How do changes in river input and sea ice affect the Hudson Strait outflow?

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1 Introduction

The waters that flow out through Hudson Strait, a 100 km long, 400 km wide coastal system that connects Hudson Bay with the Labrador Sea, constitute the third largest freshwater contribution to the northern North Atlantic, behind only Fram Strait and Davis Strait. The majority of this freshwater comes from Hudson Bay, through an annual 940 km3/yr of river input and a comparable amount of sea ice melt, with an additional portion coming from Davis Strait (Straneo and Saucier, 2008). Over the last several decades, however, large interannual changes have been documented in Hudson Bay, including a decrease in riverine input and a decrease in the length of seasonal sea ice coverage (Déry et al., 2005).

How these interannual changes are reflected in the fresh Hudson Strait outflow is unknown. Recent observations have begun to shed light on the outflow's structure on seasonal timescales, showing it to be a baroclinic buoyant coastal current, with the highest velocities and lowest salinities in late fall and winter (Straneo and Saucier, 2008). Within this seasonal envelope, though, synoptic scale variability (on the order of 4-6 days) dominates the observed salinity and velocity records.

Thus, before examining how interannual trends in forcing affect the outflow, we must first understand what mechanisms cause the freshwater export to be concentrated to a series of discrete pulses. Since the freshwater outflow modulates how high-stratification and high-nutrient water enters the northern North Atlantic, the fact that the outflow is confined to coherent eddy-like structures that preserve their properties for longer periods of time is important. The generation of these low-salinity pulses appears to be related to the passage of storms across Hudson Bay that drives variability in the cyclonic boundary current circulation (Prisenberg, 1987).

2 Location and Data

A set of moorings was deployed in the outflow region of Hudson Strait from 2004-2006 and represents the first successful yearlong mooring records from the strait (Fig. 1). Each mooring was equipped with an upward looking ADCP, as well as upper and lower MicroCATs measuring temperature and salinity. In addition, the middle mooring (A in Fig. 1) had a McLane Moored Profiler (MMP) that collected temperature, salinity, CDOM, and optical backscatter data over the depth range ~40-170 meters. Meteorological data over the strait and in eastern Hudson Bay were obtained from the six-hourly NCEP reanalysis fields.

