Physical control of primary production on the Faroe Shelf

Authors: Sólvá Káradóttir Eliasen (solvae@hav.fo), Karin Margretha Húsgarð Larsen, Bogi Hansen
Faroe Marine Research Institute

1 Background

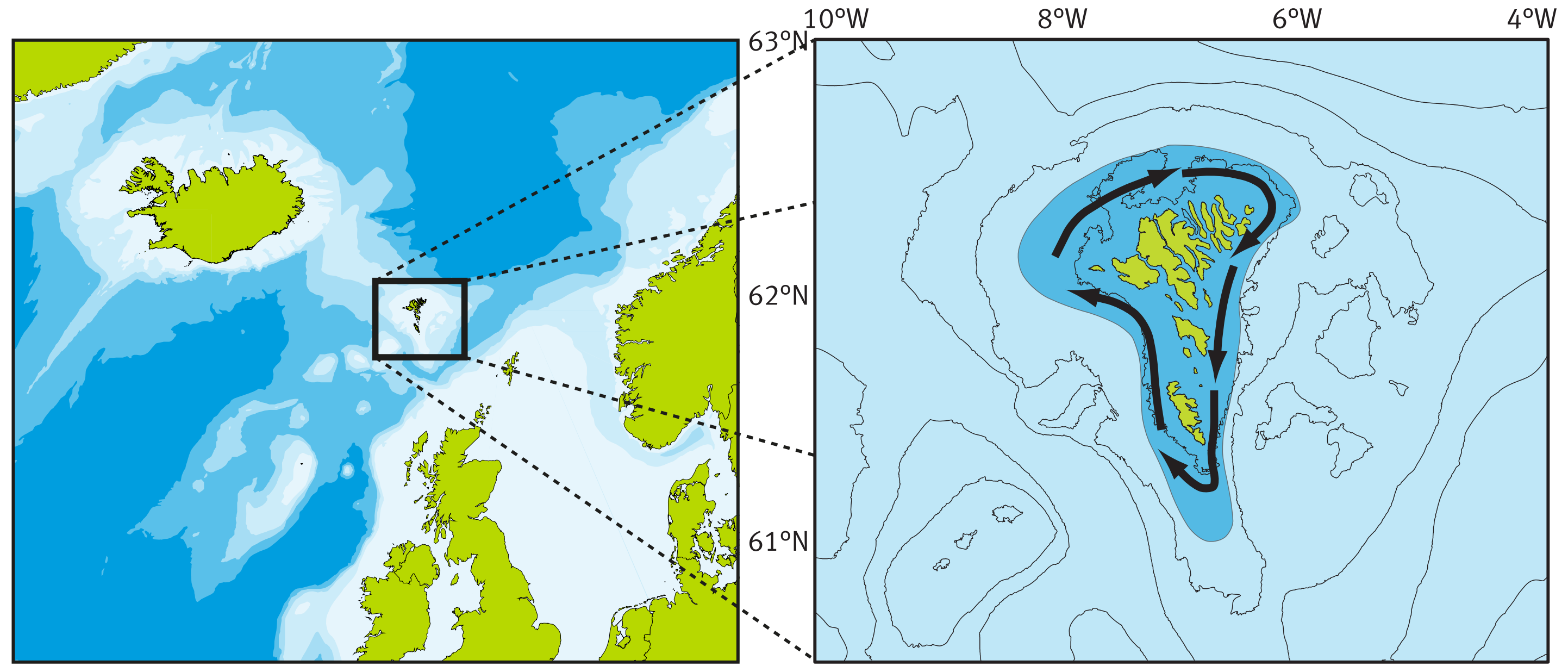


Figure 1. The Faroe Islands are surrounded by a shelf comprising 15,000 km² within the 170 m bottom contour. This shelf is partly isolated from the open ocean by a tidal front, inside of which the water circulates clockwise (Larsen et al., 2008).

Due to strong tidal currents the waters inside the front (Figure 1) are well mixed throughout the year and support a relatively uniform shelf ecosystem distinct from the waters outside.

From the reduction in nitrate during spring, Gaard (2002) defined a "PP-index", which quantifies the accumulated primary production during the spring bloom inside the front. This index exhibits high inter-annual variability, which cascades to higher trophic levels, indicating that phytoplankton production is the prime driver in the ecosystem (Gaard 2002).

