Spatial Variability of Sea Ice Drafts in the Continental Margin of the Canadian Beaufort Sea from a Dense Array of Moored Upward Looking Sonar Instruments

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ASL Environmental Sciences

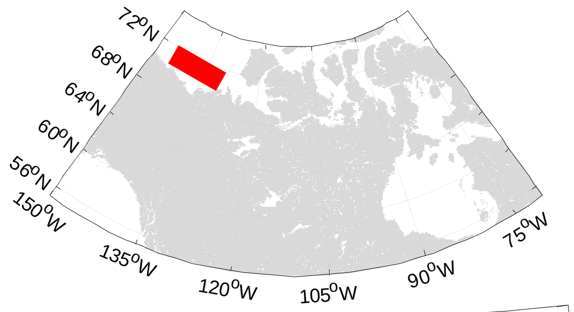
Fisheries and Oceans Canada

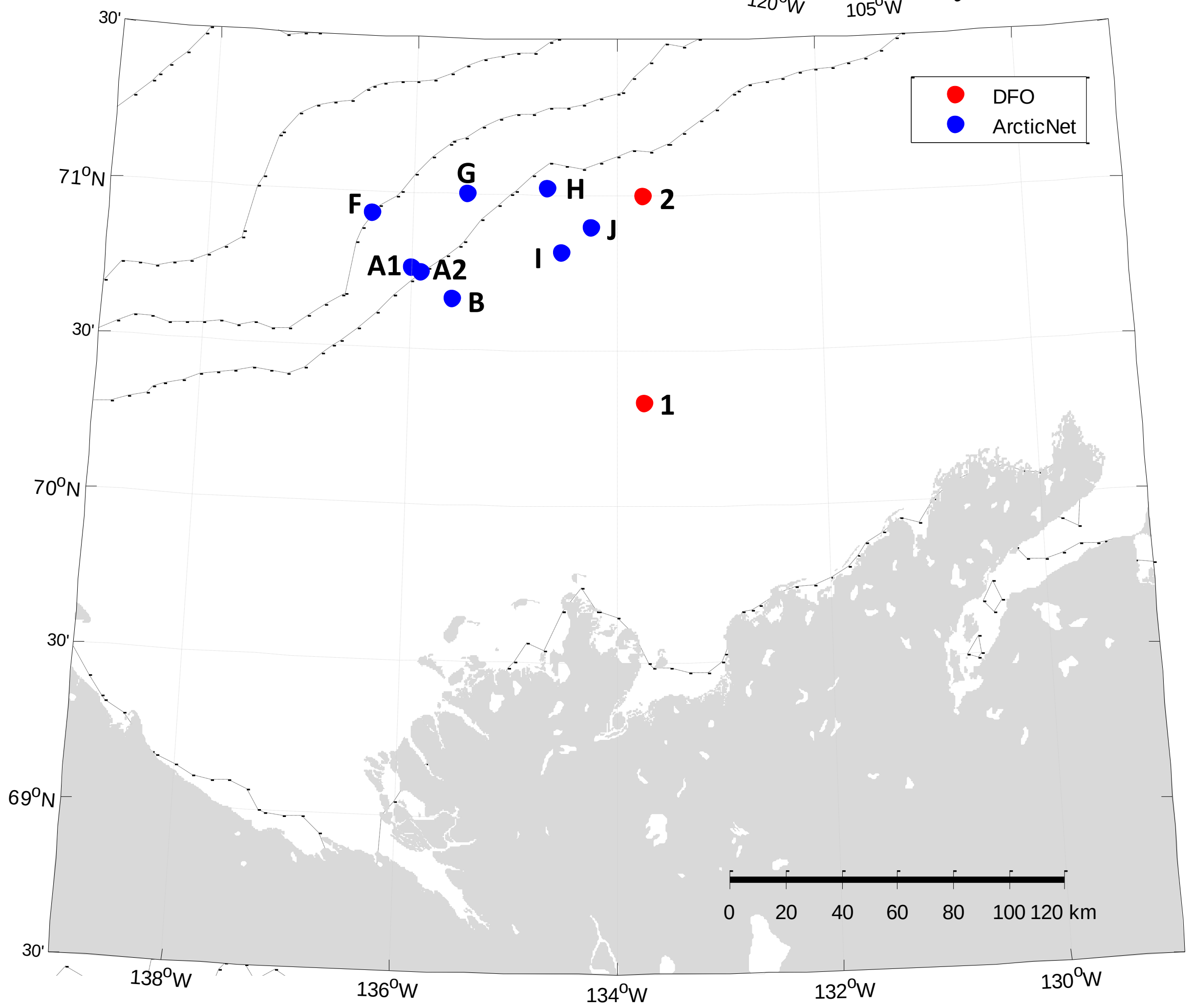
Mooring Array

- 2009 – 2011
  - ArcticNet/Industry Partnership Program
  - Fisheries and Oceans Canada