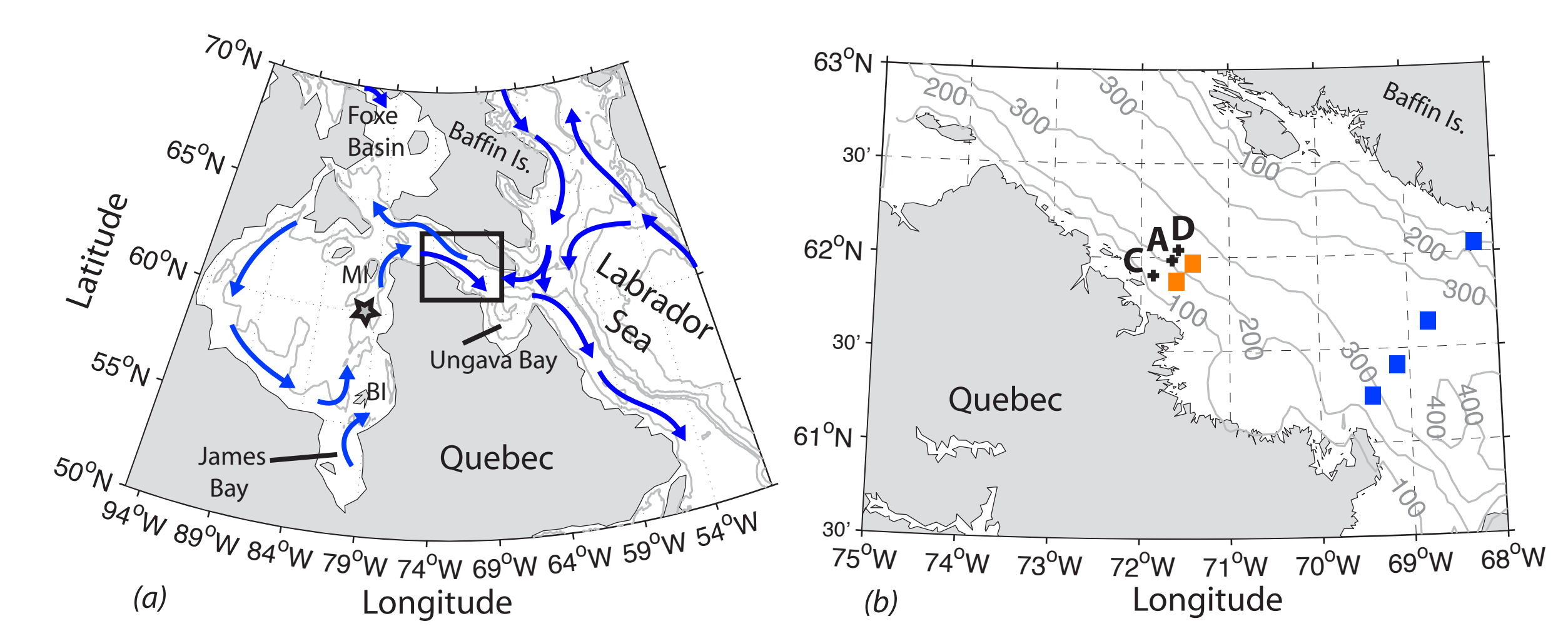

Figure 1. (a) Map illustrating how the cyclonic circulation in Hudson Bay connects through Hudson Strait to the Labrador Sea. In eastern Hudson Bay, Mansel Island (MI) and the Belcher Islands (BI) act as obstacles to the cyclonic boundary current. The star marks the location of the wind data used.

(b) Zoom-in on Hudson Strait showing the mooring locations (black plusses) and names (C, A, D) for the 2005-2006 deployment. The mooring array spans about 30 km from the coast and encompasses the peak velocity of the outflow current. Previous mooring deployments are also indicated, though they both lasted less than a full year (1986-87: orange, 1982: blue).

3 Research objectives

Utilizing a new and unprecedented set of observations, this research aims to

1) describe the series of discrete freshwater pulses that constitute the majority of the freshwater export leaving the Hudson Bay system through Hudson Strait,
2) examine the different mechanisms that could explain the observed variability,
3) and understand how these coherent, low-salinity eddy-like structures might respond to changes in forcing on interannual timescales.

4 Low-salinity events

Low-salinity waters exit Hudson Strait in a series of events that occur on a time scale of ~4-6 days during the fall/winter season (Fig. 2). These pulses are surface-trapped, but can reach depths up to 120 meters. Figure 3 illustrates the characteristics of a typical event, showing the coherent signals in salinity, CDOM, and across-strait velocity, as a pulse propagates by the array. Three mechanisms could explain this observed variability:

1) movement of the front back and forth across the mooring array,
2) individual river plumes exiting Hudson Bay,
3) or remotely-forced pulses of low-salinity water advected by the array.

Since the across-strait velocity signal is onshore then offshore, a simple salt balance (Fig. 4) shows that these events cannot be explained by the front moving across the moorings. Instead, these events are associated with synoptic-scale storms that pass over Hudson Bay and accelerate the waters there, causing a pulse of freshwater to exit past Mansel Island and reach the strait ~10-14 days later (Fig. 5). Rivers certainly play a role in supplying the freshwater for these events, but mixing and the long residence times in Hudson Bay suggest that these events are not individual river plumes.