A negative correlation between this index and zooplankton biomass was originally interpreted as top-down control of the spring bloom through grazing (Gaard et al., 1998), but modelling as well as observational studies have shown that zooplankton is not able to suppress or delay the spring bloom (Eliasen et al., 2005; Debes et al., 2008).

This indicates that the spring bloom is controlled by physical processes, but obvious candidates such as light intensity are found not to explain the variations (Gaard et al., 1998; Eliasen et al., in prep.).

This led to the hypothesis, which is tested in this study.

2 Hypothesis and Objective

Horizontal exchange controls the spring bloom inside the front

Since the water inside the front is well mixed, it is the average depth experienced by algae that controls their productivity for a given surface light intensity. When horizontal exchange is strong, algae cannot remain in shallow water for a sufficiently long period to initiate a bloom.

This mechanism (termed "Horizontal Sverdrup Mechanism" by Eliasen et al., 2005) will only be relevant for systems of small areal extent and relatively strong horizontal exchange, but a simple model of the Faroe shelf indicated that variations in exchange rate by a factor of five could explain much of the difference between years with weak and strong spring blooms (Figure 2).

The dominant zooplankton species in spring is *Calanus finmarchicus*, which is oceanic and has to cross the front. This hypothesis therefore may also explain the negative relationship between zooplankton and the spring bloom.

Test of the hypothesis with direct observations

Although consistent with available information, this hypothesis has lacked confirmation from direct observations.

In this study, we present a method to determine horizontal exchange rate from observations and test the validity of this hypothesis.