Site	Water depth [m]
1	55
2	112
A1	688
A2	615
B	154
F	1010
G	702
H	367
I	75
J	83

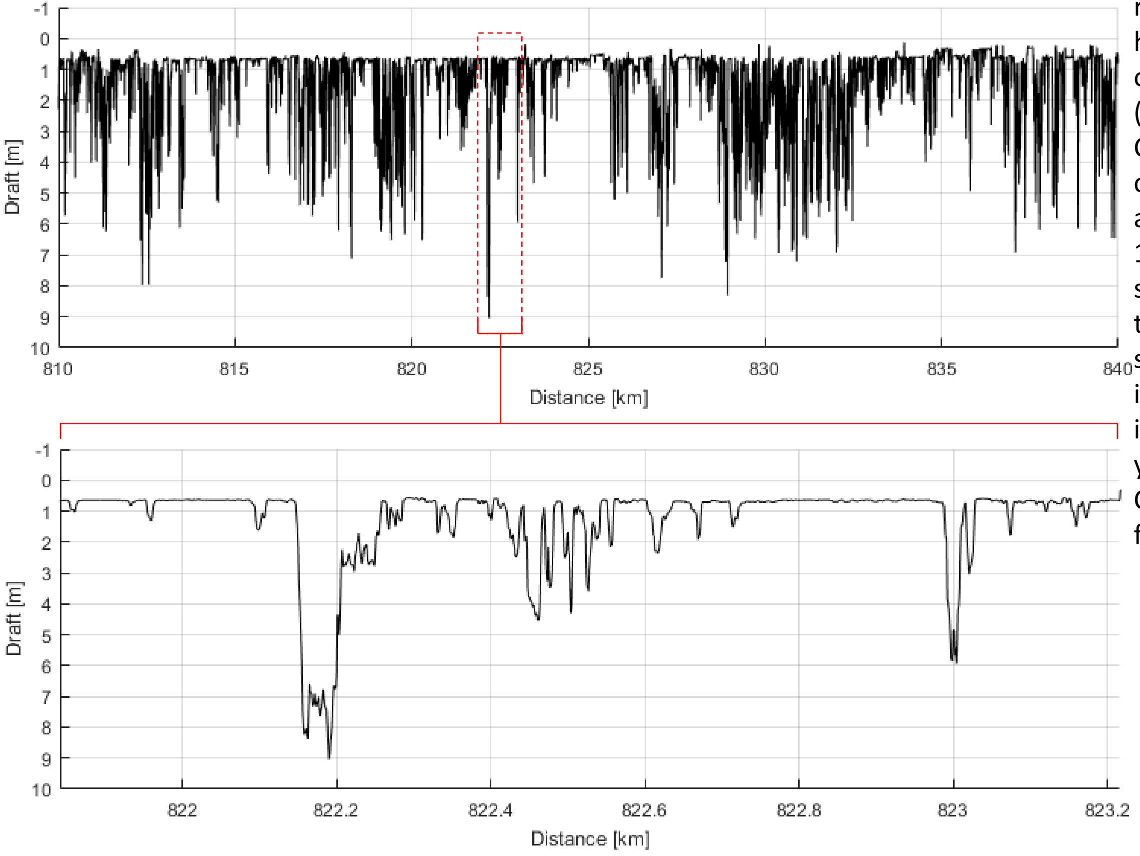
This study was based on statistical comparison of ice draft and ice velocity observations from subsurface moorings throughout the continental margin of the Canadian Beaufort Sea operated between October 2009 through October 2011. Sites A1, A2, B, F, G, H, I and J were maintained by the ArcticNet/Industry Partnership Program. Sites 1 and 2 were operated by Dr. Humfrey Melling, Fisheries and Oceans Canada, Institute of Ocean Sciences. The sites spanned a range of water depths from the shallowest at ~50 m at Site 1 on the mid-shelf to Site F in over 1000 m water depth on the continental slope. Horizontal separation between sites spanned between 4 km to more than 100 km.



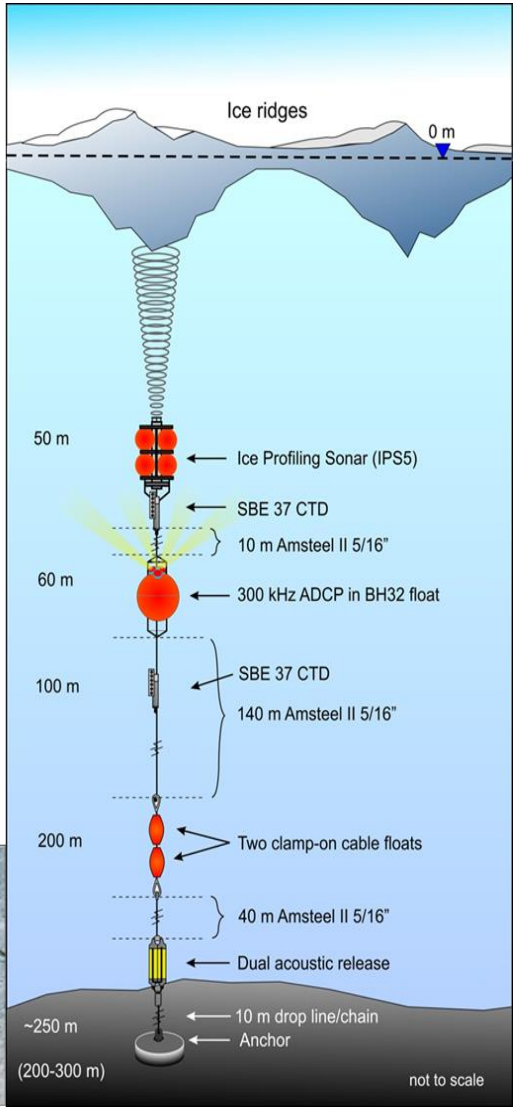


Upward-looking Sonar (ULS)

- Ice Profiler (IPS) ➡ ice draft
- Acoustic Doppler Current Profiler (ADCP) ➡ ice velocity



Each subsurface mooring was of a taut-line configuration with an anchor on the seafloor and scientific instrumentation throughout the water column up to approximately 50 m water depth. A typical taut-line mooring is shown in the cartoon on the right. The key instrumentation for this study were upward-looking sonar instruments: the Ice Profiling Sonar (IPS), pictured in the image on the bottom right, which provides continuous measurement of high-resolution ice drafts over deployments of 1 year or longer and the Acoustic Doppler Current Profiler (ADCP) which provides measurement of ice velocity. Combining these two time-series allows the computation of a two-dimensional ice profile called an ice draft spatial-series with an ice draft sample a ~ 1 m intervals. A short (~30 km) example of this spatial-series is shown in the plot in the middle on the left. The bottom left plot shows a zoomed segment showing the highly detailed ice features including deep ice keels and undeformed first-year ice that are observed in these datasets. A typical one-year two-dimensional ice profile acquired in the Canadian Beaufort Sea spans several hundreds to a few thousand kilometres of transiting overhead ice.



