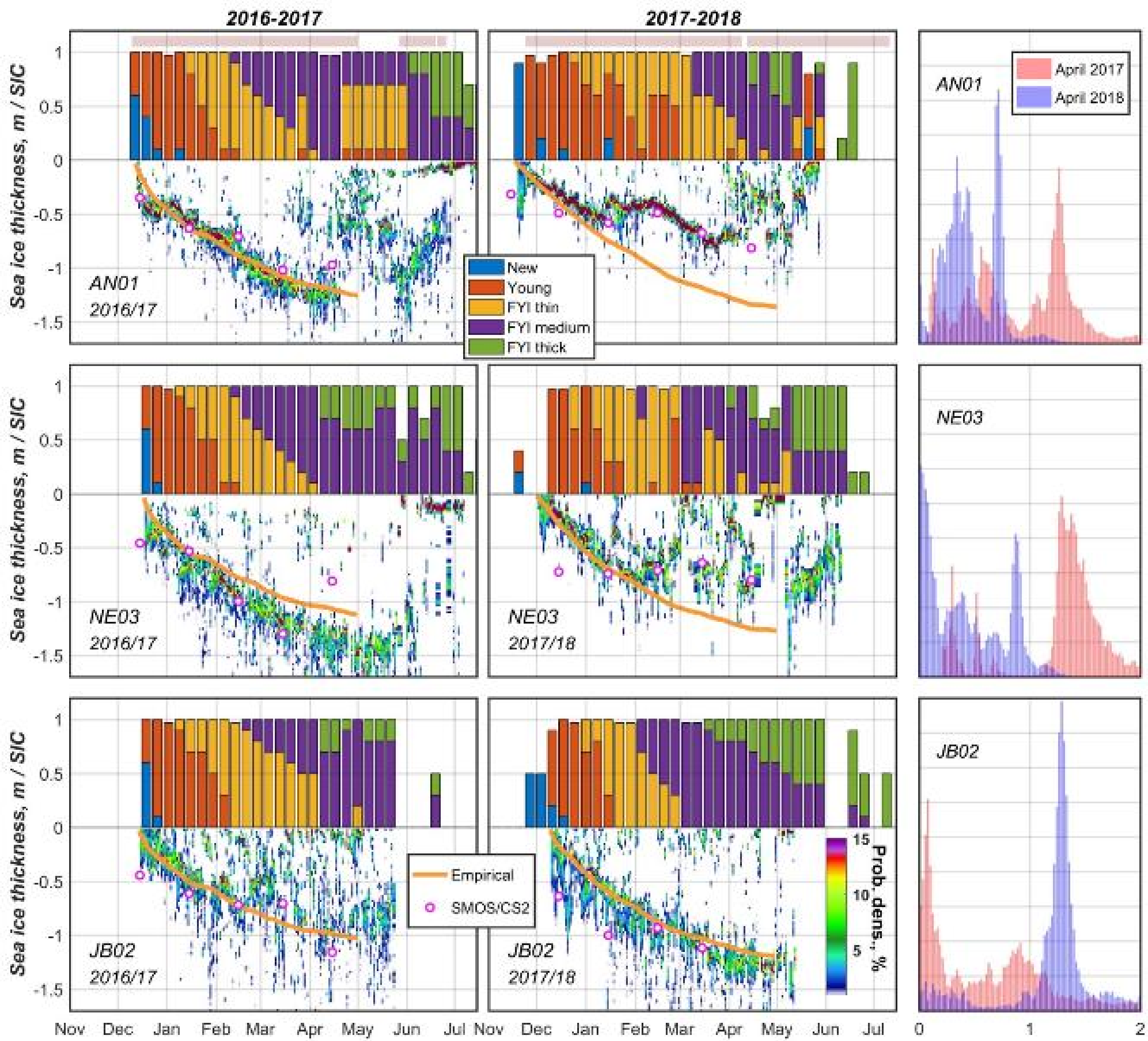
Generation of thermohaline anomalies in response to the downwelling favorable northerly wind



- The wind-driven water dynamics significantly contributes to variability of temperature and salinity due to the cross-shelf displacement of water masses as per upwelling and downwelling

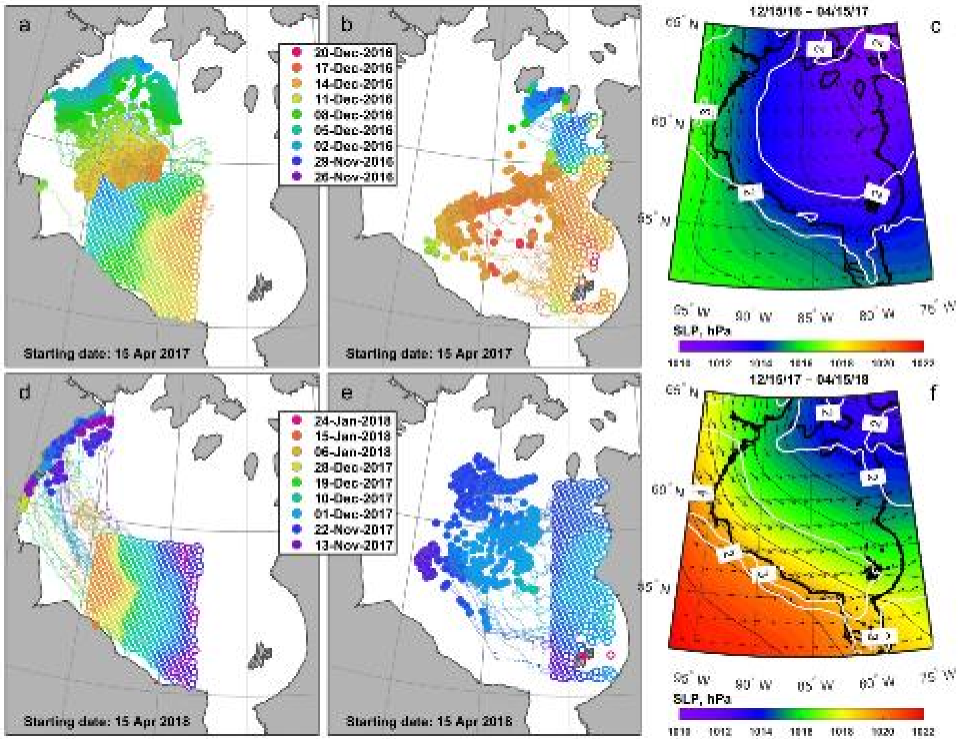
Atmospheric forcing controls cross-shelf exchange in Hudson Bay