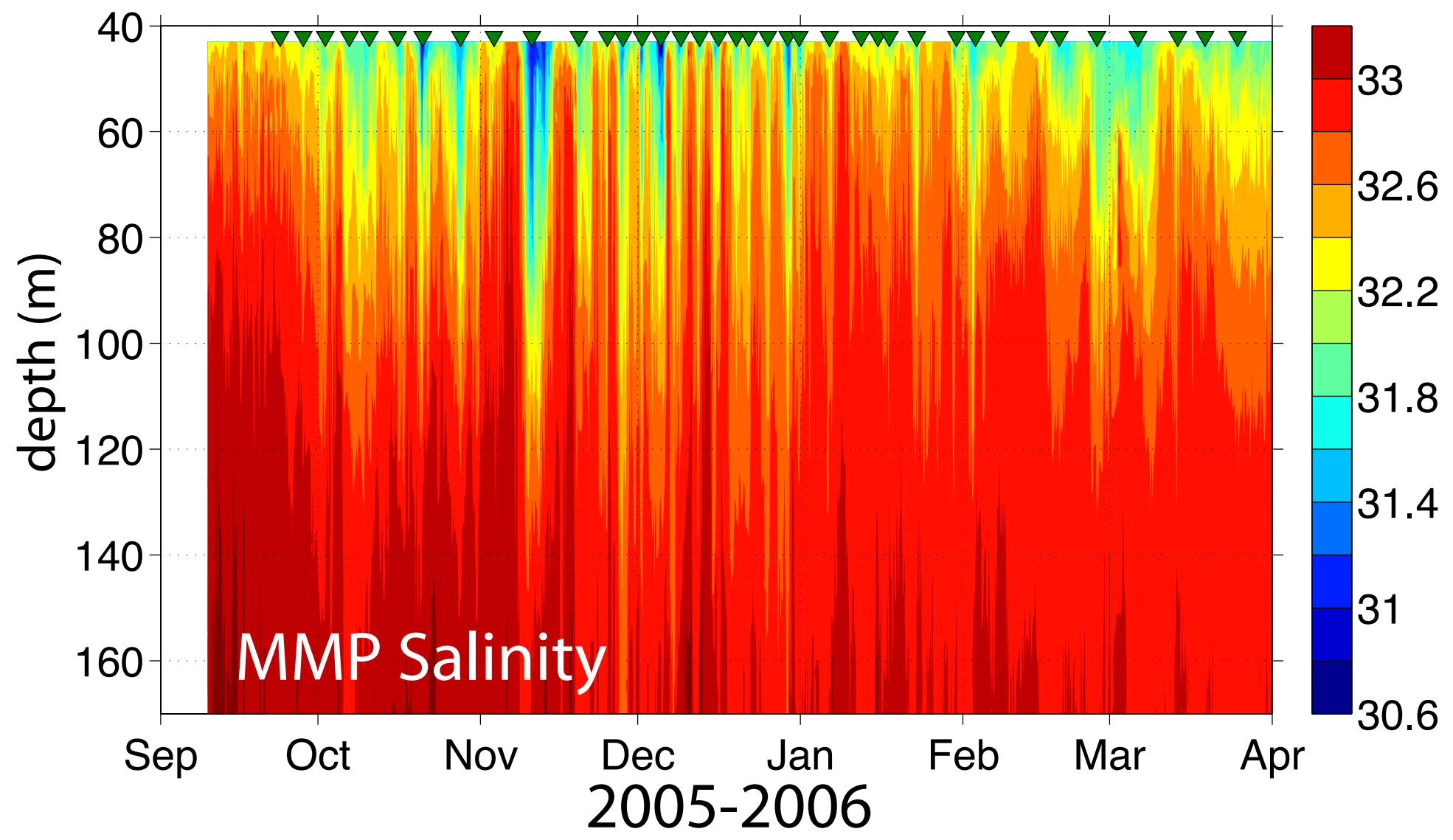

Figure 2. Salinity record from the MMP at mooring A for the fall/winter season. Low-salinity events occur on a 4-6 day timescale from late September until early April (triangles).

