The Fram Strait Acoustic System for tomography and navigation of gliders

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Fram Strait Ocean Data and Model system.

The Fram Strait is the main passage through which the ocean mass and heat exchange between the Atlantic and Arctic Ocean takes place (Fig. 1). On the eastern side of the strait the northbound West Spitzbergen Current (WSC) transports Atlantic water to the Arctic Ocean, whereas on the western side the southbound East Greenland Current (EGC) transports sea ice and polar water from the Arctic Ocean, to the Nordic Seas and the Atlantic Ocean. The Fram Stait is therefore a key area for ocean and climate monitoring in the Arctic. The topographic structure of the strait causes a splitting of the WSC into at least three branches, of which one recirculates between 78 N - 80 N.

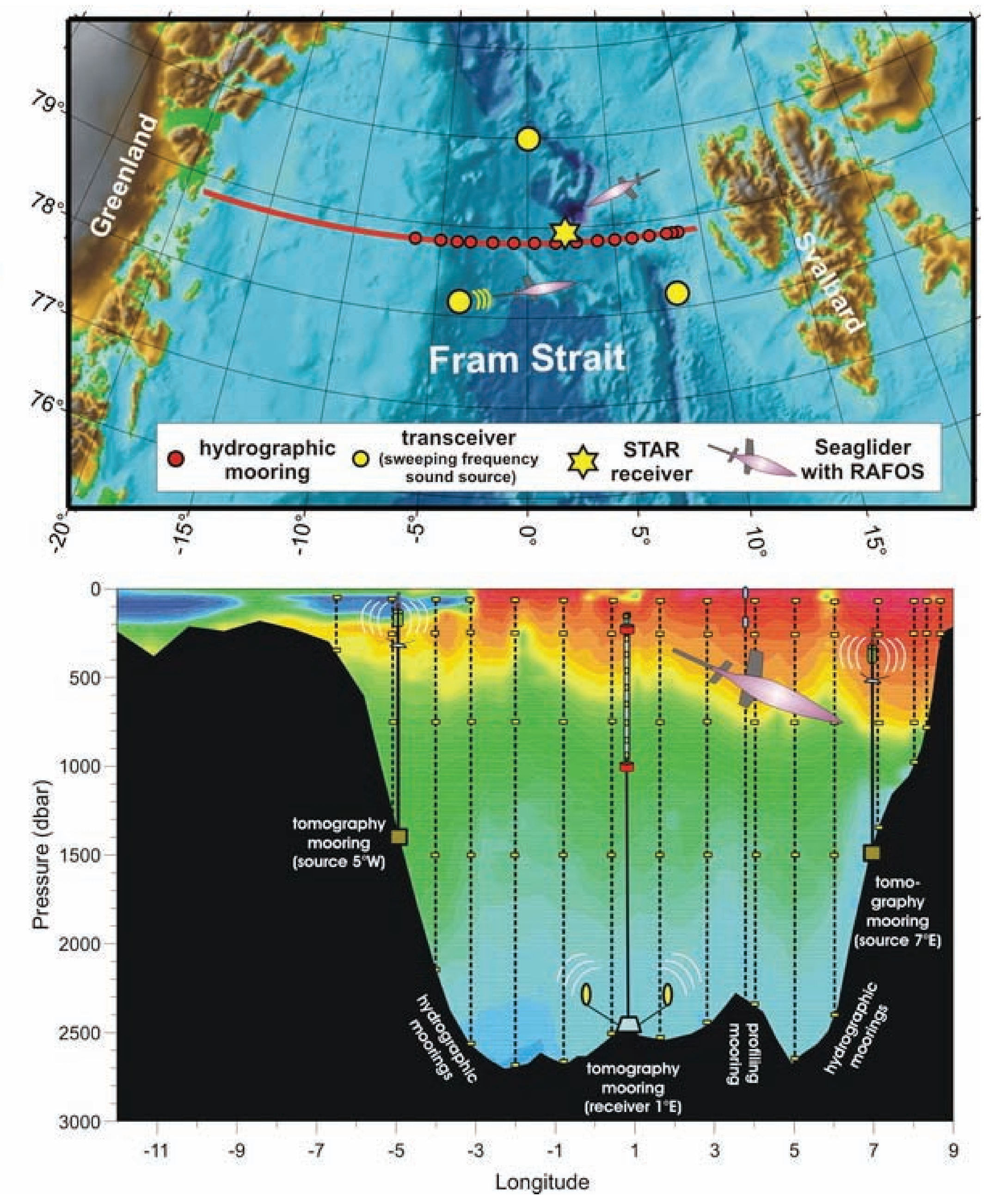

Figure 1. The Fram Strait Ocean Observatory under implementation in DAMOCLES and ACOBAR consists of oceanographic moorings, tomography moorings and gliders.

A section of oceanographic moorings across the Fram Strait was establish in 1997 to monitor the ocean volume and heat fluxes through the strait (Fig. 1). The system consists of 17 moorings with 40 instruments. Estimates of the transports over 9 years (1997-2006) indicate a mean northward transport of 12 Sv (1 Sv = 106 m3/s), mostly in the West Spitsbergen Current and a southward transport of 14 Sv, mostly in the East Greenland Current; these transports (and their variability) have significant uncertainty e.g. 40 % in the WSC and above 100 % for the EGC. The spatial resolution of the moorings, which varies from 10 to 30 km, is not sufficient to resolve the mesoscale variability and estimate the volume and heat transport by the recirculation current.

