Upwelling in the Alaskan Beaufort Sea and its impacts on primary productivity

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1. Introduction:

The general circulation of the southern Beaufort Sea consists of wind-driven westward flow in the interior and a buoyancy-driven shelfbreak jet flowing to the east. The jet is often reversed when easterly winds exceed 5 m/s resulting in upwelling . Upwelling can occur during any month of the year and in nearly all ice conditions. The upwelling has the potential to impact the ecosystem since the secondary circulation brings nutrient-rich waters from the halocline into the euphotic zone.

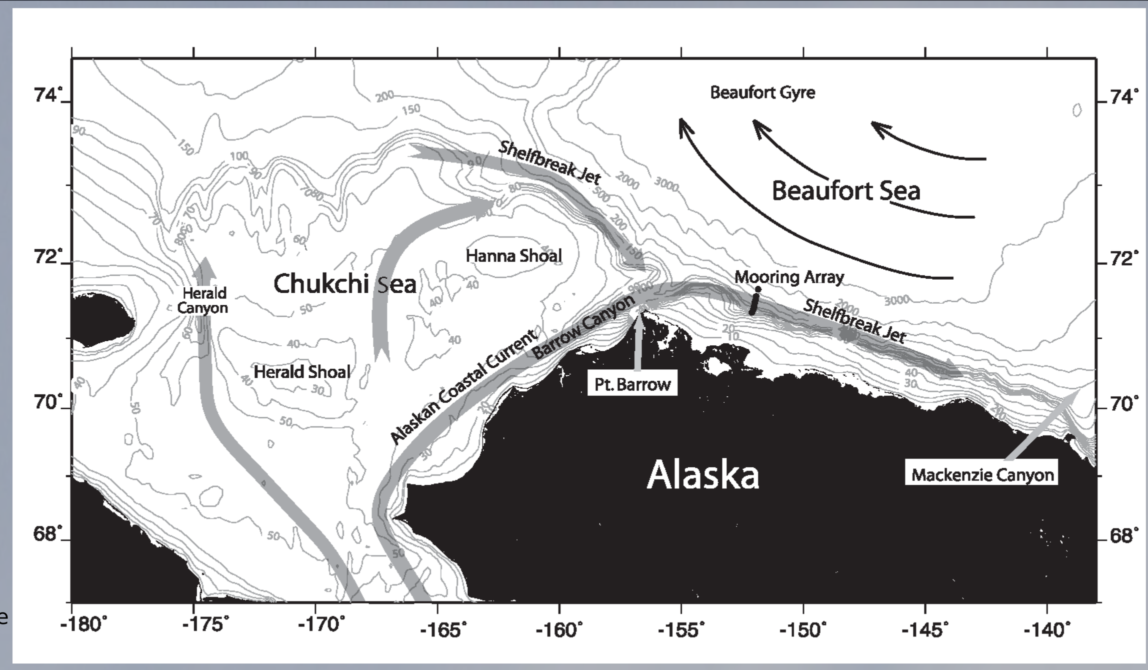

Figure 1: Major currents of the Chukchi and Beaufort Sea. Solid dots indicate the location of the mooring site.

2. Upwelling:

Using data from a mooring array deployed across the shelfbreak jet for two years (Aug 2002 - Sept 2004) and wind data from a nearby weather station, 45 upwelling events were identified. While the upwelling is strongest during times with partial ice cover, the basic response is the same for all seasons. A typical storm response is shown in Fig. 2 for a location in the shelfbreak jet.