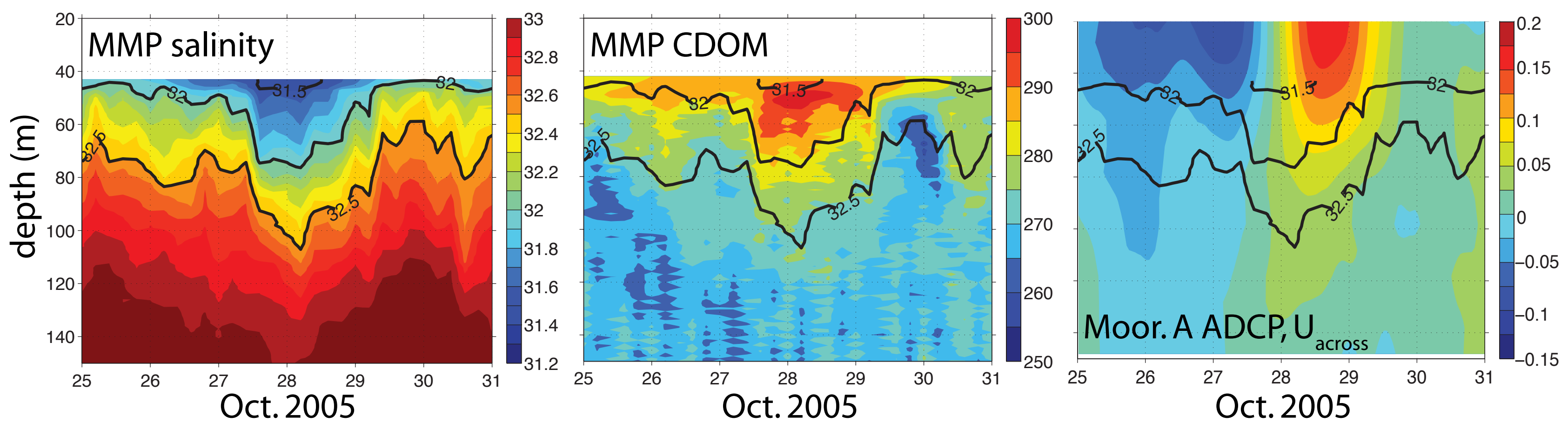

Figure 3. Salinity, CDOM, and across-strait velocity from mooring A of a typical low-salinity event. The along-strait velocity (not shown) accelerates with the passage of these pulses as well, but the timing does not show a consistent pattern.

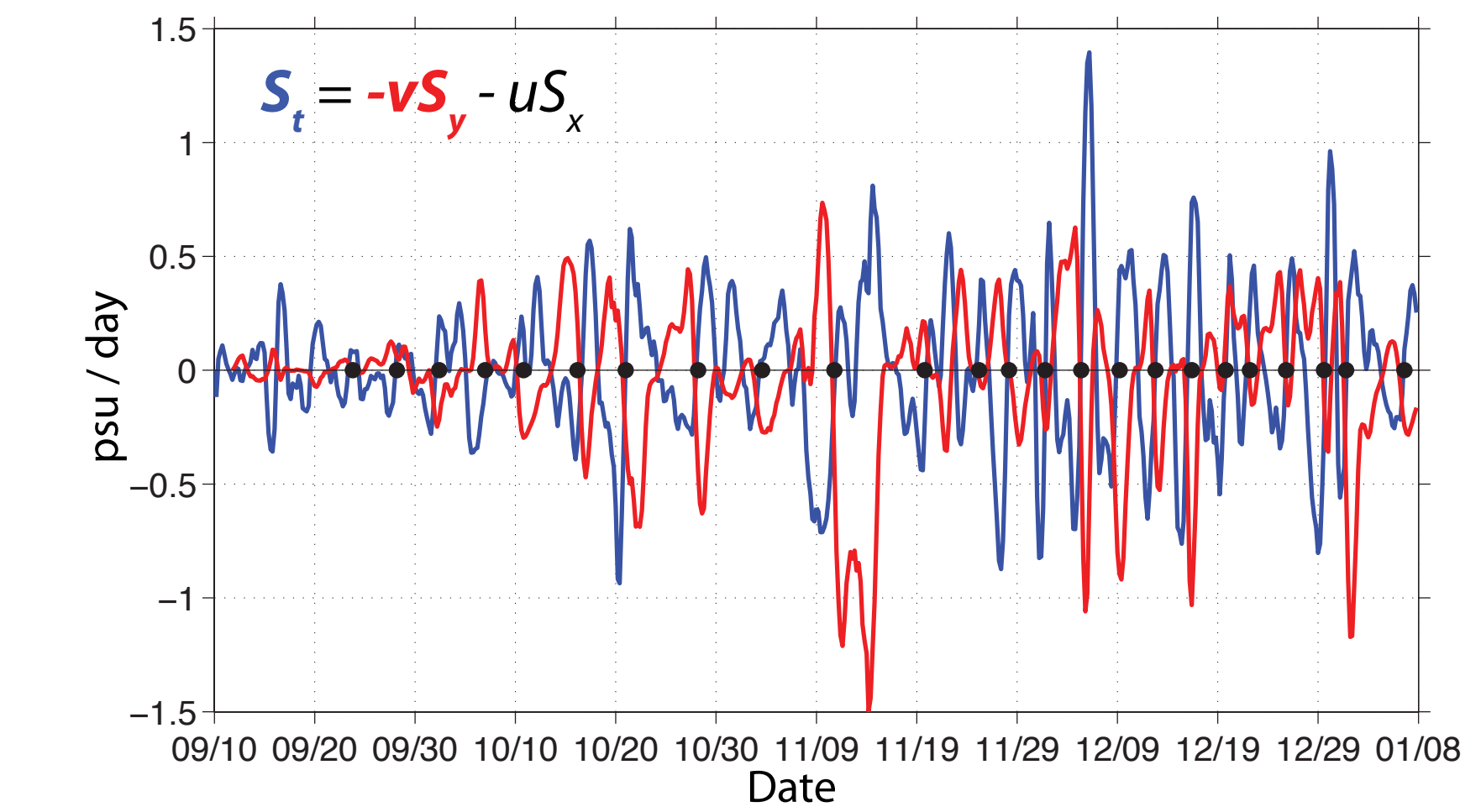

Figure 4. Two terms from the salt balance equation calculated from the moorings at a depth of 45 meters (time rate of change in blue and the cross-strait advective term in red). The along-strait advective term could not be estimated directly, but would be the residual.