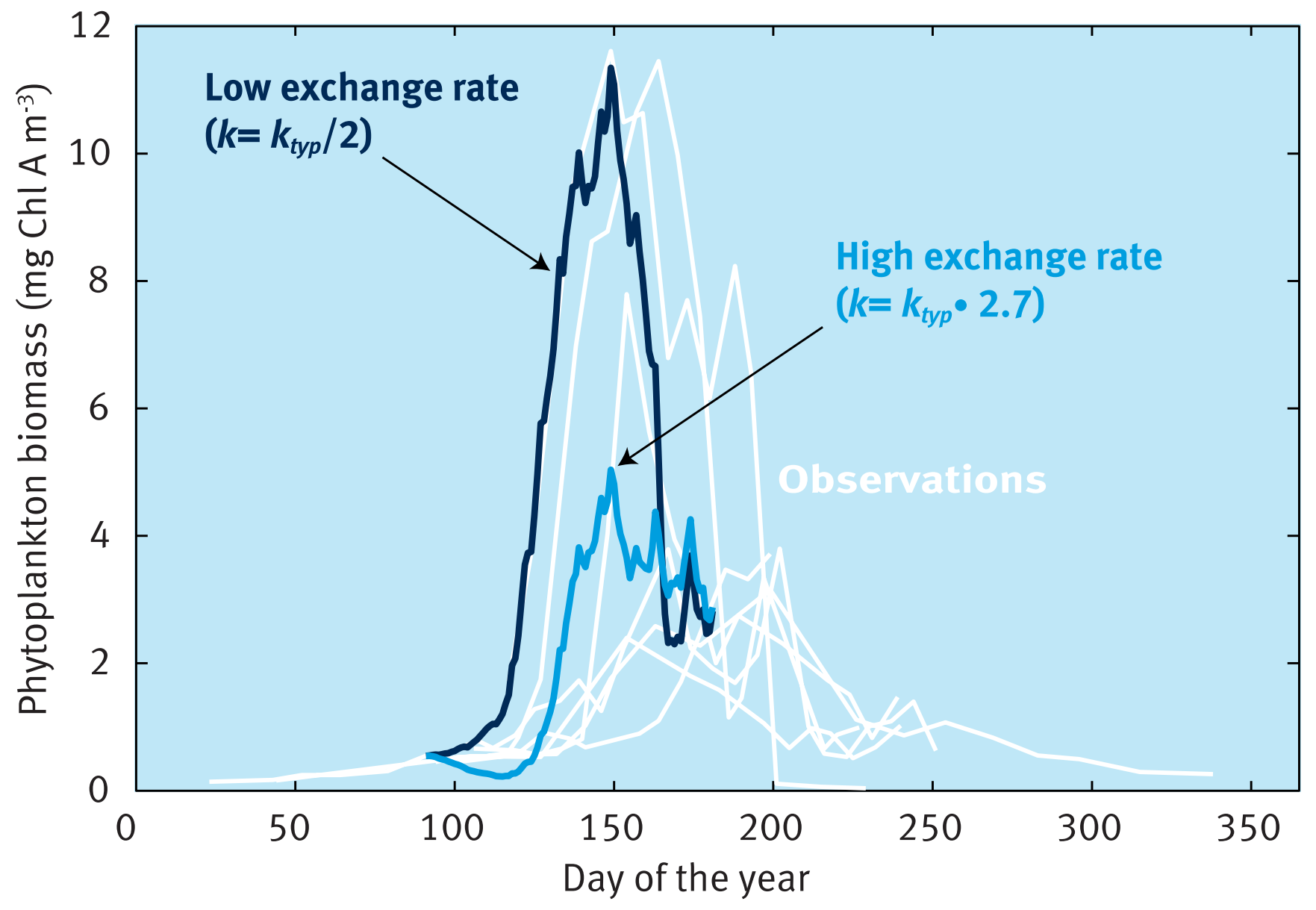


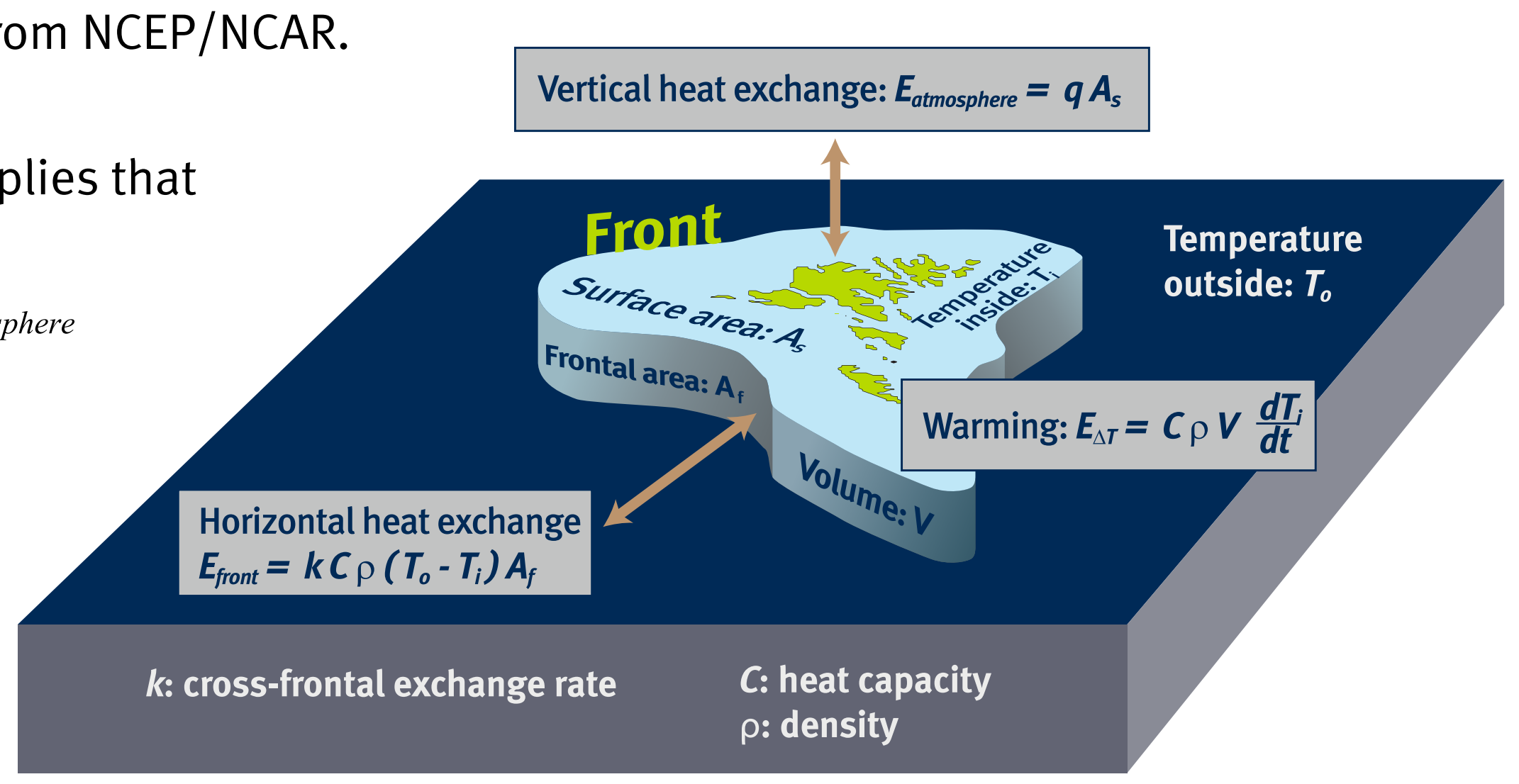
Figure 2. Seasonal development of the phytoplankton biomass inside the front based on observations from different years (white) and a model run with low and high horizontal exchange rate, as compared to the typical exchange rate k_{typ}. (Eliasen et al., 2005).