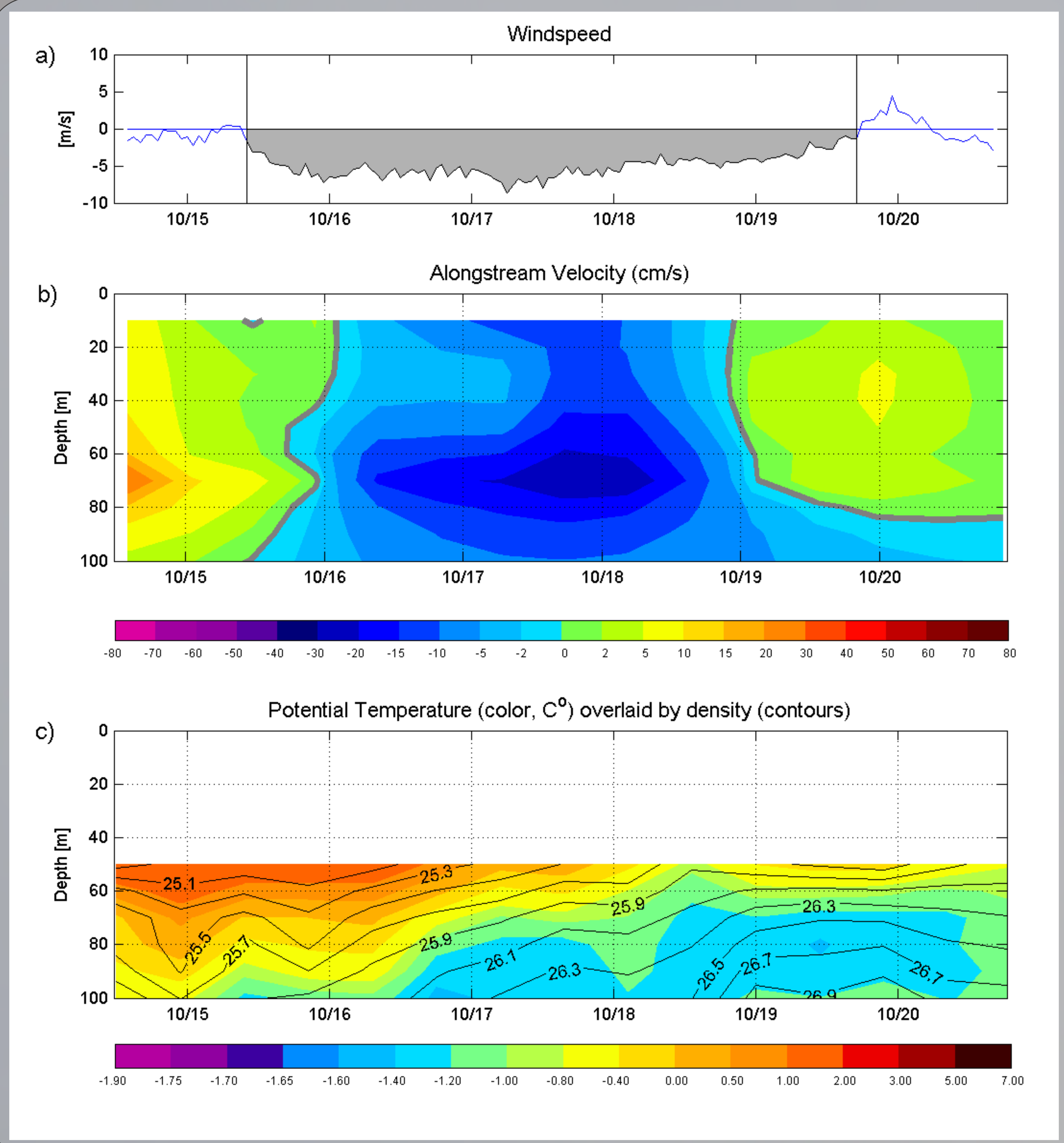

Figure 2: Upwelling characteristics for a storm in September 2002; (a) Wind measured at the Barrow, AK weather station. The vertical lines and gray shaded area indicate the length of the storm; (b) Alongstream velocity. Positive flow is to the east; (c) Potential temperature (color) overlaid by potential density (contours, [kg/m3]).

3 Biological implications:

Cold, nutrient-rich Pacific water enters the Chukchi Sea each winter through Bering Strait. Some of the water triggers a spring/summer phytoplankton bloom on the shelf, while some is fluxed offshore into the halocline. The shelf bloom is typically over by mid-August, leaving the water column stripped of nutrients.

Upwelling represents a mechanism for re-supplying nutrients to the outer Chukchi and Beaufort shelves in late-summer/early-fall by tapping the reservour of high-nutrient water in the basin. Evidence of a wind-induced bloom can be seen on Fig. 3 for a storm in August 2010.