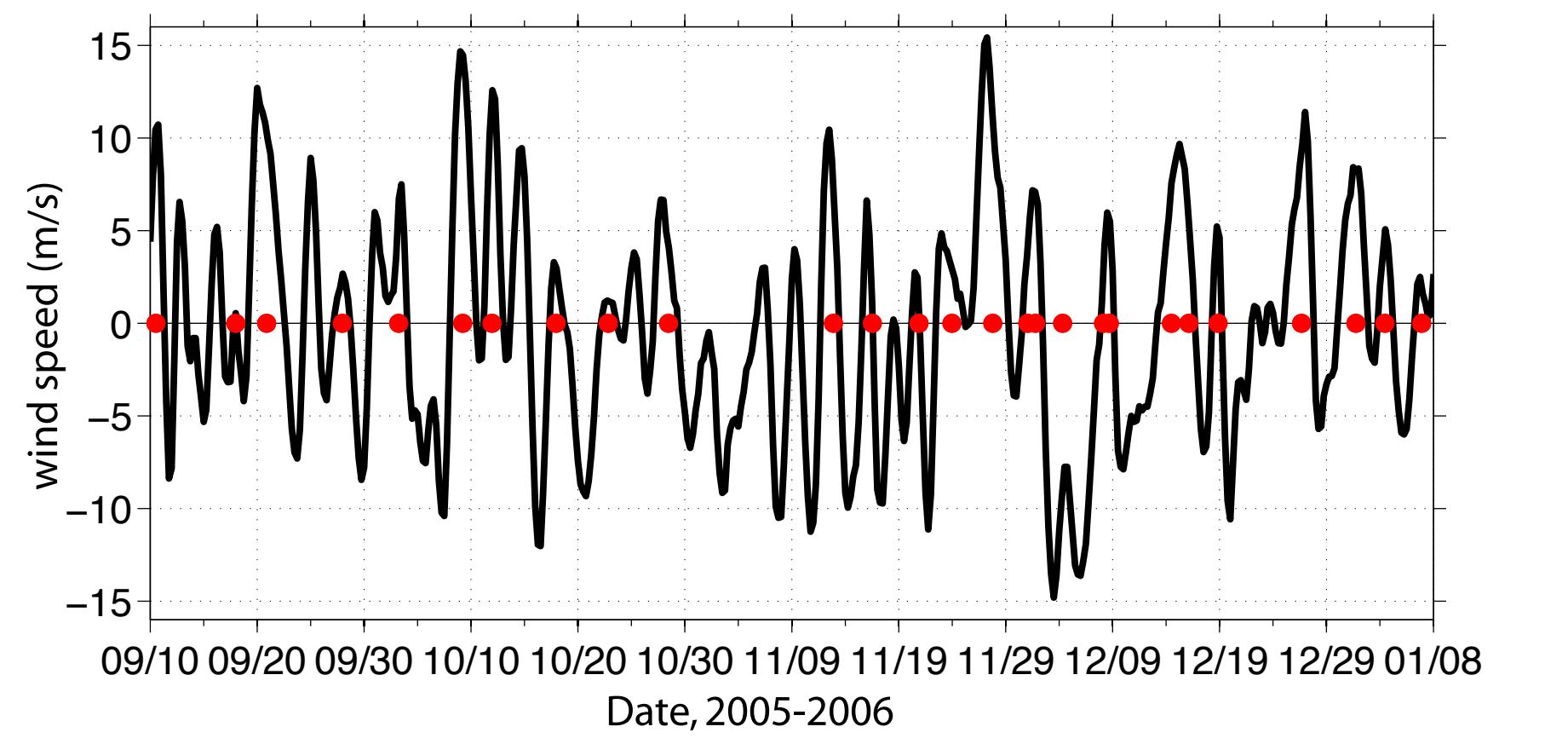

Figure 5. North-south winds in E. Hudson Bay (star, Fig. 1) from NCEP reanalysis. Strong northward winds accelerate the flow out of the bay and correspond to the passage of the low-salinity events observed in Hudson Strait (red dots), at a lag calculated with the observed propagation speed of each pulse and the distance traveled (~310 km).