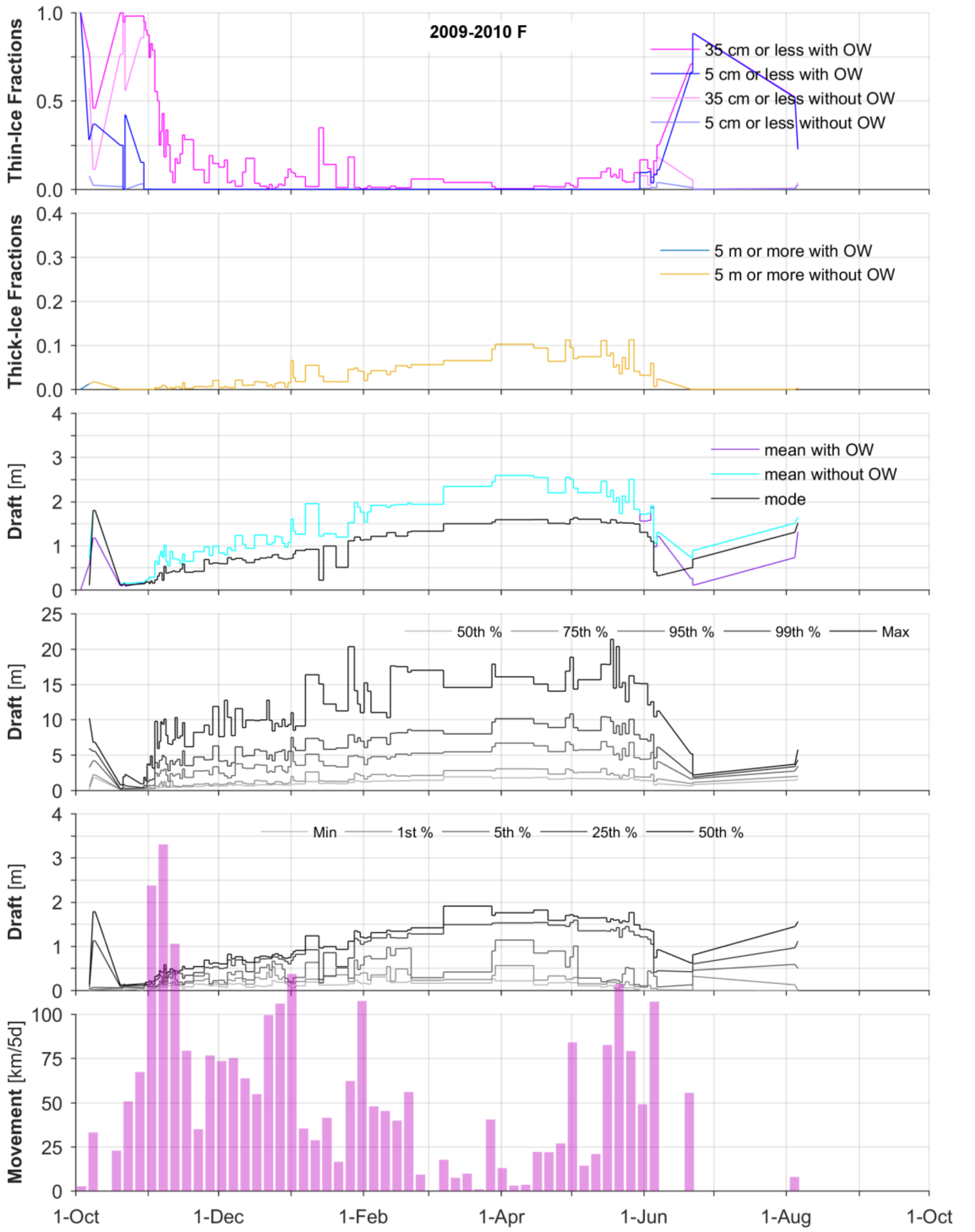
Methods

- Selected parameters:
  - Total ice transit distance (5-day windows)
  - Ice draft: mean, mode, minimum, maximum, percentiles: 1st, 5th, 25th, 50th, 75th, 95th, 99th (30 km windows)
  - Fraction of ice types: very-thin (<5 cm), thin (<35 cm), thick (>5 m) (30 km windows)
- Coordinate system
- Limitations of preliminary analysis
  - Parameters
  - Statistical approach
  - Resolution – not small-scale features, e.g. ridges, rubble fields, leads