An observing system for the Fram Strait requires both high temporal and spatial resolution of the measurements. In ACOBAR this is resolved by combining observations from two complementary systems: acoustic tomography and gliders with ocean circulation models. The tomography system provides integral travel time measurements between the source and receiver every 3-4 hour. Acoustic traveltime is indirect measurement of ocean temperature and current, which can be retrieved through data oriented inversions or through data assimilation. Gliders provide CTD profiles with high spatial resolution, but low temporal resolution. In the Fram Strait sound pulses travel 200 km in 138 s, while a glider spends 8 - 14 days to cover the same distance with CTD data. Data from both systems will be assimilated into the NERSC model system.

Assimilation of acoustics and glider data.

Because of the integral nature of the data, tomography is best employed in conjunction with numerical ocean models and data assimilation (Munk et. al. 1995). In DAMOCLES the EnKF assimilation scheme is refined to incorporate one way acoustic travel times. A raytrace model is used to establish the modelled measurement matrix (http://acobar.nersc.no). In DAMOCLES assimilation of acoustic data from one acoustic track will be done into NERSC ice ocean model system in hindcast mode (http://topaz.nersc.no).

In ACOBAR acoustic data from six acoustic tracks will be aassimilated using the same approach. A few attempts have been made to assimilate glider data into high resolution ocean models, but no such studies have been made for gliders in the Arctic.

Acoustic tomography in the Fram Strait.

Acoustic tomography systems in Arctic regions have been developed and successfully tested in ice covered regions such as in the Greenland Sea Experiment in 1988-1989 (Worcester et al. 1993), in the 6 year long Labrador Sea tomography experiment (Avics et al., 2005), in the Trans-Arctic Acoustic Propagation Experiment (TAP) (Mikhalevsky et.al. 1999), and in the 14-month long ACOUS (Gavriliov and Mikhalevsky, 2006).