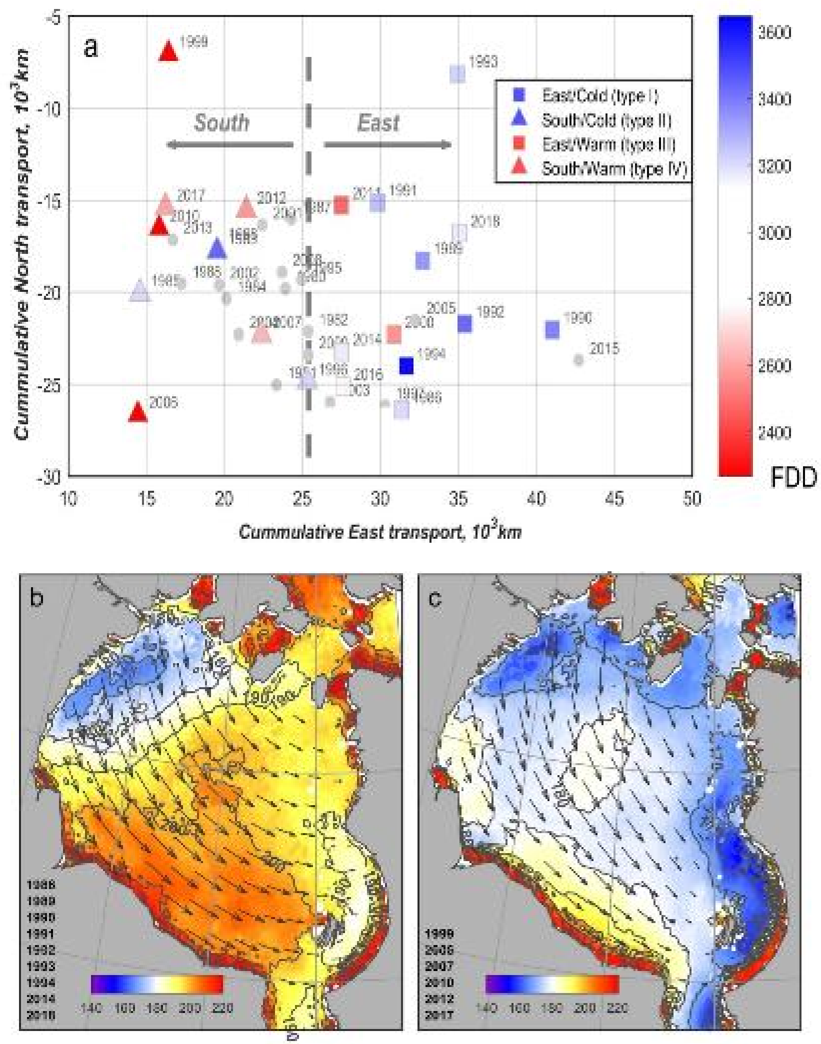
Kirillov et al., Submitted: **Atmospheric forcing drives the winter sea ice thickness asymmetry of Hudson Bay** (Tasks 1.3 & 1.4)



Kirillov et al., Submitted: **Atmospheric forcing drives the winter sea ice thickness asymmetry of Hudson Bay** (Tasks 1.3 & 1.4)

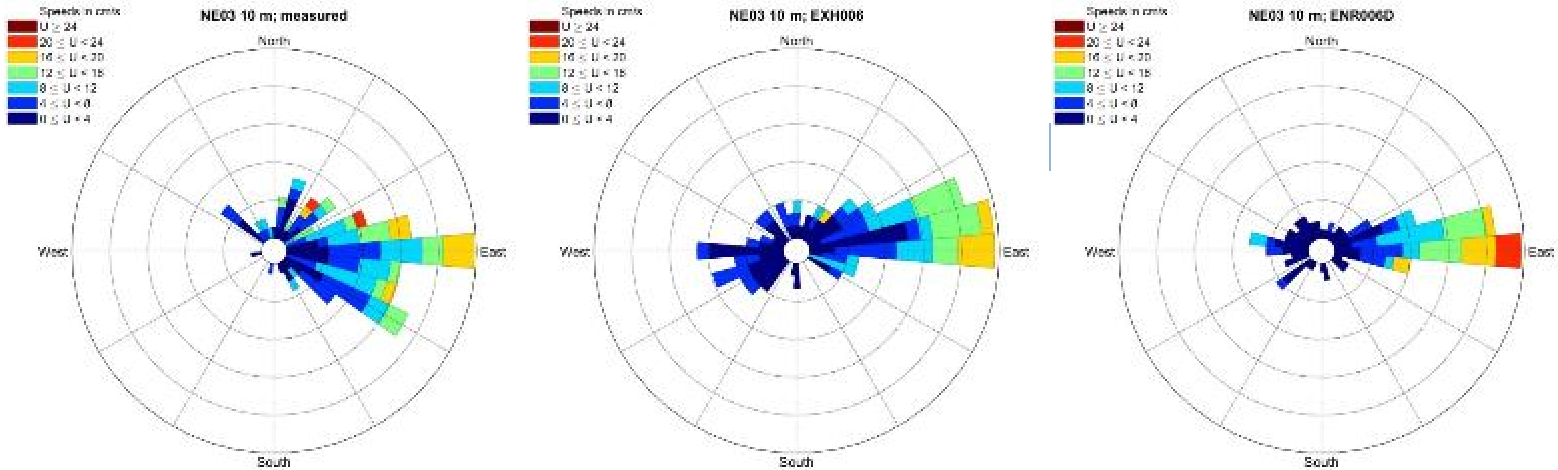
2017 vs 2018





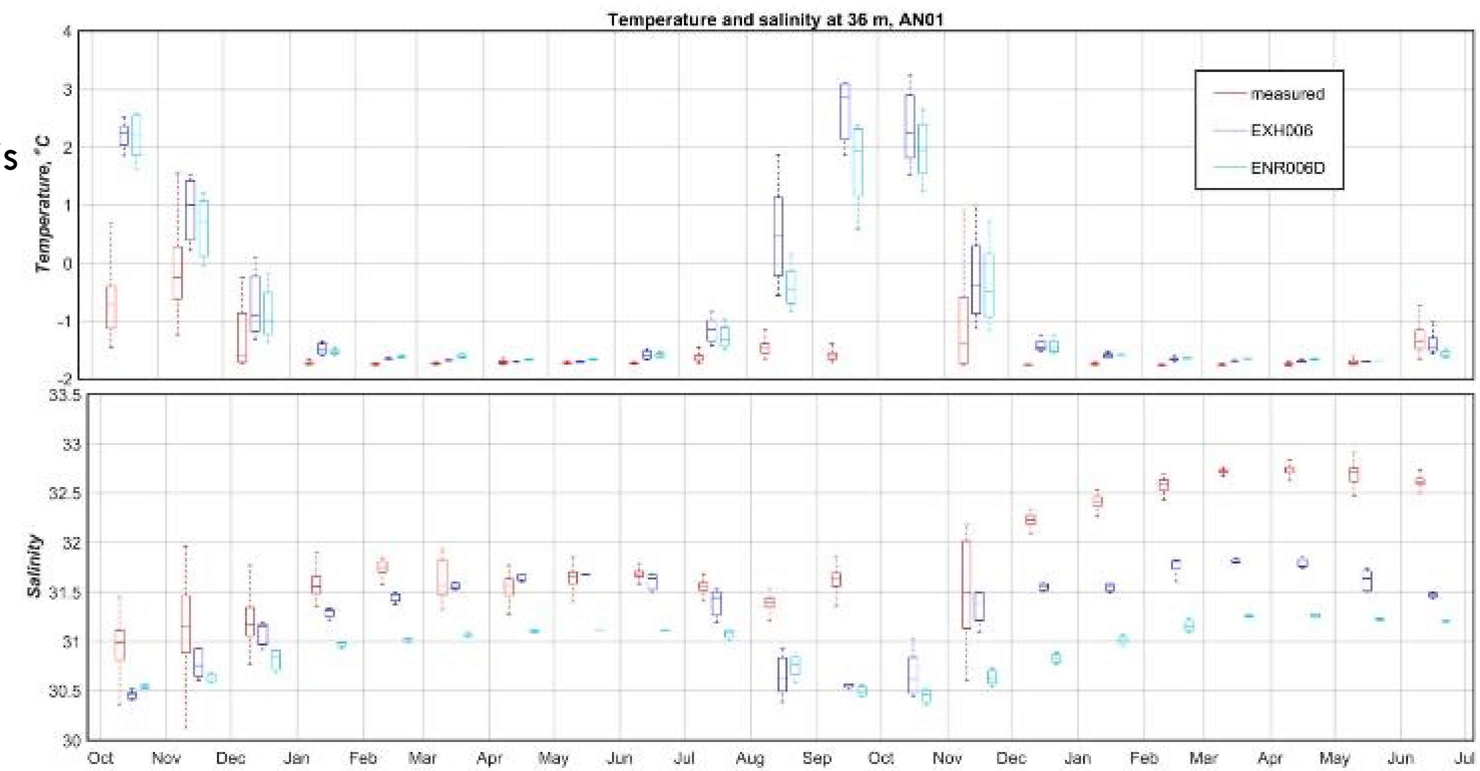
Kirillov et al. : **NEMO model validation with mooring data**