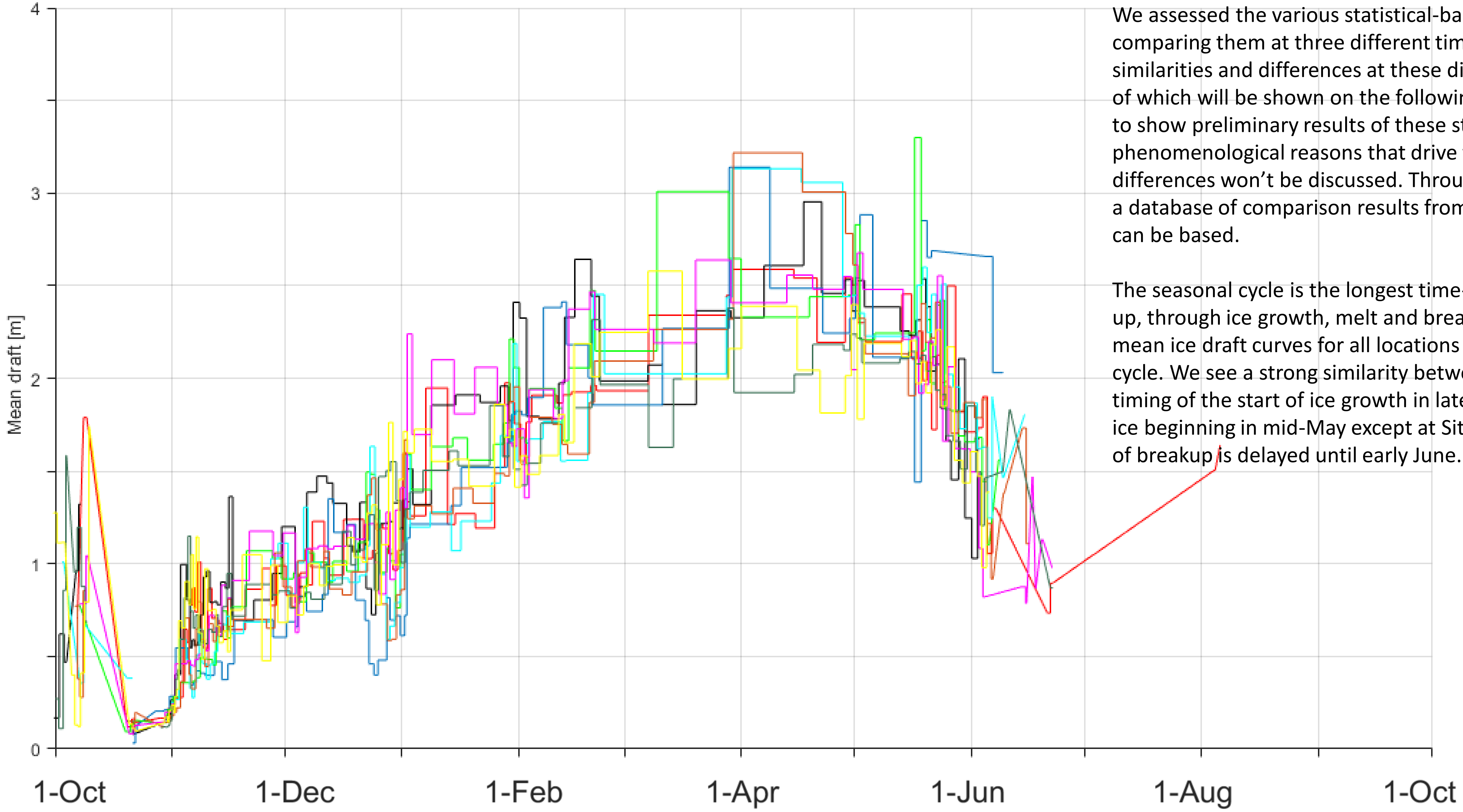
We divided each site-year of ice draft spatial-series into 30 km segments and computed the following statistics for each segment: mean, mode, minimum, maximum, and 1st, 5th, 25th, 50, 75th, 95th and 99th percentiles. For each segment we also computed the fraction of ice that was very-thin (< 5 cm), thin (< 35 cm), and thick (> 5 m). We divided the ice draft spatial-series into 5-day windows and computed the total ice transit for each window. An example of the results for a single deployment (2009-2010, Site F) is shown on the right to illustrate the volume of results. Note that as the ice velocity evolves over time with changing wind and current forcing and ice concentration, the timespan of each 30 km segment varies. This manifests as the different step size in the plotted curves.

As we were interested in the comparison of the computed ice draft statistics between measurement locations, we chose a reference coordinate system that allowed comparison between locations where minimum and maximum spatial differences were expected. The line joining Sites 2, H, G and F is approximately parallel to the general ice drift direction (along-drift) along which we expect to see the most coherence in ice draft. The line joining Sites 1 and 2 is perpendicular to the drift direction (cross-drift) along which the ice dynamics varies significantly.

The limitations of this preliminary analysis were in the selected parameters – they are statistical in nature and the sample sizes selected (30 km and 5 days) do not allow for resolution of small-scale ice features such as large keels, and small to medium sized leads and rubble fields. The parameters themselves are focused on ice draft and movement. Of course, sea ice has a number of other interesting physical parameters which were not considered including composition, strength, roughness, snow cover, etc.