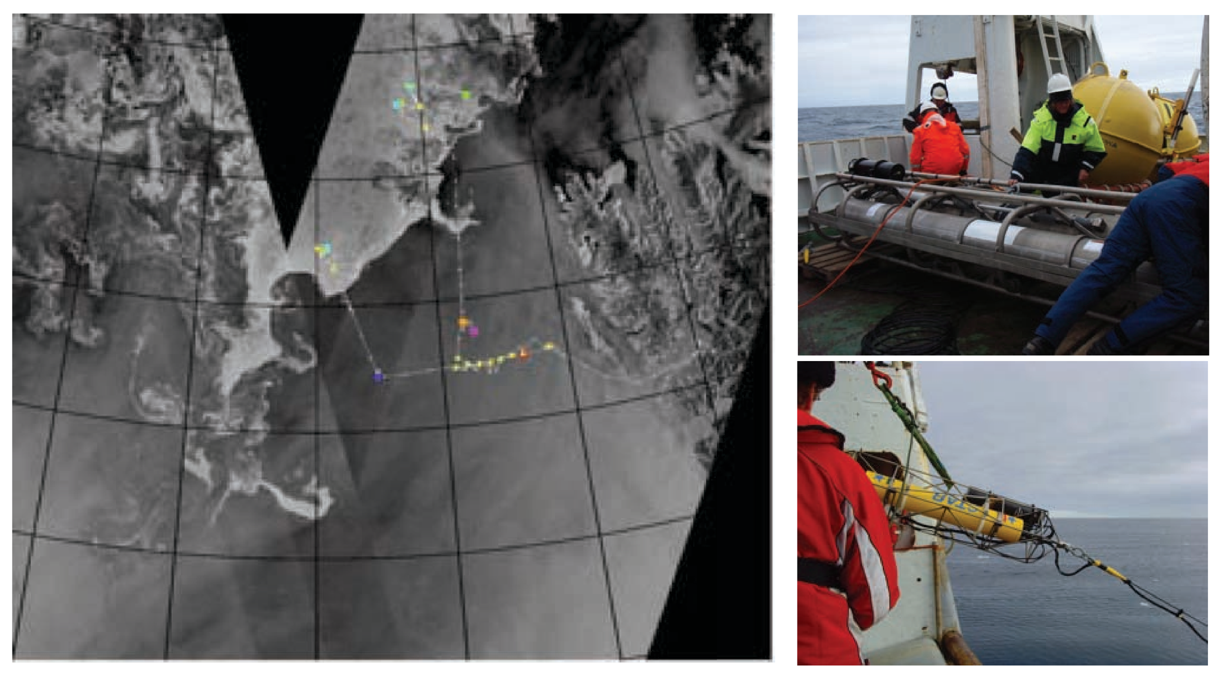

Figure 2. The first step to develop and implement tomography observing system in the Fram Strait started under the DAMOCLES project . A source mooring (red) and a receiver mooring (blue) were deployed for one year in August 2008 from RV Håkon Mosby. The two moorings are separated by 130 km and aligned along 78 30 N. Source depth is 388 m and 8 hydrophones are between 300-989 m.Yellow dots markes positions where the acoustic signal was listened using a very short receiver array in September 2008 from KV Svalbard.

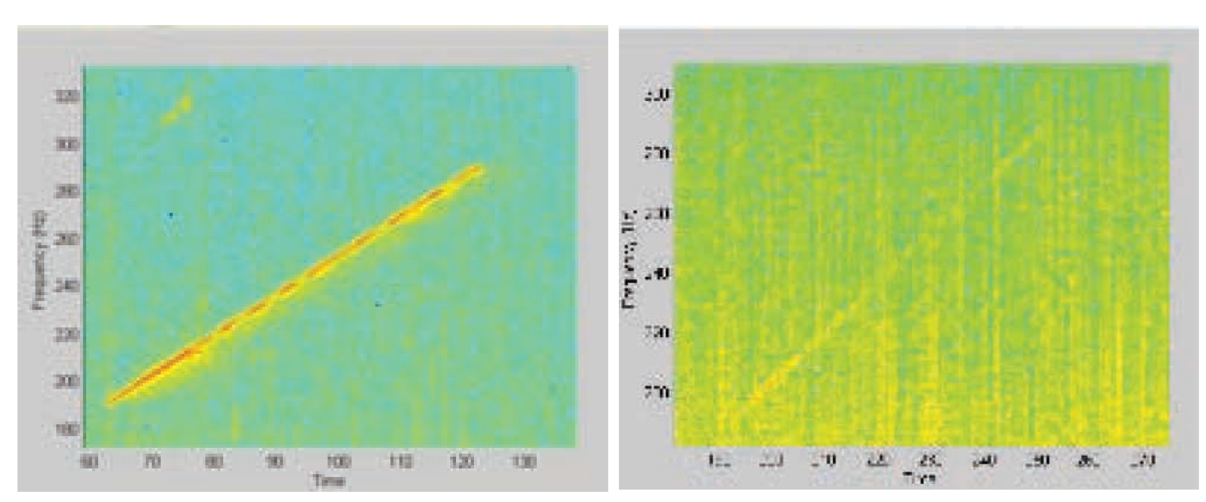

Figure 3. Source signal recorded at source position (left) and 60 km away from the source (right).