3 Deriving Horizontal Exchange Rates

We consider a 2-box model where the water inside the front is homogeneous with temperature T_i and the water outside also homogeneous, but with temperature T_o. Time series of these temperatures are available from observations. Time series of air-sea heat flux (q), are also available from NCEP/NCAR.

Energy conservation implies that

$$E_{\Delta T} = E_{front} + E_{atmosphere}$$



Vertical heat exchange: $E_{atmosphere} = q\,A_s$

Front

Surface area: A_s

Temperature inside: T_i

Temperature outside: T_o

Frontal area: A_f

Warming: $E_{\Delta T} = C\,\rho\,V\,\frac{dT_i}{dt}$

Volume: V

Horizontal heat exchange $E_{front} = k\,C\,\rho\,(T_o - T_i)\,A_f$

k: cross-frontal exchange rate

C: heat capacity
ρ: density

Figure 3. Box model of Faroe Shelf.

From this, time series of horizontal exchange rate (k) may be derived as long as ($T_o - T_i$) is not too small.

$$k = \frac{E_{\Delta T} - E_{atmoshpere}}{C\rho\left(T_o - T_i\right)A_f}$$

This is generally valid in the January – April period. Figure 4 shows an example for the year 2013.

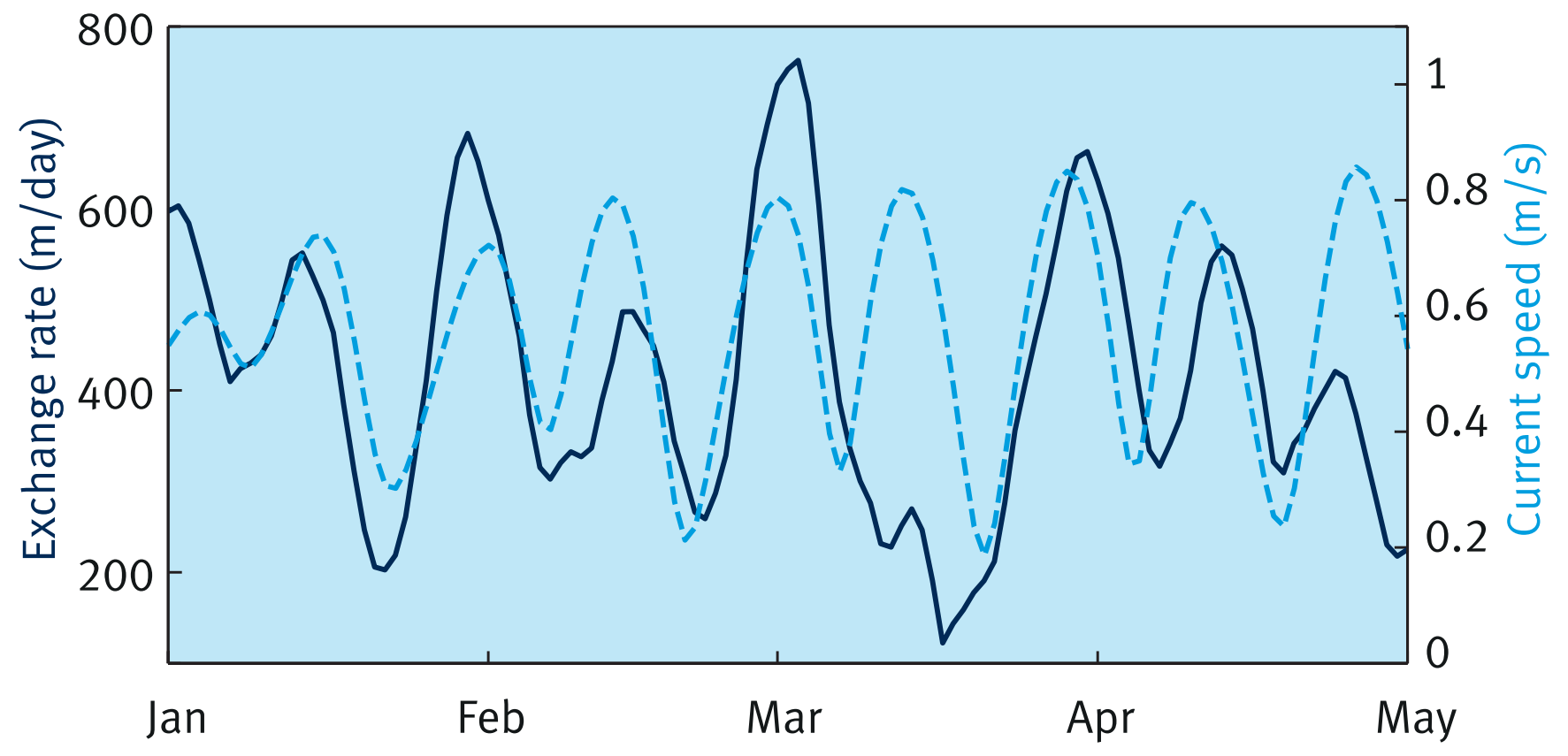


Figure 4. Exchange rate (left axis) plotted together with average current speeds (right axis) Jan 1st – May 1st 2013. The exchange rate seems to partially fluctuate in synchrony with the averaged current speeds in the same period, which indicates a relationship between current speeds and exchange rate.

4 Results

Calculated exchange rate depends on tidal currents

The computed exchange rate (Figure 4) seems to fluctuate with a period of 14 days, which indicates that the tides affect the rate of exchange. A coherence analysis where average values have been used is made.

Even though the coherence is not large (Figure 5), there is a clear signal at periods around 14 days and 29 days and with hardly any phase lag, which supports the observation that the tides have an effect on the exchange rate.

The magnitude of the exchange rate varies interannually, (see Figure 6) and the interannual variations in the exchange rate are much larger than the variations in the tidal currents.