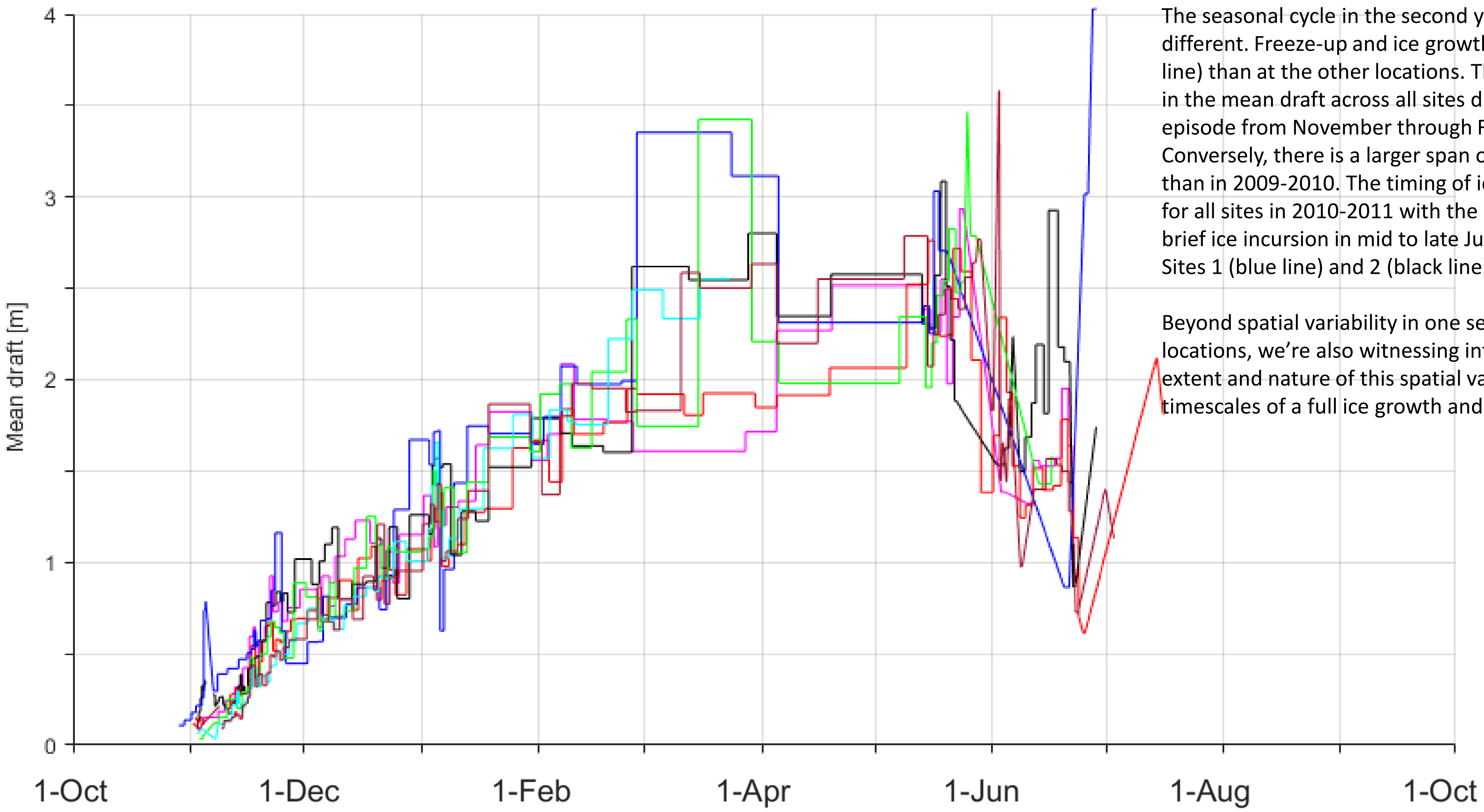
Seasonal Cycle – Mean Draft – 2009/2010



We assessed the various statistical-based time-series by looking by comparing them at three different time-scales. We found numerous similarities and differences at these different time-scales examples of which will be shown on the following slides. The objective here is to show preliminary results of these statistical comparisons. The phenomenological reasons that drive these similarities and differences won't be discussed. Through this work we've assembled a database of comparison results from on which further analysis can be based.

The seasonal cycle is the longest time-scale and spans from freeze-up, through ice growth, melt and break-up. Plotted here are the mean ice draft curves for all locations over the 2009-2010 seasonal cycle. We see a strong similarity between all the locations of the timing of the start of ice growth in late October and the breakup of ice beginning in mid-May except at Site 1 (blue line) where the start of breakup is delayed until early June.

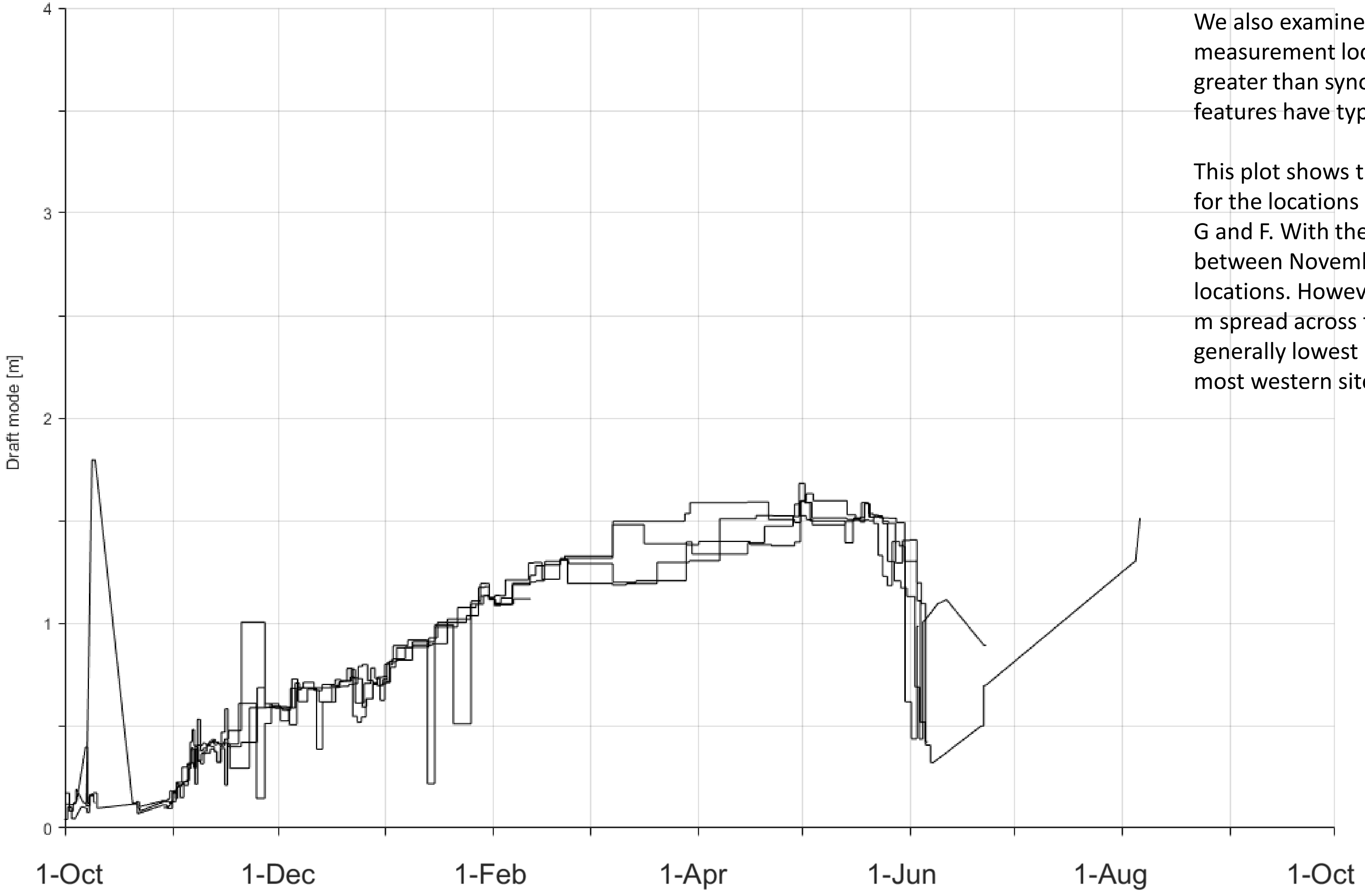
Seasonal Cycle – Mean Draft – 2010/2011



The seasonal cycle in the second year, 2010-2011, is slightly different. Freeze-up and ice growth begins earlier at Site 1 (blue line) than at the other locations. There appears to be less variance in the mean draft across all sites during the main ice growth episode from November through February than during 2009-2010. Conversely, there is a larger span of mean ice draft during March than in 2009-2010. The timing of ice breakup and decay is similar for all sites in 2010-2011 with the exception of a significant but brief ice incursion in mid to late June which is most prominent at Sites 1 (blue line) and 2 (black line).