- Comparative diagrams of 5d mean current velocities at 10 m in NE03 mooring position

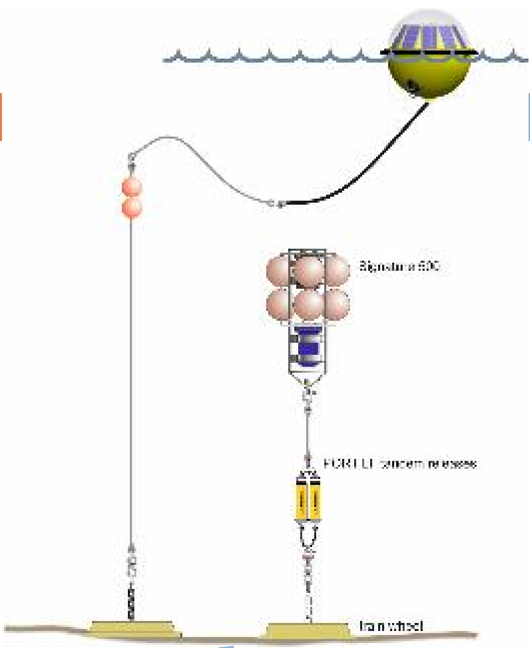


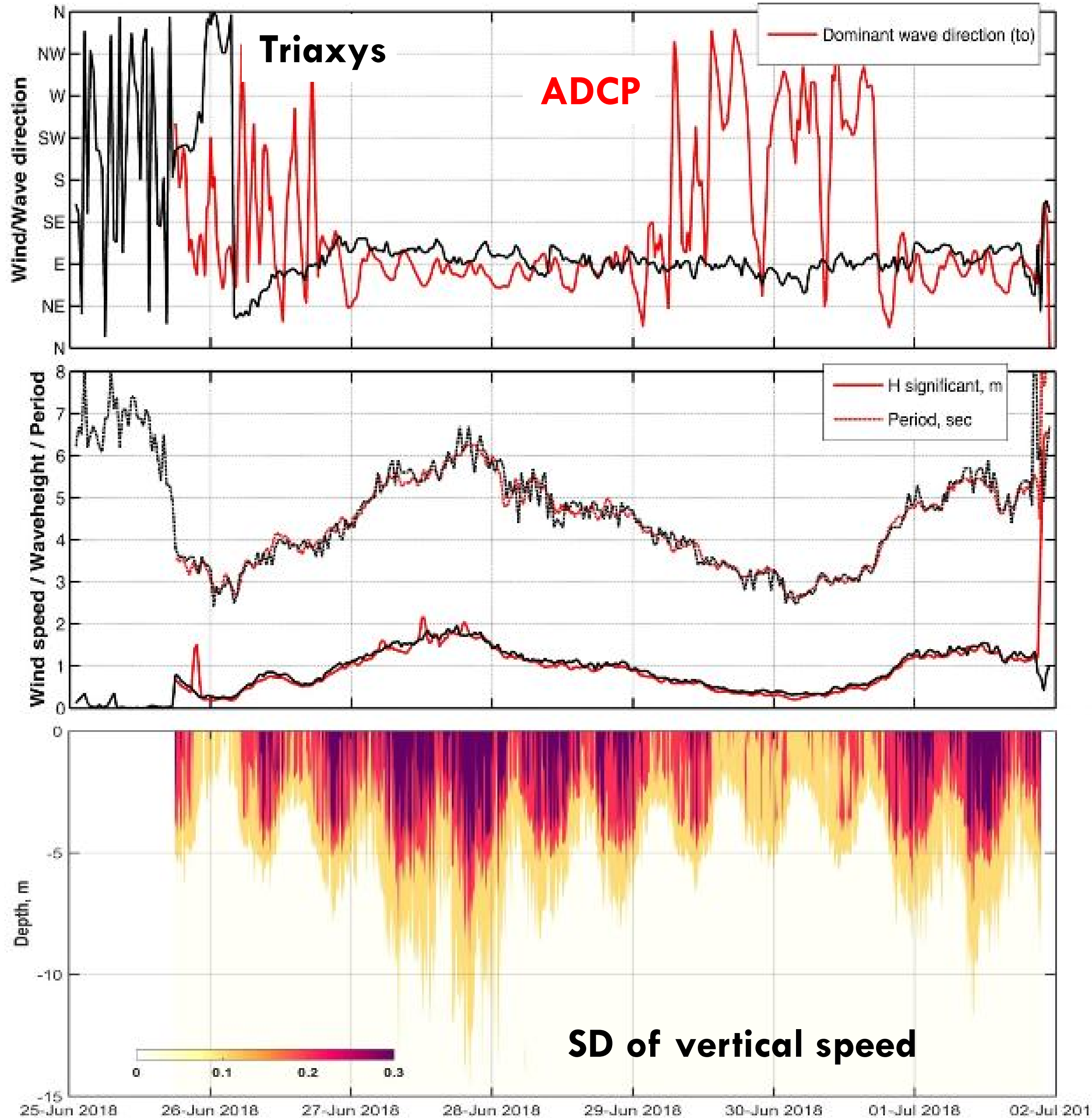
Water dynamics is represented reasonably good in the model.