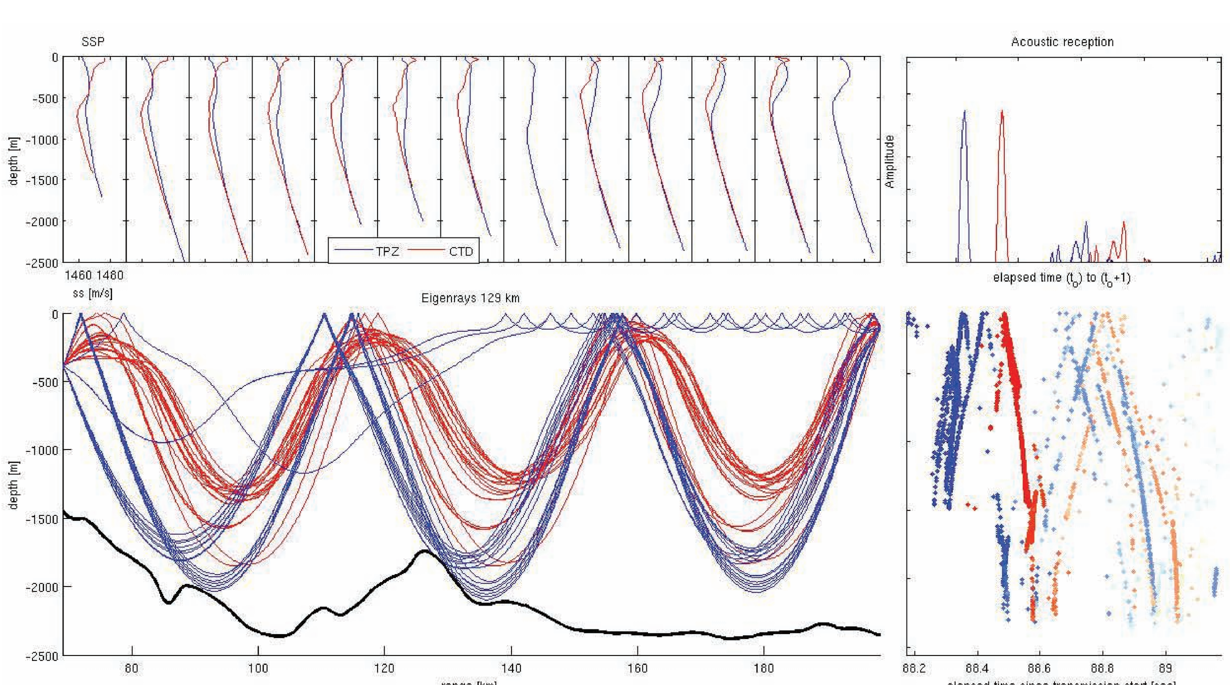

Figure 4. Upper panel compares CTD data (red) with TOPAZ profiles (blue). Travel times and eigenrays are calculated using CTD data and TOPAZ fields as input. The less bright coloured dots correspond to reflected arrivals. TOPAZ predicted rays (blue) arrive faster than travel times calculated using CTD observations (red) . This reflects that TOPAZ is too warm in the intermediate water masses. In the upper right, the measured acoustic arrival time pattern is compared to predicted arrival times below (red: CTD, blue: TOPAZ). Best correspondance with acoustic observations is found with the CTD predicted field. This indicates how we can use acoustics to validate models.