Beyond spatial variability in one season between measurement locations, we're also witnessing inter-annual differences in the extent and nature of this spatial variability even at the long timescales of a full ice growth and decay cycle.

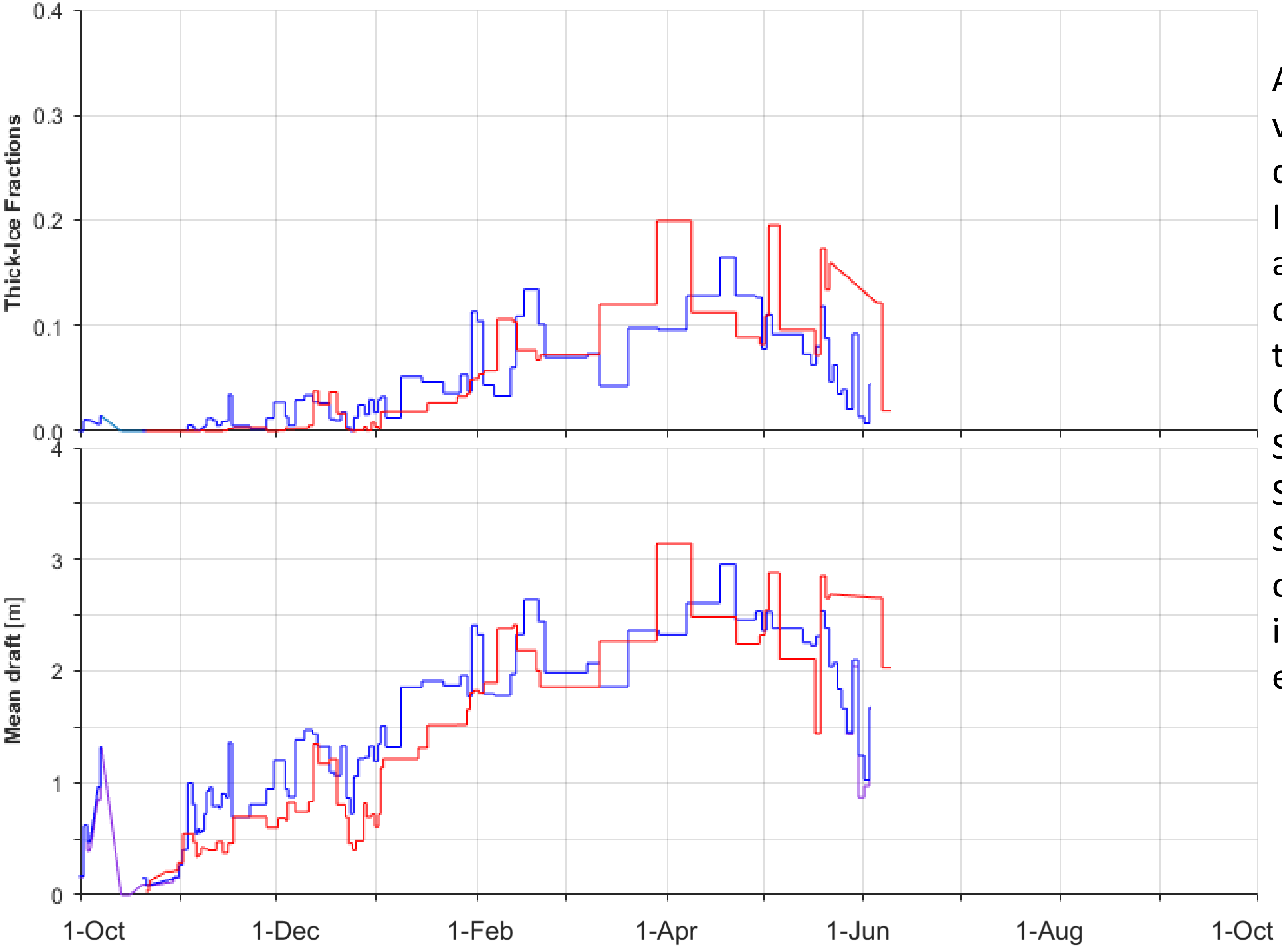
Sub-Seasonal– Mode Draft Along-Drift – 2009/2010



We also examined the ice draft statistics for differences amongst the measurement locations at timescales less than the full ice season but greater than synoptic time scales. We call these sub-seasonal and the features have typical timescales of several weeks.