However, the vertical mixing seems to be considerably overestimated

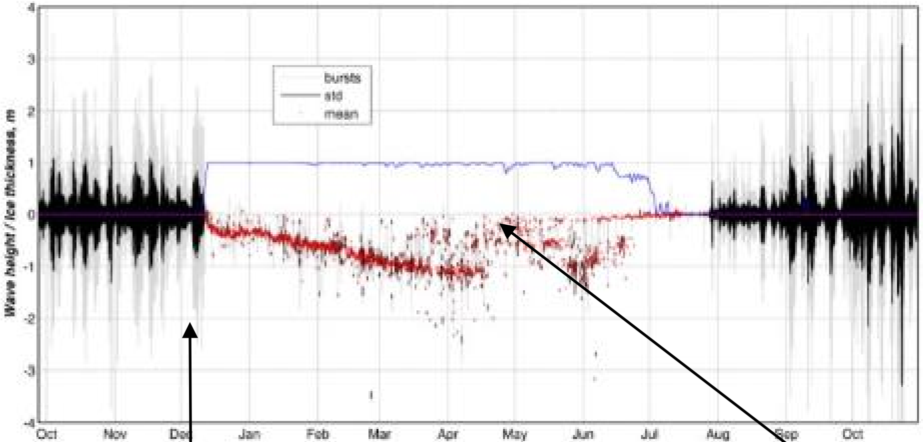


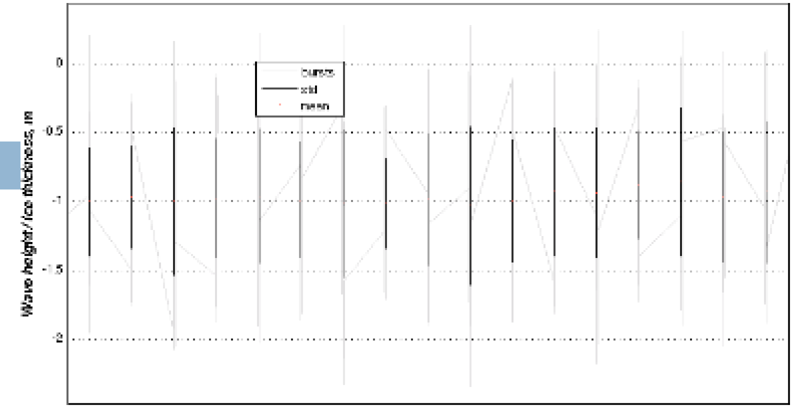
TRIAXYS wave buoy in the MIZ of Nelson estuary (NE02 position)



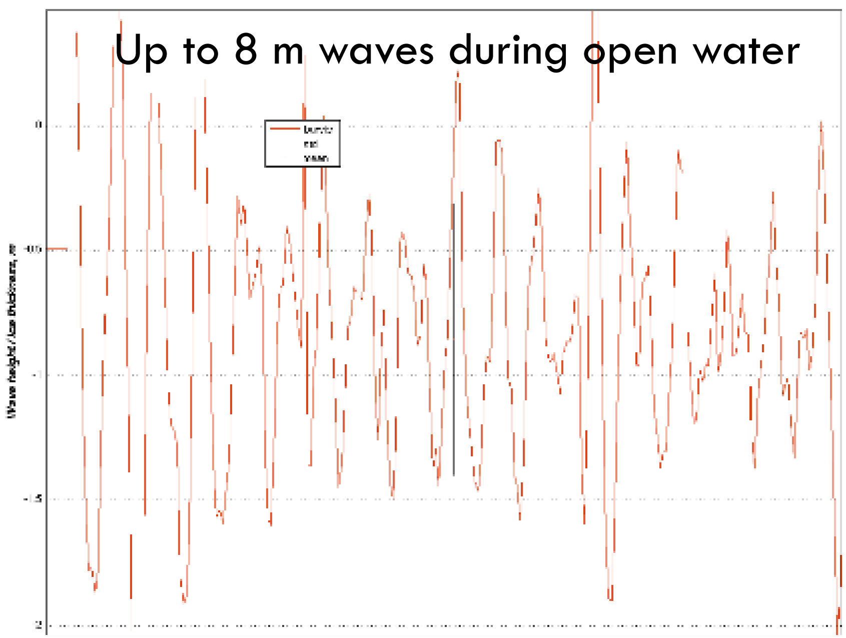


AN01 Waves (Yanique Campbell, planned)

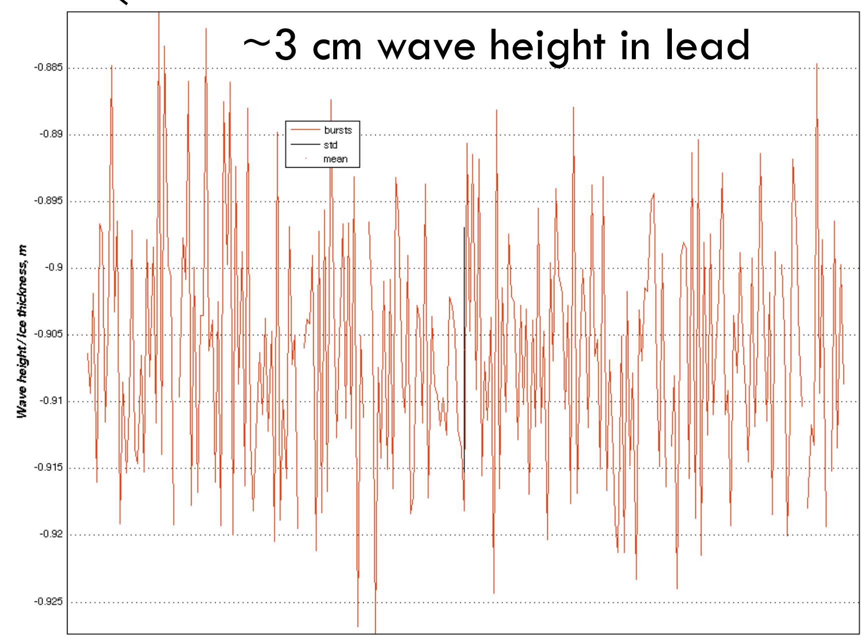




2Hz bursts for 2 min every hour



Up to 8 m waves during open water



~3 cm wave height in lead

RESULTS

Task 1.4 – Remote Sensing

Characterization of the Nelson/Hayes River plume dispersion in Hudson Bay: A quantile-based statistical approach using ocean color data

Manuscript in preparation: Basu et al. (Task 1.4)

Research Question: How far does the Nelson River plume influence the Hudson Bay?

Rationale

- This study characterizes the Nelson River plume dispersion in Hudson Bay in terms of its spatial extent in different tidal condition.
- The result of this research work directly feeds to the objectives of BaySys Team: 1 To determine the effect of magnitude of river discharge on the freshwater distribution in Hudson Bay.

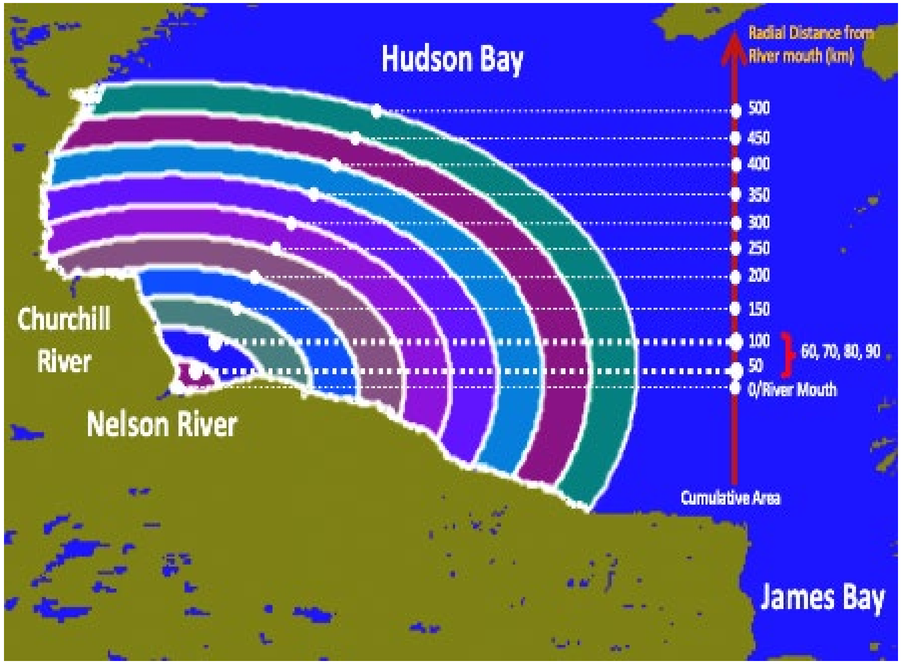
Methodology

- Retrieved Color Dissolved Organic Matter (CDOM) and Total Suspended Sediment (TSS) used as proxy to characterize river plume dispersion using optimized MODIS satellite derived Remote Sensing Reflectance (R_{rs}).