5 Seasonal to interannual variations

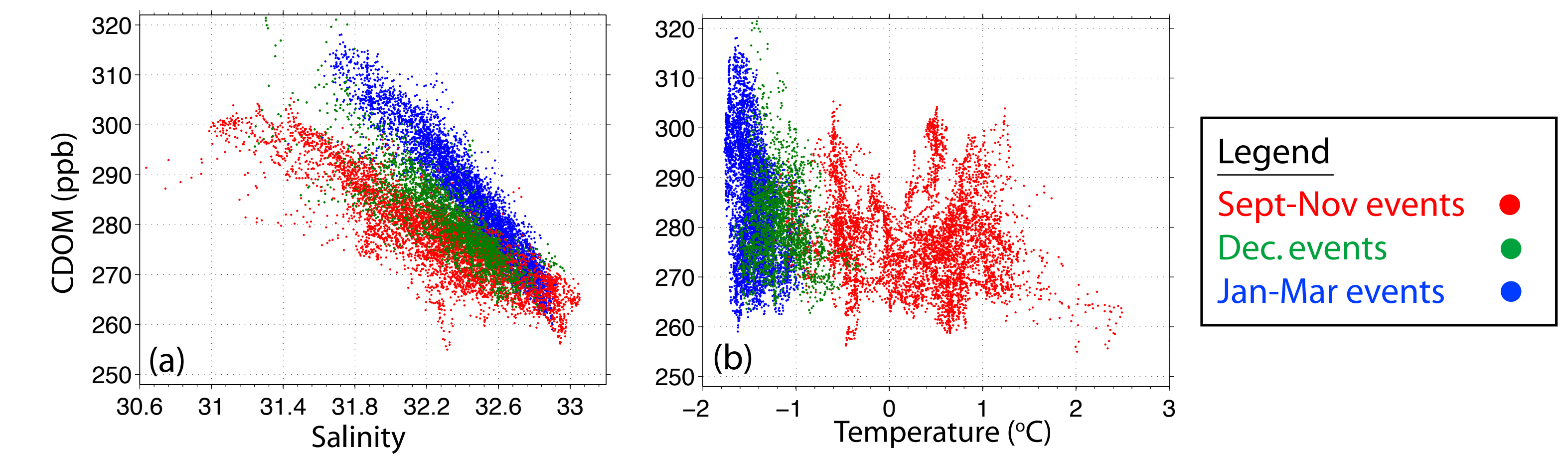

Figure 6. The occurrence of low-salinity events is limited to the fall/winter season due to the timing of the river input into Hudson Bay, but the sea ice cycle also imprints a seasonal signal. The entire Hudson Bay system undergoes a complete freeze/melt cycle every year, which can be seen in plots of CDOM vs. salinity (a) and temperature (b). High CDOM is associated with a high river water %, but once sea ice formation and the associated brine rejection begins, the S vs. CDOM mixing line changes (a), and the temperature goes to freezing (b).