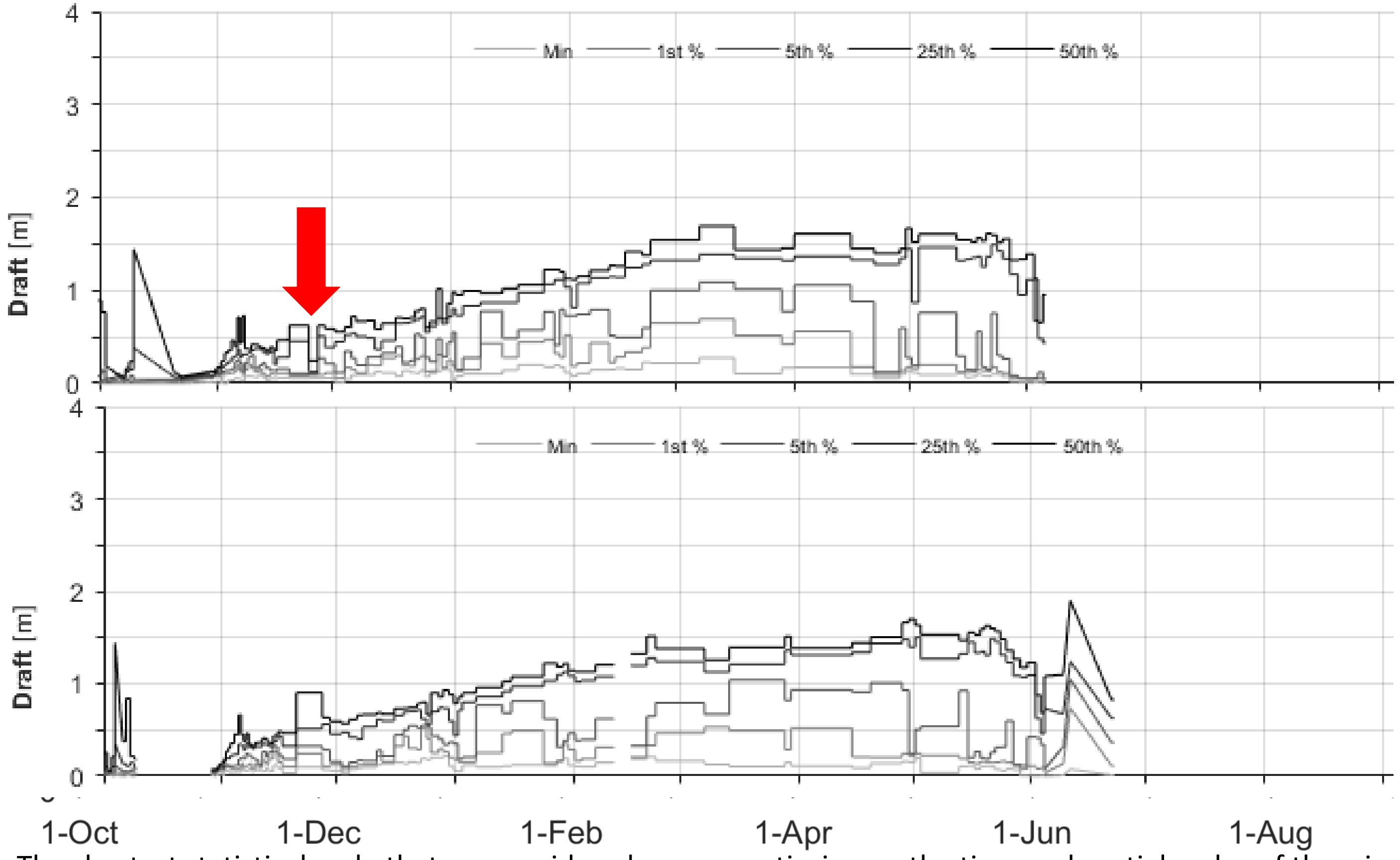
This plot shows the ice draft mode as it develops through 2009-2010 for the locations along the direction of the general ice drift: Sites 2, H, G and F. With the exception of very brief perturbations, the draft mode between November through February is very consistent across these locations. However, during late February through April, there is a ~0.5 m spread across the values during this time. The ice draft mode is generally lowest at the most eastern site (Site 2) and highest at the most western site (Site F).

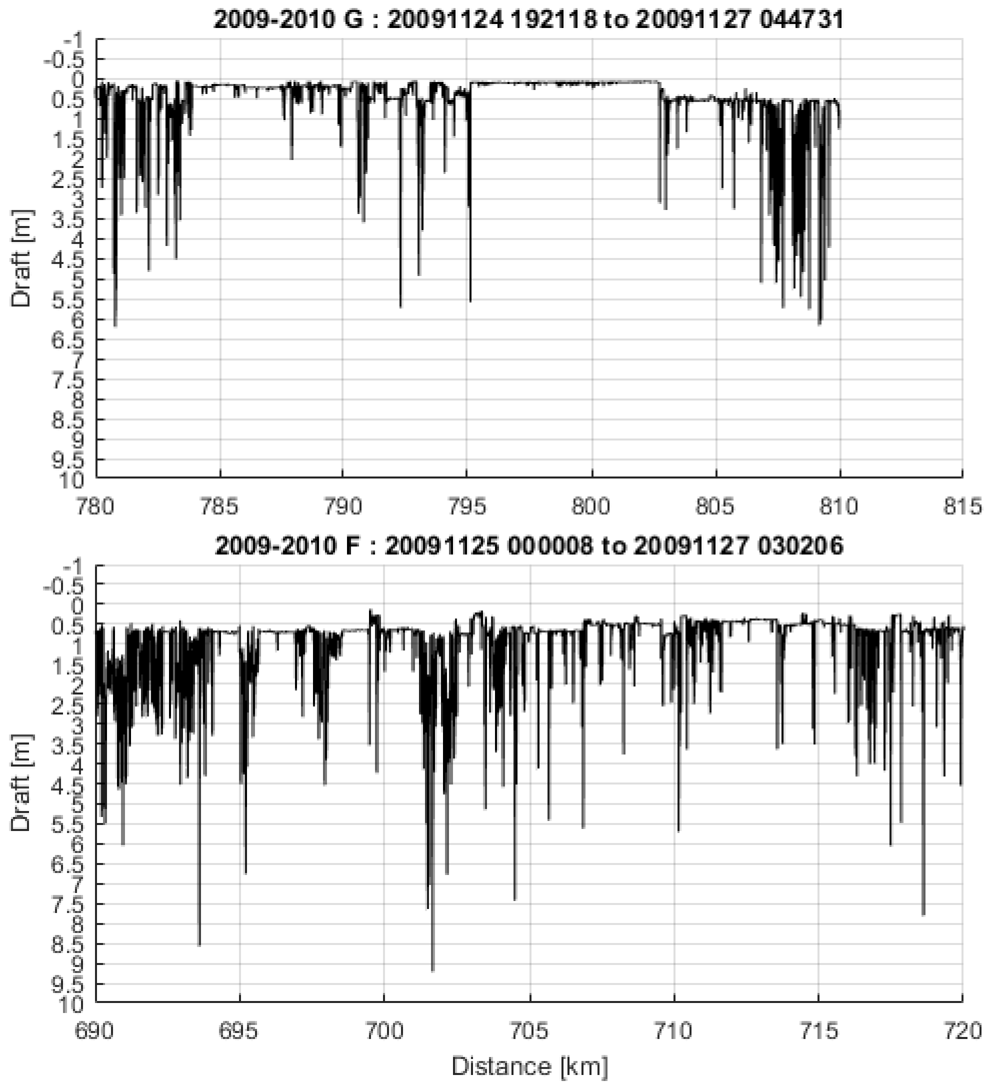
Sub-Seasonal – Cross-Drift – 2009/2010



As expected, we see greater spatial variability across the general ice drift direction than between sites along the drift. In these plots, Site 1 on the mid-shelf appears as the red line and Site 2 on the outer shelf appears as the blue line. During the main ice growth episode between late October through January, the mean draft at Site 1 remains lower than the mean draft at Site 2. This difference reaches up to ~0.5 m. Similarly, the thick-ice fraction – the fraction of ice draft observations that exceed 5 m – is higher at Site 2 except for a very brief exception in mid-December.