$$a_{cdom}^{sat.}(412\ nm) = 3.08651 \cdot R_{rs}^{sat.}\left(\frac{678}{488}\right) - 0.5825$$

$$TSS^{sat}(g/lt.) = 811.11 \cdot R_{rs}^{sat.}(678) + 2.442$$

- **Quantile thresholding (0.95 to 0.5) of aCDOM and TSS conc. for each of the successive cumulative area of MODIS image (Fig.1).**

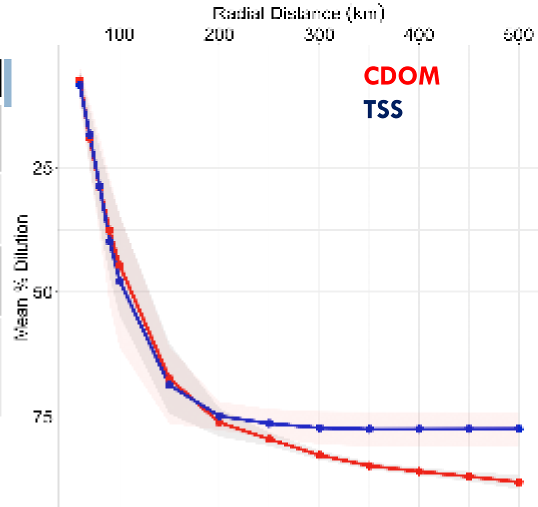


0-50 km threshold of a_{CDOM} (412nm) & TSS (g/L): Reference plume signal modeled for dilution

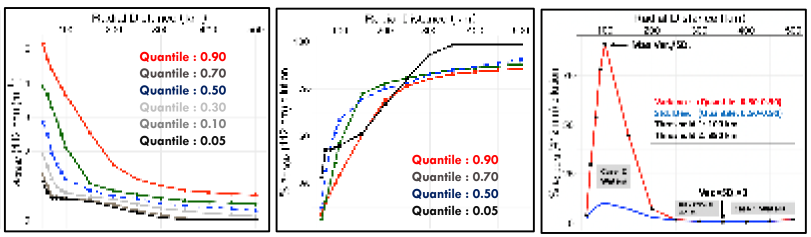
Basu et al.: EBB TIDE CONDITIONS in August 2005: MODIS AQUA)

Dilution of CDOM and TSS from Nelson River mouth

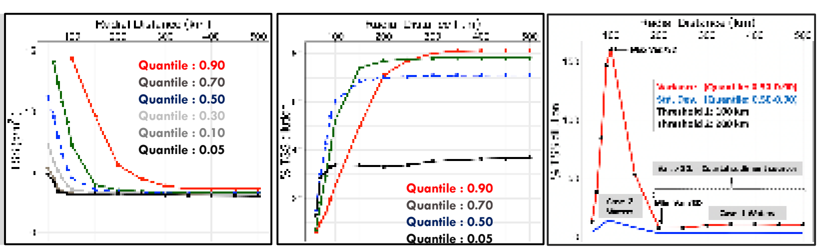
Var.	Distance	Slope
aCDOM	<200km	0.47 (linear)
TSS		0.46 (linear)
aCDOM	>200 km	0.16 (power)
TSS		0.03 (power)



Quantile: CDOM



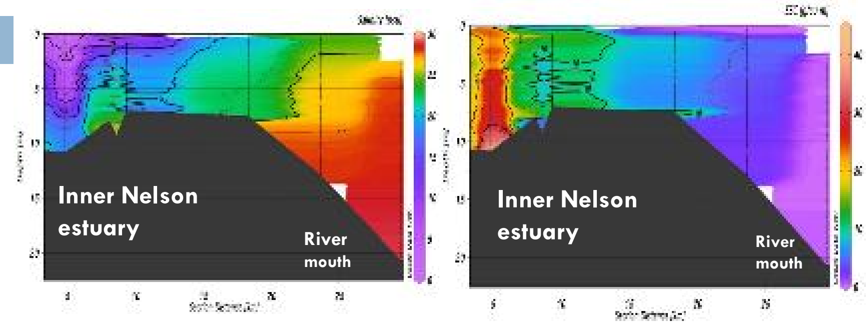
Quantile: TSS



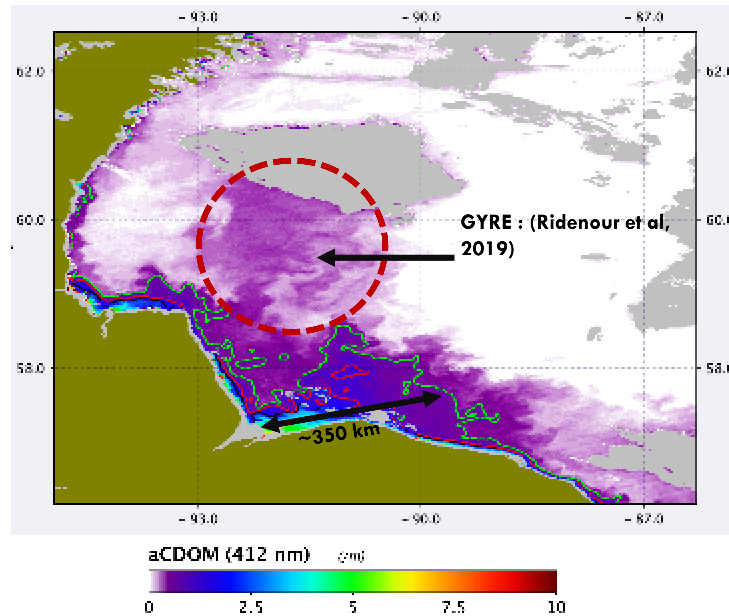
TSS saturates closer to the river mouth thus underestimating the plume dispersion extent