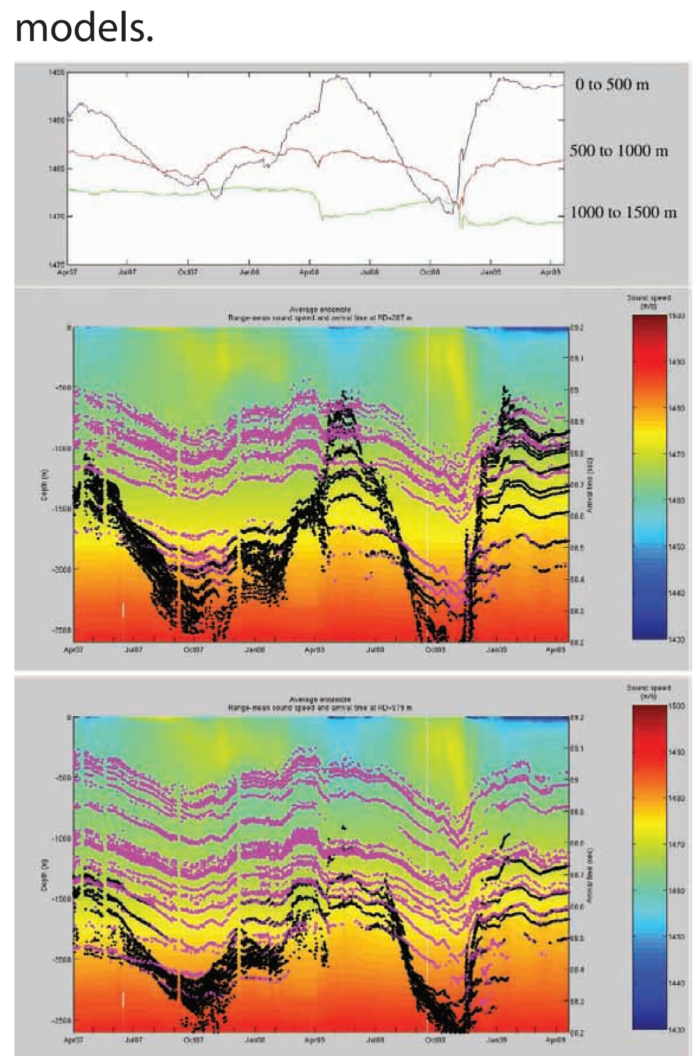

Figure 5. Prediction of acoustic arrival times using input from TOPAZ to RAY model over a period from April 2007 to April 2009. Horizontally averaged temperature profiles between the two moorings are plotted as Hovmöller diagram. Black dots are arrivals of waterborne rays, pink arrivals have been bottom reflected one or more times.
The arrivals of the waterborn rays is strongly related to variability in upper 500 m of the ocean.

Glider technology

While floats drift passively with the current, gliders can be remotely steered by an operator via satellite communication when they are at the surface. In ice-covered areas gliders and floats cannot rise to the surface to use satellite based navigation (GPS) and data telemetry via IRIDIUM and ARGOS. In order to operate underwater platforms in ice-covered regions, it is necessary to develop acoustic navigation and telemetry systems. The need for a mid frequency acoustic navigation system for gliders and floats in selected Arctic regions coincide to a large extent with the requirements for the acoustic tomography/thermometry system. The first under-ice operation of a glider using 780 Hz narrow banded RAFOS sources was done by Craig Lee (Applied Physics Laboratory, Seattle, USA) in the Davis Strait in 2008.

Gliders in the Fram Strait.

A similar approach will be used in the Fram Strait using acoustic signals provided by the triangular net of acoustic tomography/RAFOS sources under the ACOBAR project.

Figure 6. The first operational mission took place in Fram Strait in July-Semptember 2008. The upper photos show the launch of the glider from RV Polarstern and the lower photos show the recovery of the glider from the KV Svalbard. The lower panel show a map of glider's surfacing points during the summer mission in 2008, overlaid on a bottom topography in Fram Strait. The Seaglider SG127, manufactured by SFG (Seaglider Fabrication Center) Seattle, was operated from the base station at OPTIMARE in Bremerhaven. SFG in Seattle served as the second, backup base station. The Seaglider carried standard CTD and RAFOS receiver for underwater acoustic navigation. One RAFOS sound source was deployed in the central Fram Strait for testing the range of RAFOS transmissions received by the glider.