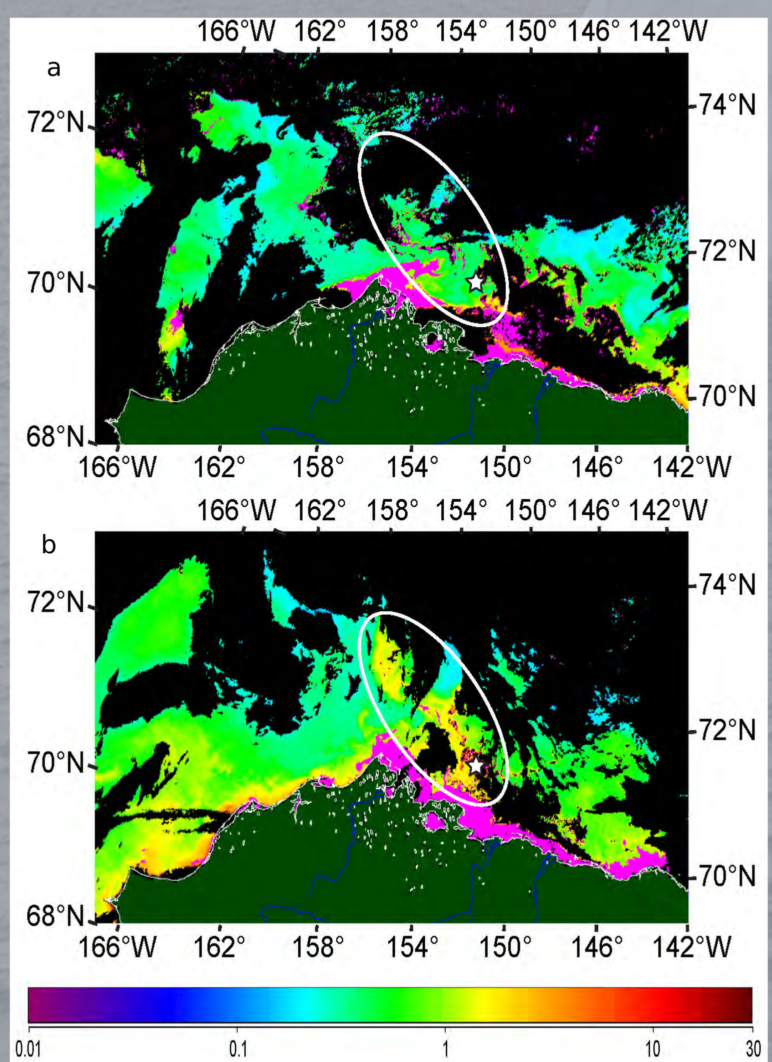

Figure 3: Oceancolor image of the study area (the white star denotes the mooring array); a) Chlorophyll two days before a strong wind event (4-5 August 2010); b) Chlorophyll four days after the wind event (14-17 August 2010). The white circle shows an area of high productivity that developed during the storm. (The pink shadng is a

4. Upwelling-induced primary productivity:

A nitrate-density relationship was used in conjunction with the mooring data to calculate vertical nitrate fluxes to the euphotic zone during seven upweling events in open water conditions (August to early-October 2002-2004). Results indicate that upwelling supplied an average of 142 mmol N/m^2 per open-water season, which converts to 936 mmol C/m^2 (Table 1). This average is only slightly less than in-situ data measured for the Chuckchi shelf and slope during August 2002 (in storm-free conditions.).

Season	N Flux [mmol/m2]	C uptake [mmol/m2]
2002	63	418
2003	326	2151
2004	36	239
Annual Average	142	936
Per Storm Average	61	401

Table 1: The nitrate flux and carbon uptake for the storms in Aug - early Oct 2002-2004 under ice free conditions.