In-situ CTD data

Inner estuary transect of salinity and TSS



Limit of dilution during ebb tide

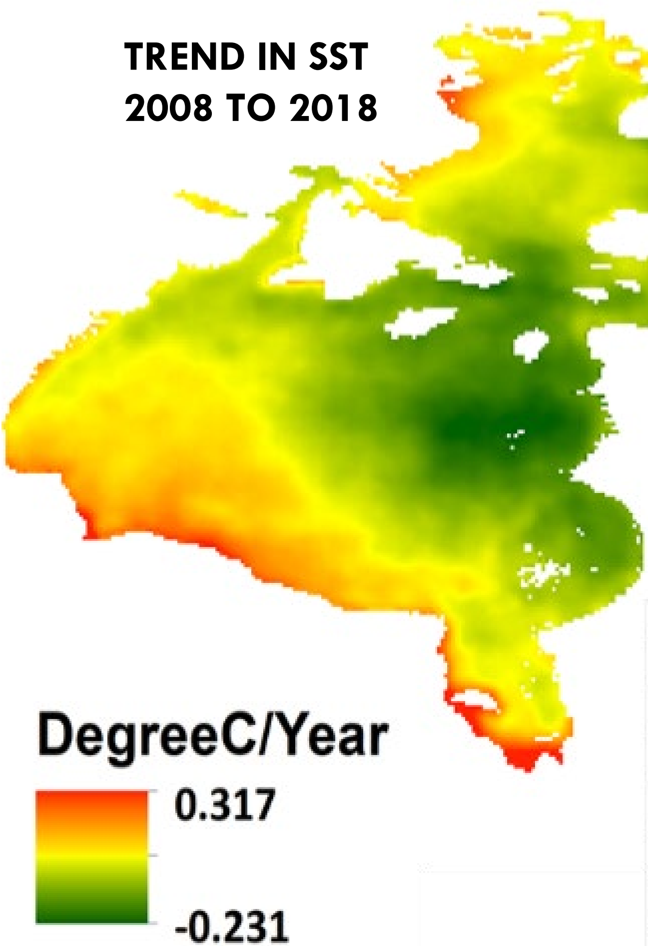


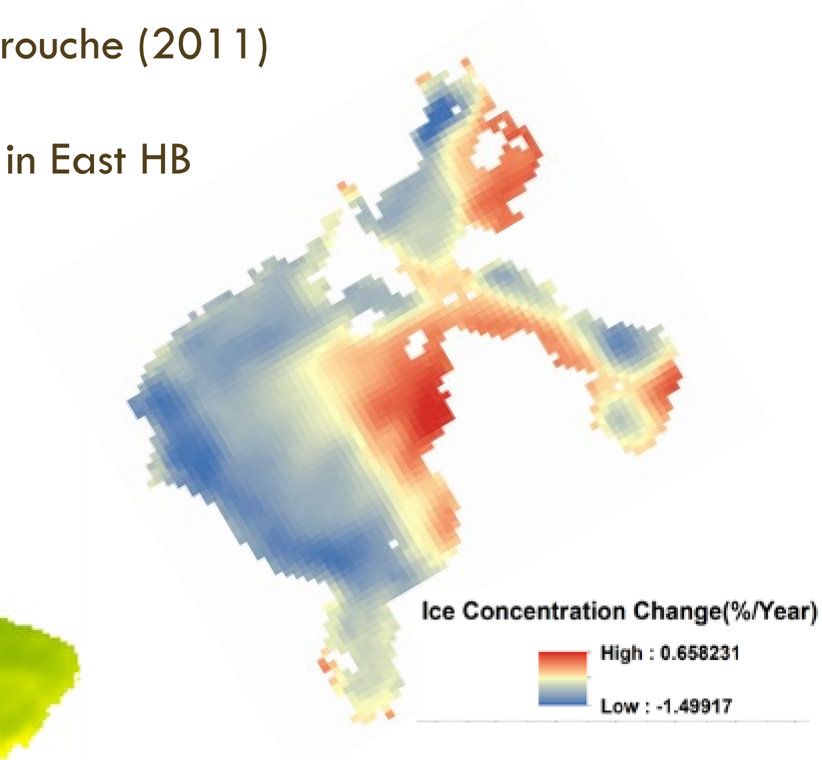
a_{CDOM} (412 nm) (m^{-1}) 200 km (1 STDV)

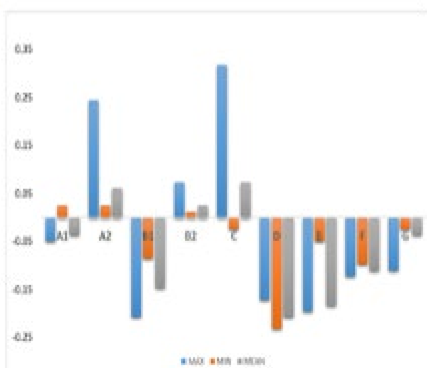
Threshold: 1.92, 1.24, 0.56

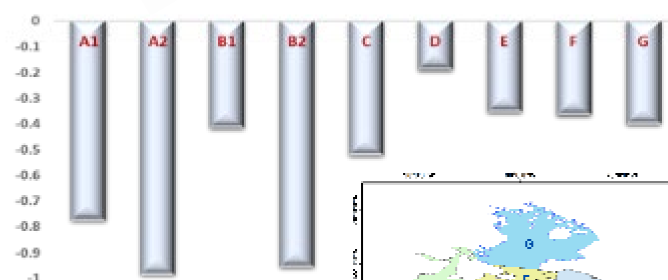
Sea surface temperature (SST) trends and pattern from 2008-2018

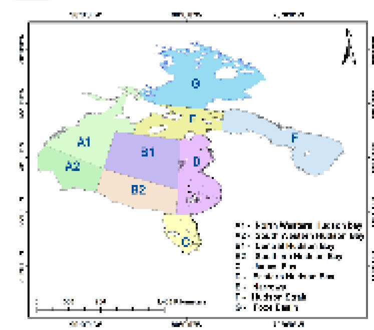
- Mukhdopadhyay et al. (draft completed).
- Extend and update work by Galbraith and Larouche (2011) that analysed up to year 2009.
- Warming trend in SW HB/Nelson, but cooling in East HB
- Relate to sea ice break-up patterns