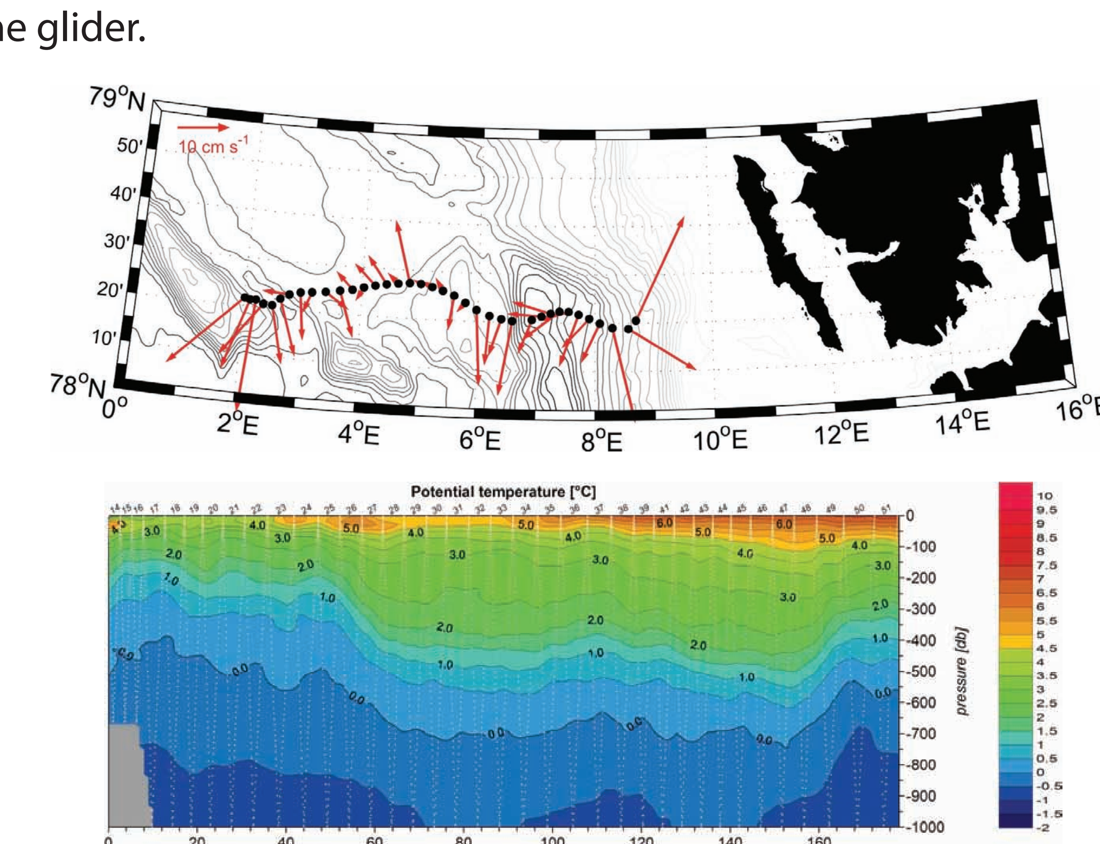

Figure 7. Upper panel show surfacing positions and depth averaged currents at the Section 1 (July 20-27) defining section 1. Lower panel show the temperature measured along Section 1 (July 20-27) across the central and eastern part of Fram Strait.

Forthcoming work

Narrow banded RAFOS systems have been used for several decades with travel time residuals of up to 2-3 s which causes inaccuracies up to 5 km in localization. Duda at al. 2006 show that the accuracy of kilometres accuracy for basin-wide RAFOS based navigation is reduced to less than 50 meters of accuracy by using broadband acoustic tomography signals for navigation.

In 2010, under the ACOBAR project, the Fram Strait acoustic system will consist of 3 acoustic transceiver moorings in a triangle configuration with a receiver mooring in the middle , see Fig. 1. Each of the sources will produce broad-band acoustic signals for 3 D tomography and standard narrowband 260 Hz RAFOS signals for navigation of autonomous underwater vehiles every 3-4 hour. First glider trial under ice in Fram Strait is planned for 2010 under the ACOBAR project.

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