Description of Ph.D.-project

Title: Marine climate effects on primary production around the Faroe Islands

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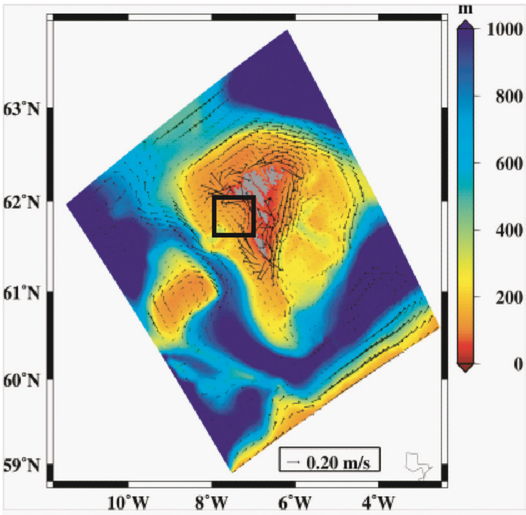
Background



The Faroe Islands are surrounded by a shelf that covers an area of 20 000 km^2 within the 200 m bottom contour. Due to strong tidal currents, the shallow parts of the shelf (less than 100m) are well mixed throughout the year, while the deeper parts (100 – 200m) exhibit a variable degree of stratification during the summer season (Larsen et al., 2008). Additionally, the tides generate a clock-wise residual circulation on the shelf (Fig. 1) that tends to isolate the shelf waters from the open ocean. This is demonstrated in a tidal front that is most pronounced in the early spring (before the onset of atmospheric heating) and which separates the colder and fresher shelf waters from the warmer and more saline North Atlantic Waters surrounding the shelf.

The hydrographical settings allow the on-shelf areas to support a relatively uniform shelf ecosystem, which in many ways is distinct from off-shelf waters. The shelf water largely maintains its own neritic ecosystem, which, both with regards to the phytoplankton (Gaard 1996, Gaard 1998, Debes et al. 2005, Debes et al. 2008) and zooplankton (Gaard 1999, Debes and Eliasen, 2006), is quite different from the oceanic surroundings (Hansen et al. 2005).

Earlier analyses have shown high inter-annual variability in biological production, with high correlation between fluctuations in the various trophic levels. The ecosystem seemed to fluctuate simultaneously at all trophic levels, from primary production to recruitment, growth and production of demersal fish (Gaard et al., 2002; Gaard et al., 2006) with the phytoplankton production seemingly as the prime driver in the ecosystem (Steingrund and Gaard, 2005). Understanding the dynamics and variability in the primary production and the relations to higher trophic levels in various circumstances is thus a prerequisite for explaining the biological production on the Faroe Shelf. This includes e.g. influences from environmental variables on the primary production (hydrography, light, nutrients, etc.) as well as the interplay between phytoplankton and its main predators (copepods).

Observations of primary production and nutrient concentrations on the shelf and the surrounding open ocean were initiated in 1990 and in 1995 regular sampling started at coastal station Skopun in the central part of the shelf. The observations soon revealed the large inter-annual variations and Gaard et al. (1998) compared these findings to several physical parameters that are known to be important to the spring bloom. But with only seven years of data, Gaard et al. (1998) were not able to find any explanation in the physical parameters. On the other hand, they found a negative correlation between nitrate loss and zooplankton biomass on the shelf and thus suggested that grazing was responsible for the variations in primary production. Later, however, Debes et al. (2008) found that grazing by the zooplankton community does not seem to explain this relationship since the grazing pressure during pre-bloom and the early bloom phase is not large enough to postpone and suppress the phytoplankton spring bloom.

In the early 2000s, a simple primary production model for the shelf was developed (Eliasen et al., 2005). To compensate for nutrient loss it allowed exchange with the open ocean and through that also import of zooplankton (Calanus). The exchange rate was based on a heat and a salinity budget for the shelf (Larsen et al., 2008) and, by varying the exchange rate in the model, it was found that a large exchange rate imported a large zooplankton biomass, but at the same time exported a large part of the phytoplankton. In contrast, a low exchange rate keeps the zooplankton off the shelf and the primary production on the shelf, such that a large spring bloom can develop. This mechanism, called “Horizontal Sverdrup mechanism”, was tested for shelves and banks with a cylindrical symmetry of variable size (Eliasen et al., 2005). Intuitively, the exchange rate is linked to the properties of the tidal front and Hansen et al. (2005) found a positive correlation between the primary production and the cross-frontal density difference in spring for the period 1990 – 2003. The density difference is expected to be related to winter/spring atmospheric cooling that efficiently cools the shallow shelf water (Hansen et al., 2005).

As mentioned above, the primary production correlates well with for instance the cod growth on the shelf and if the exchange rate is the whole story, then we should find a correlation between winter/spring atmospheric forcing and the cod growth that goes back to the 1960s, but that is not the case (Hansen et al., 2005). Additionally, the primary production in recent years has not fitted as well to the exchange rate hypothesis as during the 1990s and has also varied considerable within the season with double (2008) and even triple (2009) peaks during spring/summer. It has also been noted that the phytoplankton biomass (chlorophyll concentration) is highest in an area on the western part of the shelf (Fig. 1). This area is characterized by low tidal currents, high exposure to frequent south-westerly winds and a shallower location of the tidal front compared to neighbouring regions (Larsen et al., 2009). In recent years, the Faroe Marine Research Institute (FAMRI) has focused its shelf observations to that area through current meter deployments, a dedicated cruise in spring 2010, high resolution CTD sections and more. Several of these observations seem promising and indicate for instance that the western area responds quickly to changes in the atmospheric forcing.