5. Decadal variability of upwelling and productivity:

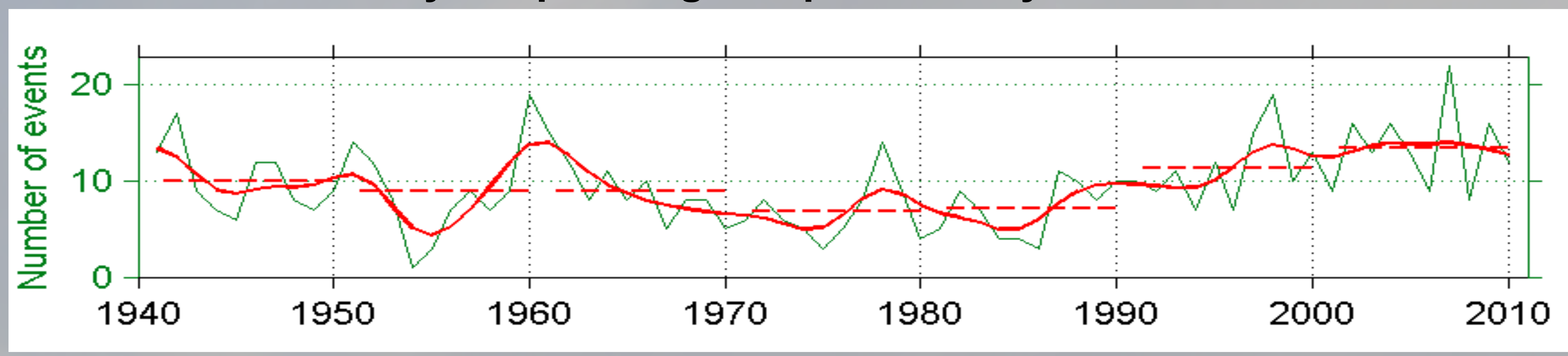

Figure 4: Yearly number of upwelling events (green curve) and the 7-yr low-pass (red curve). The red dashed lines mark the decadal averages..

A 70-yr timeseries (1941-2010) of windspeed, along with a previously determined wind-upwelling relationship, allowed us to establish a long-term record of upwelling on the Beaufort Slope (Fig 4). During this period, 149 open-water storms were deemed sufficiently powerful, and long enough in duration, to allow initiation of a phytoplankton bloom.

Using the carbon uptake from the storms discussed above we estimated the storm-induced carbon production during the open water season of each of the 70 years (Fig.5). Storm count and carbon uptake show an enhancement over the last two decades.

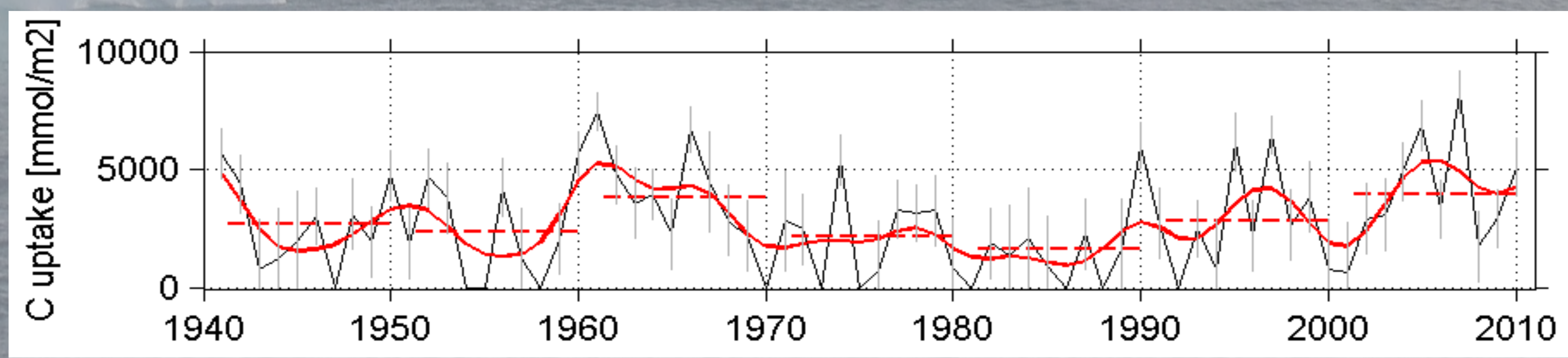

Figure 5: Yearly mean carbon uptake (black curve) and the 7-yr low-pass (red curve). The red dashed lines mark the decadal averages, and the grey vertical lines indicate the standard erros.

6. Conclusion:

Transport of nutrients into the euphotic zone via upwelling can trigger significant primary production in late-summer and early-fall. This has potential to result in as much carbon uptake as during a storm-free spring/summer bloom. Early-season, under-ice blooms have recently been observed in the Chukchi Sea, and, as the pack-ice continues to melt earlier and freeze later, upwelling in the spring and fall may promote even higher carbon production in the future.