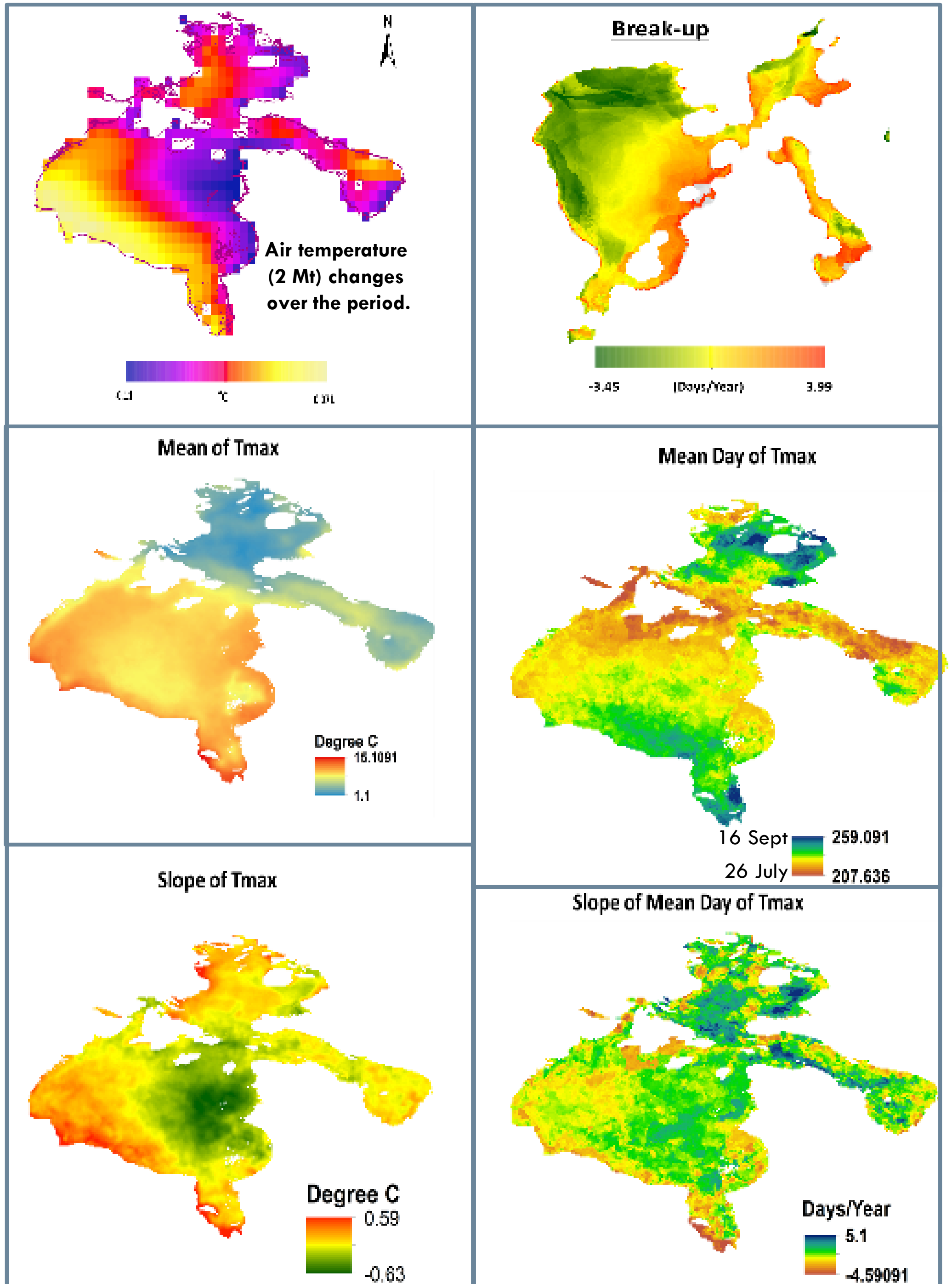






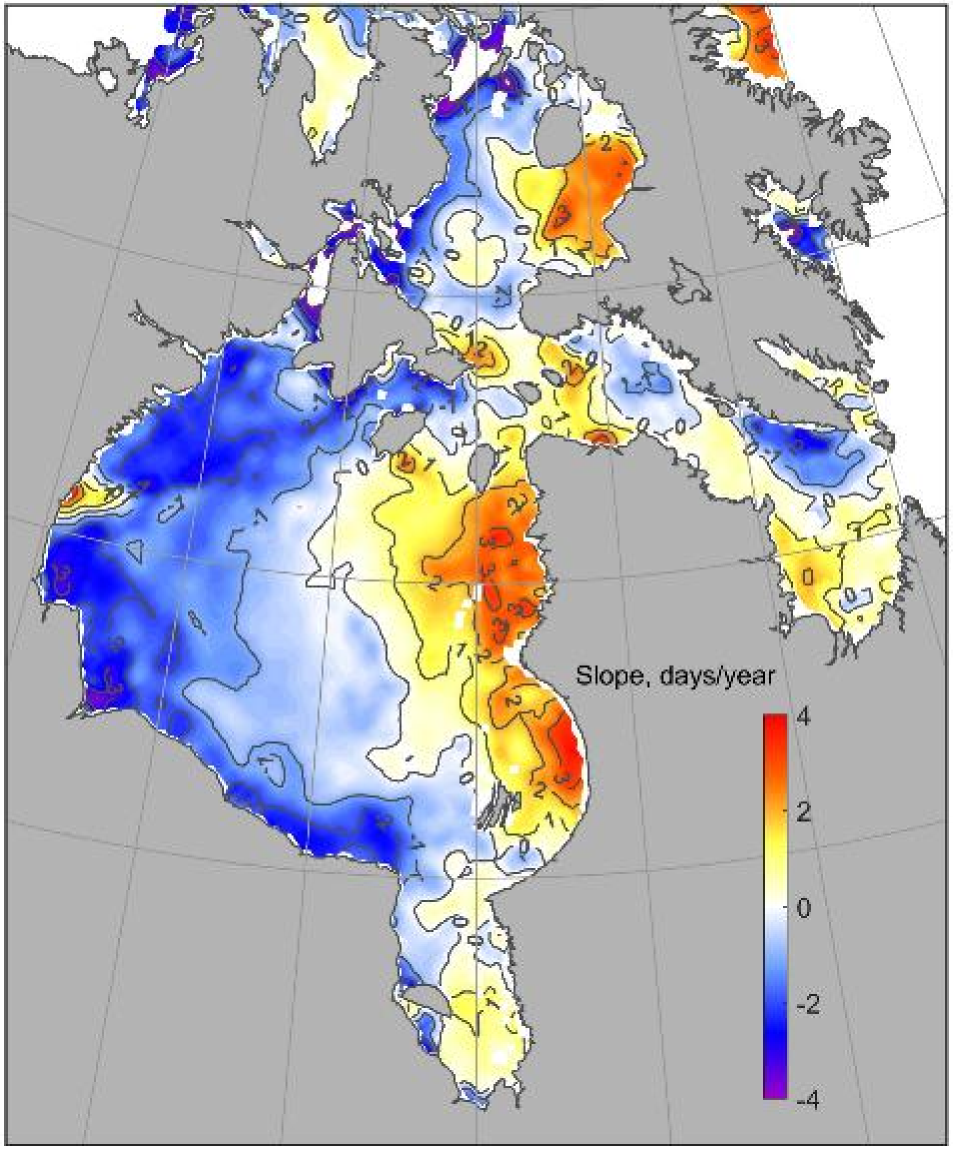




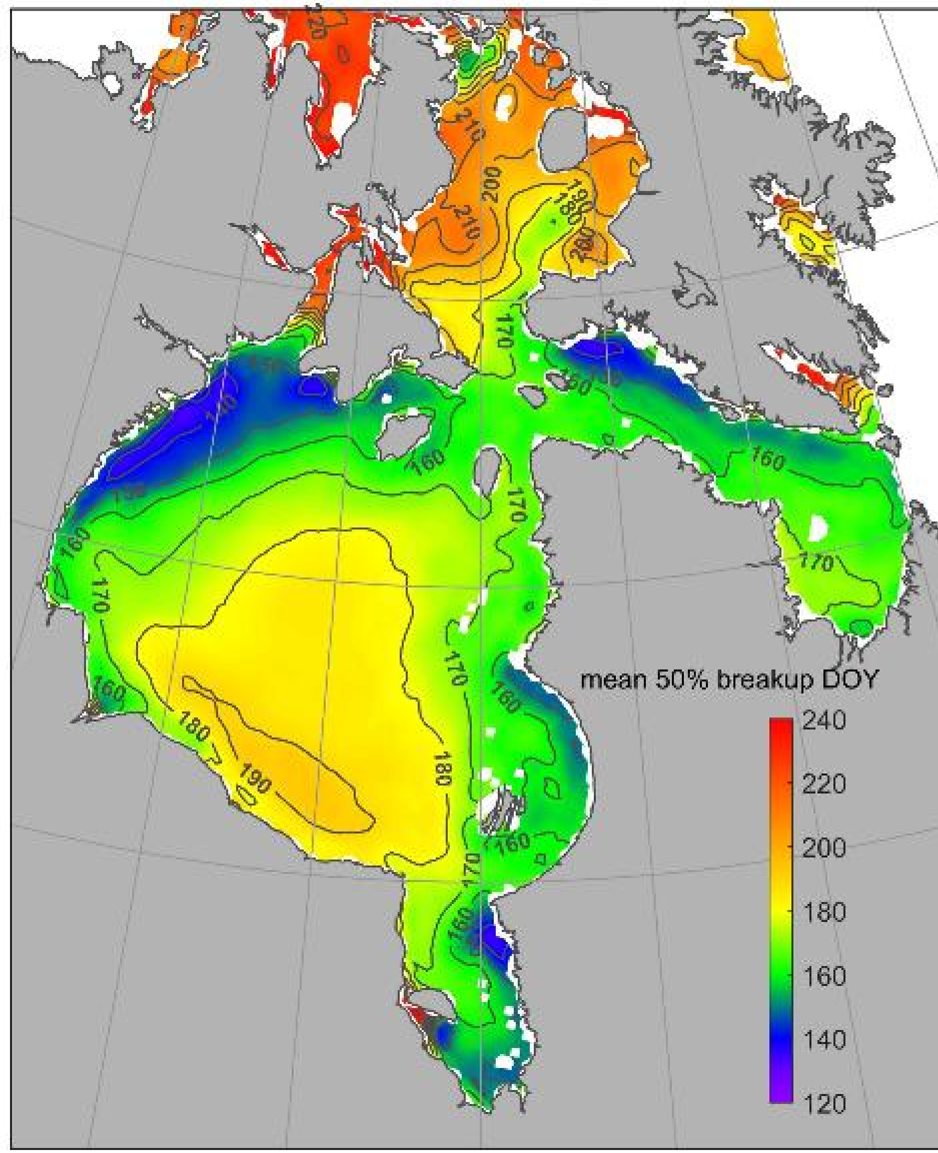


- A steady increase in SST was observed in the western and southwestern coastal regions in Hudson Bay and James Bay.
- A decreasing SST trend over the 10 year period was observed along the central and eastern Hudson Bay & Hudson Strait.
- Areas with increasing SST gradient are associated with trend towards earlier sea ice breakup, while opposite true for areas with decreasing trend.
- Sea ice concentration is decreasing across the HBS over last decade, except the northeastern Hudson Bay and eastern Foxe basin.
- Western + southern coastal region of Hudson Bay and west coast of James Bay, along with west coast of Foxe Basin, show significant positive trend in SST over 2008-2018.

50% SIC breakup DOY (Ifremer ASI)



Linear slope of breakup DOY 2008-2018



Average breakup DOY 2008-2018

Task 1.4 – Remote sensing

g of Environment 200 (2017) 281–294

Contents lists available at ScienceDirect

Remote Sensing of Environment

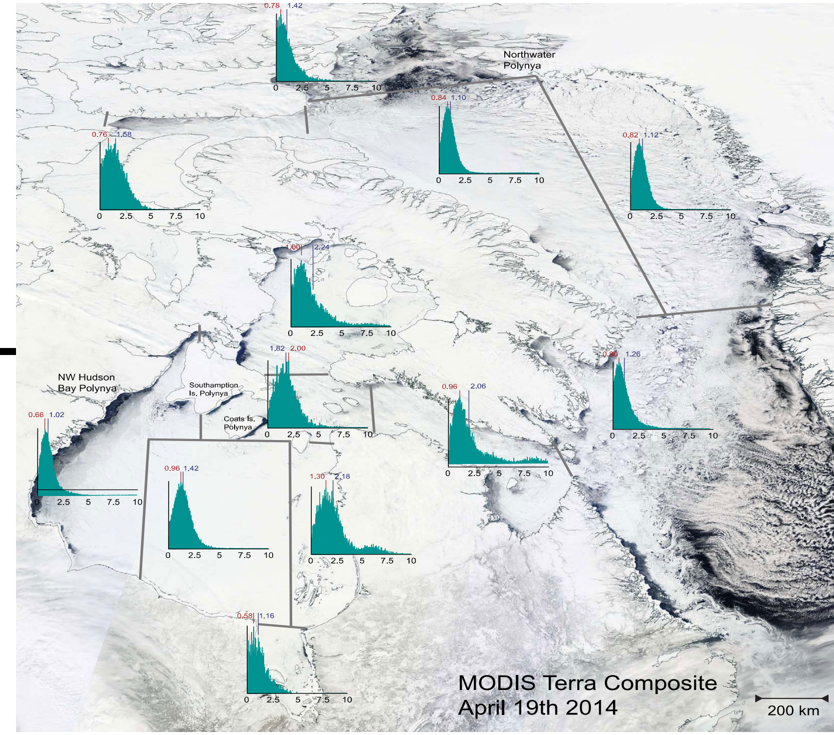