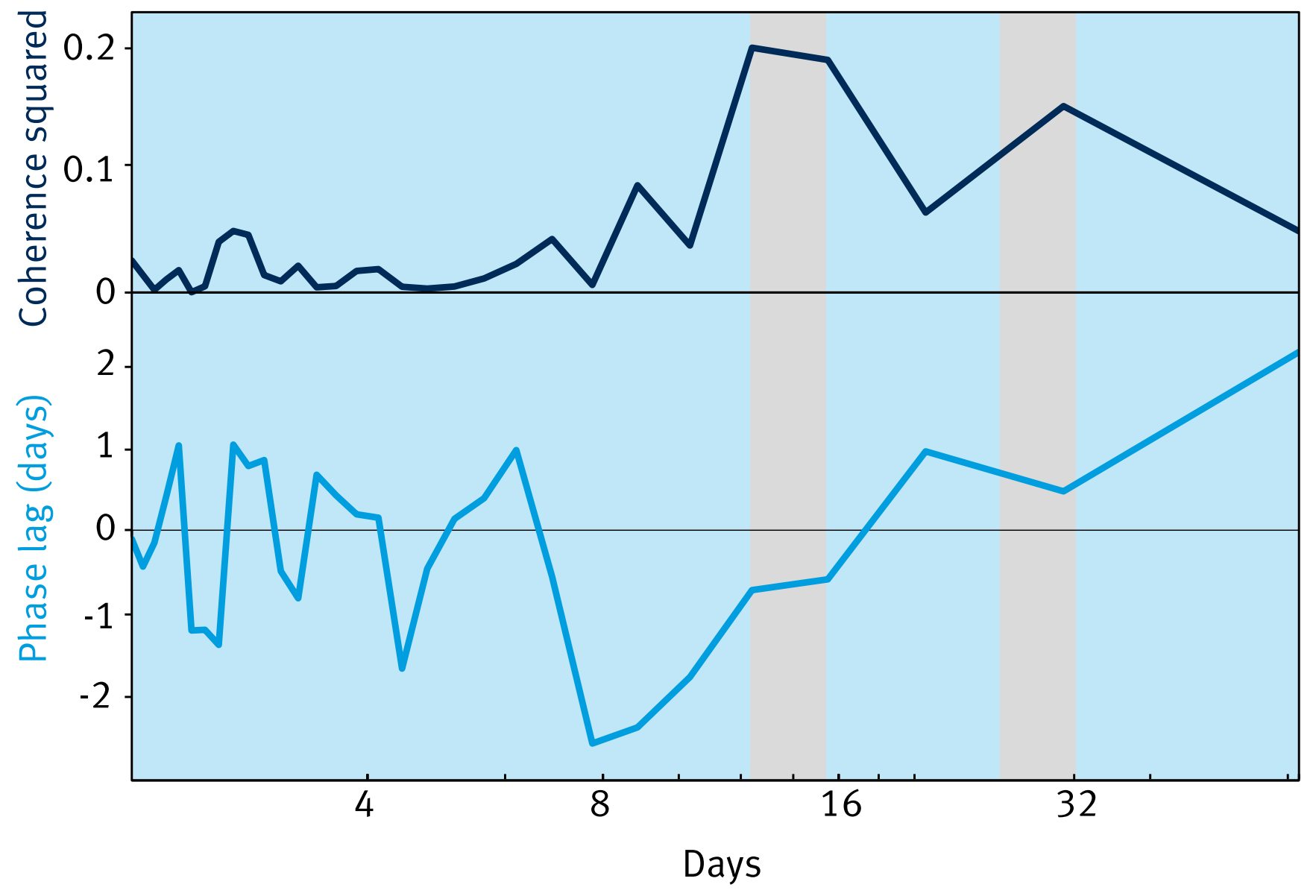


Figure 5. Coherence squared (top panel) and phase lag (bottom panel) between exchange rate and tidal current speed. Gray areas indicate the two main periodes of tidal currents, 14 and 29 days.

Calculated exchange rate is inversely related to spring bloom

Observations of temperatures date back to 1992 and these have been used to compute a timeseries of k back to 1992 (Figure 6). When comparing average values of k with the PP-index, we observe that in years with high primary production there is a low exchange rate prior to the bloom, whereas in years with low primary production there is a large exchange prior to the bloom.

This indicates an inverse relationship between primary production and horizontal exchange. The relationship is statistically significant when autocorrelation is considered (p=0.027) and has a correlation coefficient of 0.62.