Synoptic – Along-Drift – 2009/2010

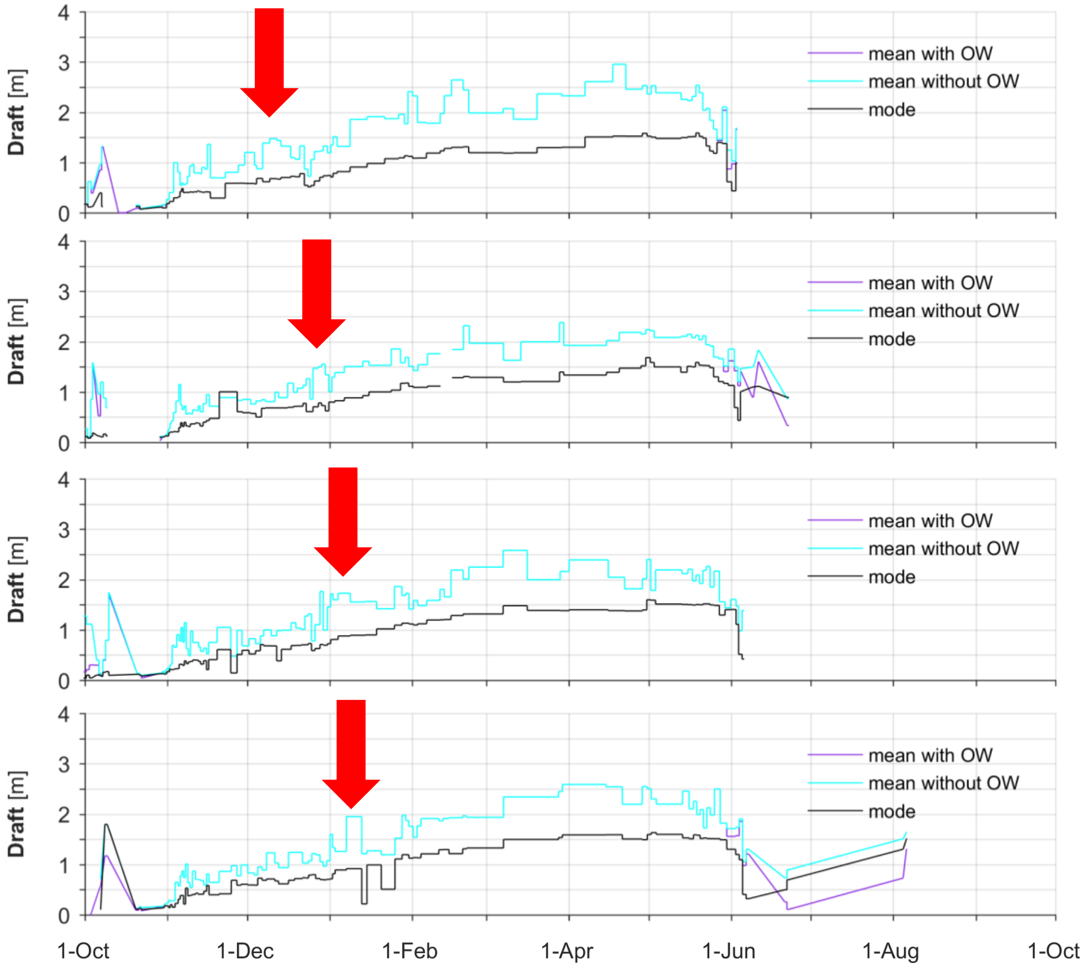




The shortest statistical scale that we considered was synoptic, i.e. on the time and spatial scales of the wind and current forcing events that drive variability in the ice drift.

There are many examples of inter-site differences at synoptic scales in the various ice draft parameters that we examined. Above in the lefthand panels, we show the low ice draft percentiles (minimum, 1st, 5th, 25th, 50th) at two sites (Site G – top, Site F – bottom) aligned in the along-drift axis. There is a distinct drop in all of the low ice draft percentiles at Site G in late November that is not visible at Site F. The plots on the righthand side show the ice draft values that contribute to these statistics and clearly show the presence of a thinner ice sheet at Site G relative to Site F which are separated by only ~40 km.

Synoptic – Along-Drift – 2009/2010



Whereas the last slide showed an example of a synoptic scale ice draft feature that appeared at one site but not at its neighbour, here we see a possible example of an ice draft feature visible at all several sites with a phase difference. In mid-December, a deviation of ~0.5 m from the long-term mean ice draft growth curve is seen at Site 2 (top panel). The other panels show the mean ice draft at Sites H, G and F in that order, i.e. from east to west in the direction of the general ice drift. The arrows indicate a mean ice draft deviation at all sites of approximately the same amplitude and time duration. This possibly is an example of one expected component of inter-site variability - that variability between these measurement locations will be in part due to phase differences as a distinct ice feature transits over each location.

Summary

- Preliminary results of a statistical analysis on ice draft variability
- Seasonal cycle is similar across array; however, some inter-annual variability
- More coherence along-drift then cross-drift
- Many synoptic-scale differences between neighbouring locations

We compared ice draft statistics between measurement locations within a dense mooring array operated over two years. We used three scales for our analysis – seasonal, sub-seasonal and synoptic. Our results are preliminary and at this stage we've generated numerous observations of differences and similarities between sites at these three scales. We've shown several examples of these comparisons. The seasonal development of ice draft is relatively coherent across the array within a single measurement year; however, there is some inter-annual variability in the extent of this coherence. We see less spatial variability between sites in the along-drift direction then across-drift. There are significant differences between neighbouring measurement locations particularly at synoptic scales; the closest sites were separated by only 4 km and differences were even seen at this scale. Future work will involve finalizing the database of inter-site comparisons and investigating the phenomenological basis for these differences and similarities.