journal homepage: www.elsevier.com/locate/rse

Sea ice thickness in the Eastern Canadian Arctic: Hudson Bay Complex & Baffin Bay

Jack C. Landy[a,b,*,1], Jens K. Ehn[a], David G. Babb[a], Nathalie Thériault[a], David G. Barber[a]

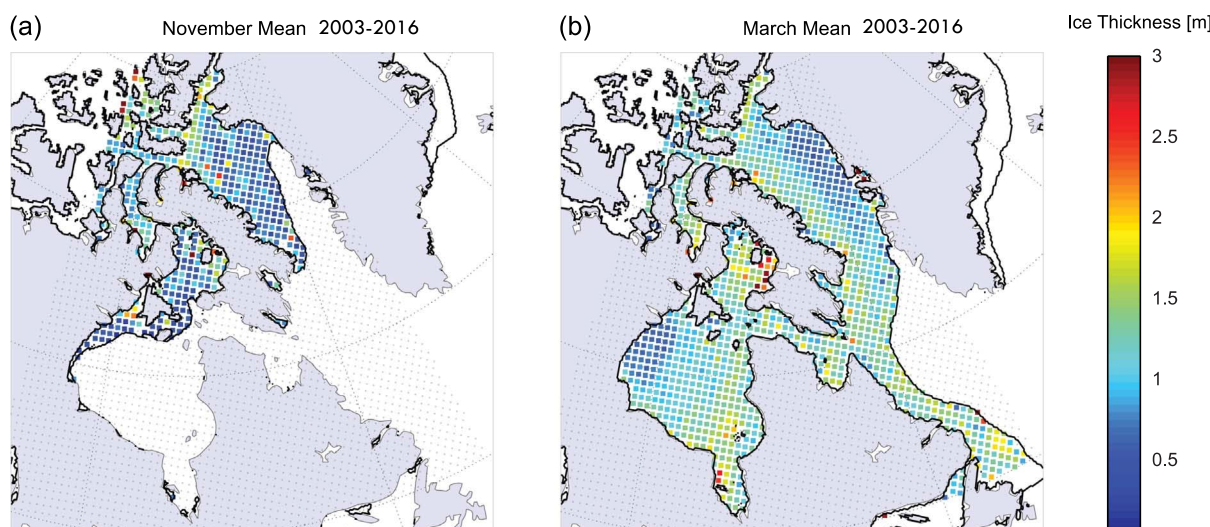
[a] Centre for Earth Observation Science, Riddell Faculty of Environment Earth and Resources, University of Manitoba, Winnipeg, Canada
[b] Bristol Glaciology Centre, School of Geographical Sciences, Faculty of Sciences, University of Bristol, Bristol, United Kingdom

Ice thickness distributions for April 2014



2003-2016

Passive microwave derived snow depth



Ice thickness derived from satellite altimetry

Investigation of multiyear variations in landfast ice cover in the Hudson Bay region.

Kaushik Gupta et. al (Manuscript in preparation) [Task 1.4]

Methodology:

- weekly ice charts from Canadian Ice Service, IceSat-2 altimetry products, RADARSAT imageries and NASA Worldview.
- daily weather records from Environment Canada's meteorological service
- snow melt date products from the National Snow and Ice Data Centre (NSIDC, USA).