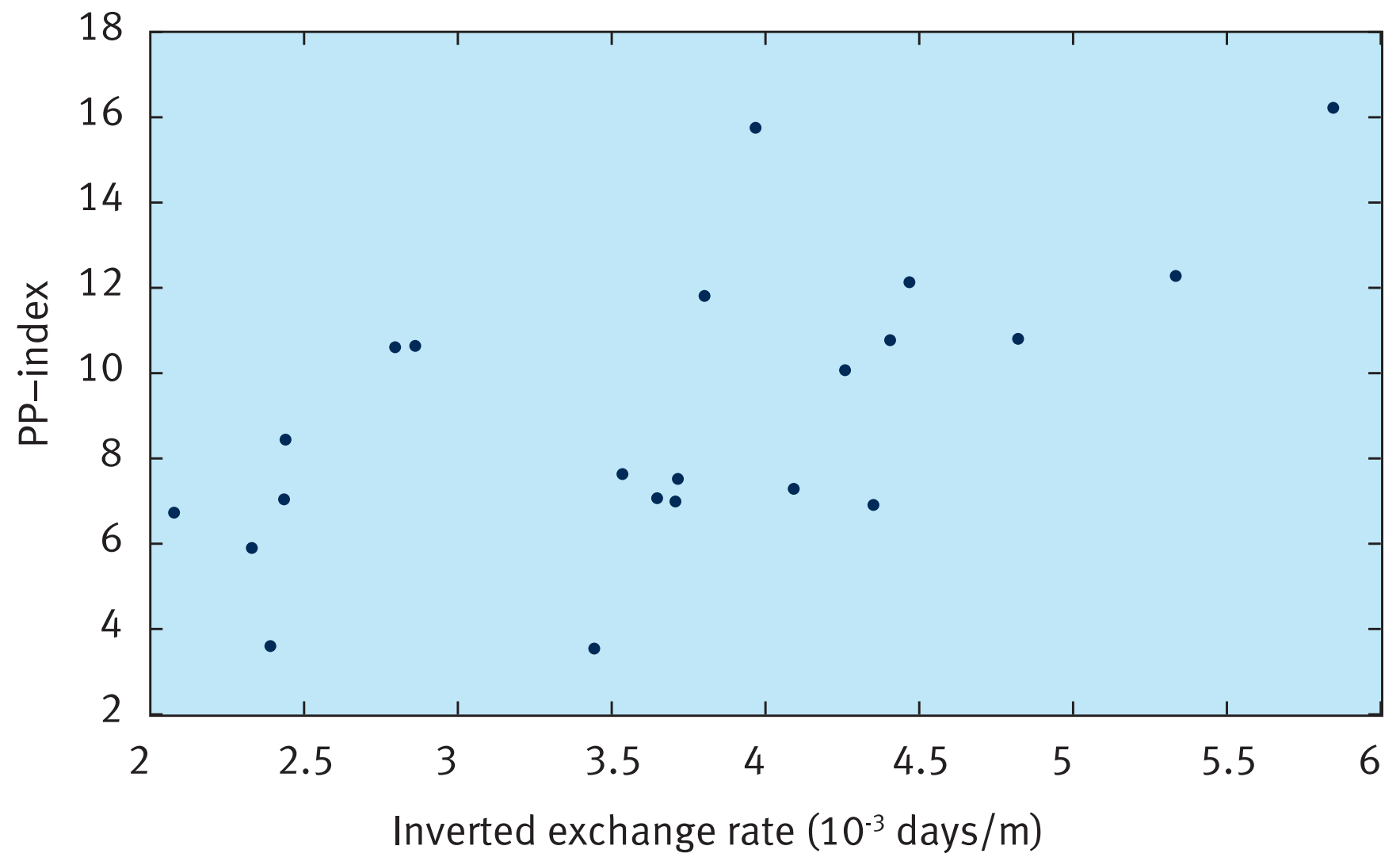


Figure 6. PP-index versus inverted average (Jan — Apr) exchange rate (k^{-1}). Based on observations from 1992 to 2013.

5 Discussion and Outlook

- A correlation coefficient of 0.62 supports the hypothesized link between exchange rate and the PP-index.
- Also, a clear relationship is observed between tidal currents and exchange rate, but some additional factor is needed to explain the large interannual differences in the exchange rate.
- One possible candidate is the density difference across the front (suggested by Hansen et al., 2005). According to this, a large density difference would enhance the tidal front and thereby reduce the exchange.
- If that is the case, an early establishment of a high density difference would be self-sustaining and might explain why we find a relationship between exchange rate in Jan-April and the spring bloom in May-June (when our method for calculating exchange rate is not applicable).
- This and other alternatives will be further explored in this PhD-project.

References: *Gaard et al. (1998) ICES Journal of Marine Science, 55, 688–696. • Debes et al. (2008) Journal of Marine Systems, 74(1-2), 686–697. • Eliasen et al. (2005) Journal of Marine Systems, 56(3-4), 352–362. • Gaard et al. (2002) Sarsia: North Atlantic Marine Science, 87(3), 37–41. • Hansen et al. (2005) ICES Journal of Marine Science, 62(7), 1224–1232. • Kalnay et al. (1996) Bulletin of the American Meteorological Society, 77, 437-470. • Larsen et al. (2008) Continental Shelf Research, 28(14), 1754–1768. • Gaard et al. (2002) In Large Marine Ecosystems, Volume 10, 2002, ed. by K. Sherman & H. R. Skjoldal. Elsevier, London. Pages 245–265.*