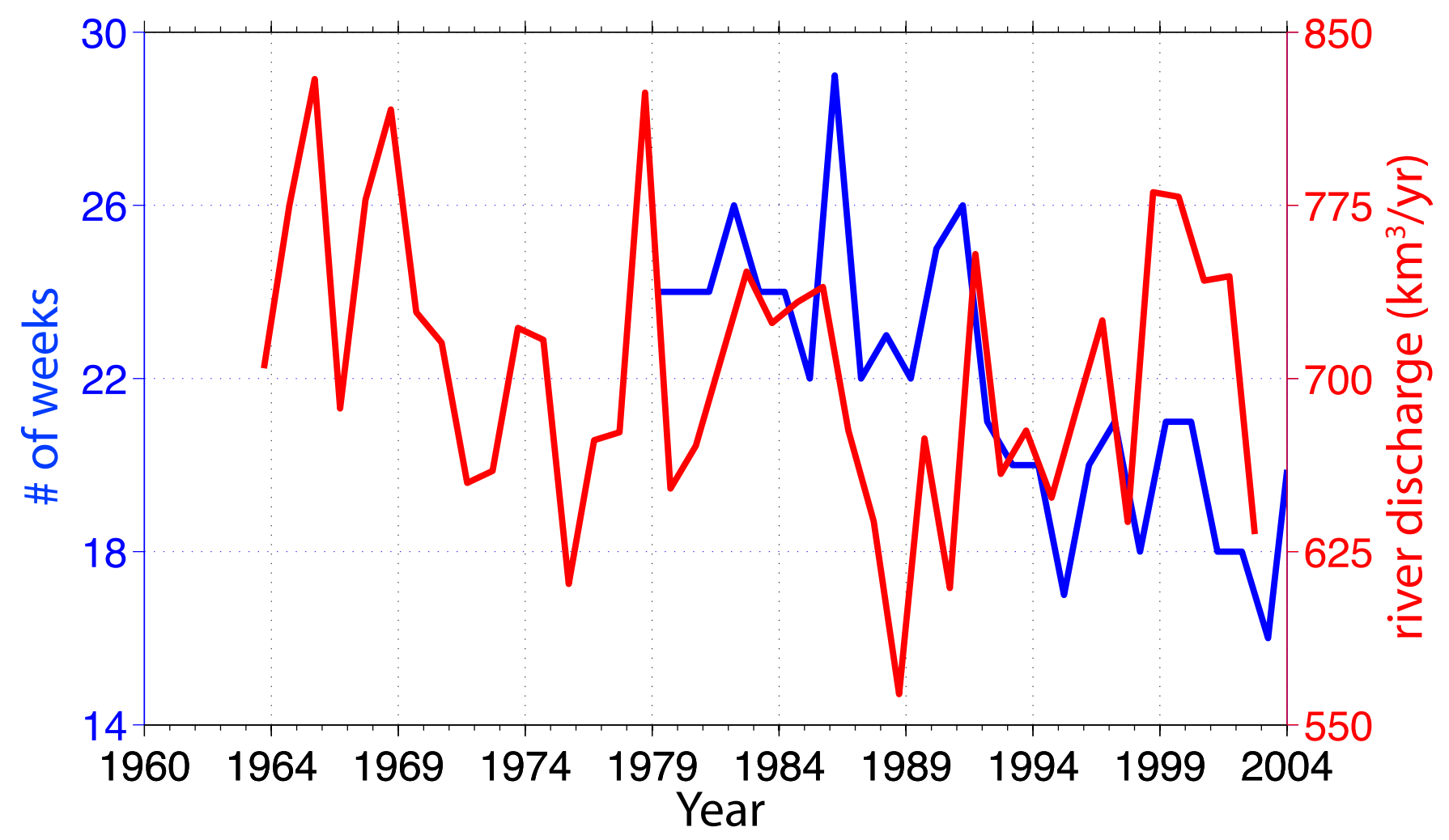

Figure 7. Since the river input into Hudson Bay and the annual sea ice cycle modulate the low-salinity events seasonally, any interannual trends in these forcings might also imprint interannual variations in the structure and timing of the pulses. From 1964-2003 the input of 42 rivers into Hudson Bay (red) decreased by 10% (Déry et al., 2005). In addition, satellite measurements show that the number of weeks of 100% sea ice coverage over Hudson Bay (blue) has decreased as well, with the sea ice season both starting later and ending earlier (Armstrong and Brodzik, 2005).

The low-salinity events are common features in all previous years' observations (1982, 1986-87, 2004-06). We are currently investigating how the changes in river input and sea ice have impacted their structure.

6 Summary

- The series of discrete, low-salinity pulses observed in the Hudson Strait outflow are surface-trapped, anticyclonic eddies with vertically and horizontally coherent salinity, CDOM, and velocity signals.
- These eddies dominate the salinity record during the fall/winter season, and make up 40% of the volume transport and 50% of the freshwater flux of the outflow.
- Generation of these eddies is related to the passage of storms over Hudson Bay and the forcing of low-salinity waters out of Hudson Bay near Mansel Island.
- Changes in river input and sea ice over interannual timescales have been documented, but their effects on the low-salinity events is unknown.

Mean characteristics (std. devs.) Fall/Winter 2005-06
38 events, one per 4.4 days
horizontal scale ~ 25 km (12 km), 3-4 times Rossby radius
g′ ~ 0.011 m/s^2 (0.003 m/s^2)
advective speed ~ 0.18 m/s (seasonal max/min)
vertical extent ~ 75 m (10 m)

Acknowledgments and references

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