Summarizing, there are clear indications that physical effects associated with marine climate may be the main controlling factor for the primary production on the Faroe shelf, but none of the mechanisms suggested for this control have been proven. Since the seminal Gaard et al. (1998) paper, the observational data set has been substantially extended. In addition, a high-resolution 3-D model has been developed for the Faroe Shelf (Rasmussen et al., in prep), which allows much more detailed investigations of the variations and interplays between physical parameters during a 10-year period (2000 – 2009), in which there have been large variations in the primary production.

It therefore seems timely to re-analyse the physical forcing parameters for the primary production using both the accumulated observational evidence and the output from the high-resolution model with the aim to pinpoint the main controlling mechanisms. That is the focus of this project.

Main objectives: Based on a broad suite of observations that includes *in situ* time series approaching 20 years or more, large-scale data sets and output from a high resolution model, this project will try to explain the large variation in primary production in the waters surrounding the Faroe Islands. This includes:

- To explore the hydrographical settings and especially the dynamics of the mixed layer (ML) around and on the Faroe shelf. Study the depth and timing of the ML and the relative role of tidal mixing, air-sea heat exchanges and horizontal advection.
- To explore the effect of the physical dynamics on the primary production in well mixed and stratified areas.

Data sets

FAMRI data (selected Faroese datasets suitable for this project)

- a hydrographic database with CTD data (including temperature, salinity, PAR, fluorescence and dissolved oxygen) and water sample data (chlorophyll and nutrients) from R/V Magnus Heinasons's surveys on the shelf (e.g. recurring biological, o-group and hydrographic cruises).
- Current meter moorings (using traditional current meters and recently also profiling Acoustic Doppler Current Meters) from more than 10 sites around the shelf.
- Underway SST data from R/V Magnus Heinason and other ships.
- Comprehensive SST and bottom temperature data from annual trawl surveys during spring and fall.
- Temperature, salinity, chlorophyll and nutrient data from coastal station Skopun and temperature from other coastal stations.
- Surface and bottom temperatures at a wave buoy mooring within the western region.
- Hydrographic and biological data from a planned weekly section between Gomlurætt-wave buoy (within the western region)-Skopun, starting in spring, 2013.

Large-scale (Two large-scale data sets that are freely available)

- Atmospheric reanalysis fields (e.g. from NCEP/NCAR): Primarily air-sea heat and momentum exchanges.
- Ocean colour data from satellites: Primarily Chlorophyll concentrations, sea surface temperature (SST) and Photosynthetically active radiation (PAR). Both from standard and widely available medium resolution (9-km and 4-km spatial resolution) products (http://oceancolor.gsfc.nasa.gov/), and very high-resolution (1-km and even 300-m) from Natural Environment Research Council (NERC) Earth Observation Data Acquisition and Analysis Service (NEODAAS)

Other

- The extensive NISE hydrographic database.
- Seaglider data in the Faroe-Iceland waters, including hydrography, fluorescence, oxygen, currents and turbulence.

The model

The model is a high-resolution (~ 1 km) three-dimensional numerical model of the region surrounding the Faroe Islands, which was run at the Danish Meteorological Institute (DMI) from the beginning of 2000 to the end of 2009 with ERA-Interim atmospheric forcing (Fig. 1). From this model run, the physical parameters are stored for every hour and will be available for analysis.

This data set contains very much information, which may be analysed in different ways. In the initial analysis (Rasmussen et al., in prep.), it was demonstrated that the area between the 100 and 150 m depth contours became stratified considerably earlier in 2000 and 2001 compared to most other years. These are the two years that seem to have had an exceptionally intensive spring bloom according to observations, which indicates that the model may well capture features that are essential for the primary production, but are there some special areas critical to bloom development and what physical conditions are important?

Quantitative exchange rates are difficult to estimate from the model and the model does not directly support the hypothesis that variations in on-shelf/off-shelf exchange control the spring bloom (Eliasen et al., 2005; Hansen et al., 2005), but the model indicates that on-shelf/off-shelf exchange may have been especially weak in these two high-production years. Since the exchange rate is highly dependent on the tides, this could indicate that weak tidal currents in the critical period (April – June) could be an essential factor, especially since that would favour early stratification.

Work plan

Within this project the aim is to achieve the following tasks:

Task 1: Based on the extended data set that is now available, an analysis (similar to Gaard et al., 1998) of the inter-annual variability of different physical parameters (e.g. tidal strength, air-sea heat flux, wind speed, stratification, PAR) will be performed and compared to the observed spring bloom development.

Task 2: Analyze the physical model (in collaboration with DMI) to investigate a) the outcome of Task 1 and b) areas and physical parameters that favour early stratification.

Task 3: Implement a one-dimensional (depth) biological/physical primary production model with the aim to extend previous more idealized studies (Eliasen et al., 2005) in a more realistic setting.

Task 4: Integrate the biological model into the 3 dimensional model (in collaboration with DMI). Depending on the results from the previous tasks to:

- Validate the biological model output against the available spatio-temporal data
- Explore where the most intensive primary production might take place - near the tidal front or closer to the Islands.
- Explore the impact of shelf-slope water exchanges on the primary production.
- Explore the open-ocean primary production variability, and ensuing nutrient limitation, in relation to the ML variability with focus on the western region.
- Explore a potential relationship between the primary production in well mixed waters on the inner shelf and in potentially stratified outer areas, again with focus on the western region.
- Explore previously established linkages between the primary production and the air-sea heat exchange. Does this forcing act vertically and independently on the inner and out regions, or are lateral processes important?

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