Secondary Sound Channels in the Fram Strait: Structure, Variability, and Environmental Controls

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Fram Strait Circulation and Water Mass Structure

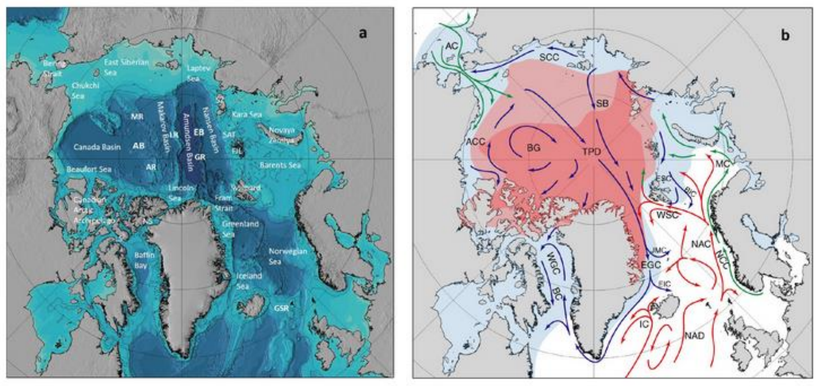


Fig. 1. (a) Arctic and subarctic seas (b) Schematic of Arctic circulation. Fram Strait has northward Atlantic Water transport in the West Spitsbergen Current and southward Polar Water export in the East Greenland Current. (Finnish Meteorological Institute et al. 2022)

Identification and Spatial Distribution of Secondary Sound Channels

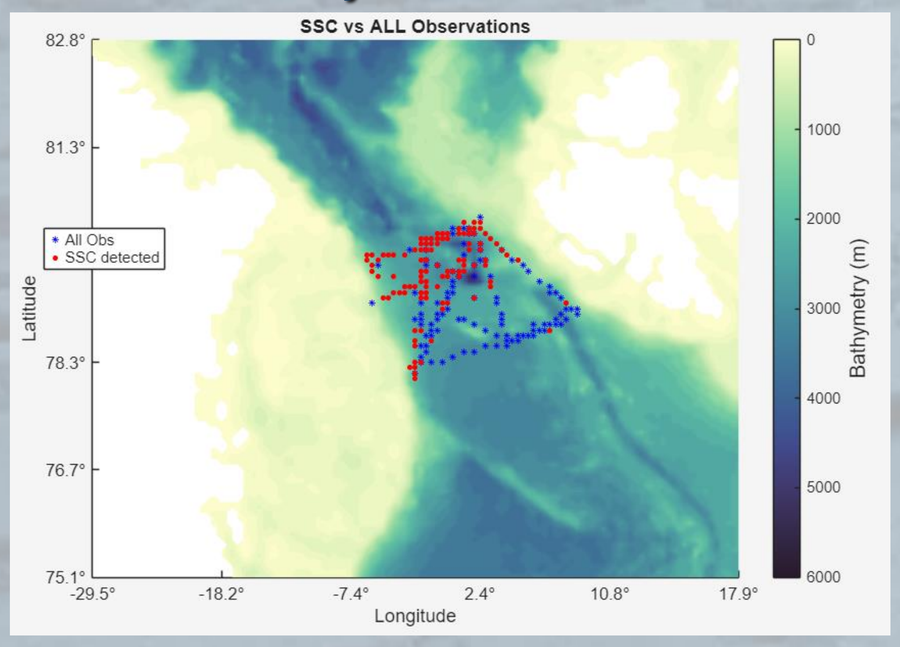


Fig. 2. Bathymetry (m) in the Fram Strait region displaying locations of sound speed data points from 2010, 2011, 2014, and 2016. In situ XBT and XCTD observations were obtained from the ACOBAR and UNDER-ICE campaigns (Sagen and Beszczynska-Moeller 2014, 2015a, 2015b, 2020).Blue markers indicate locations without an SSC and red markers indicate where SSCs were identified.

Identified SSC Structure From Profiles

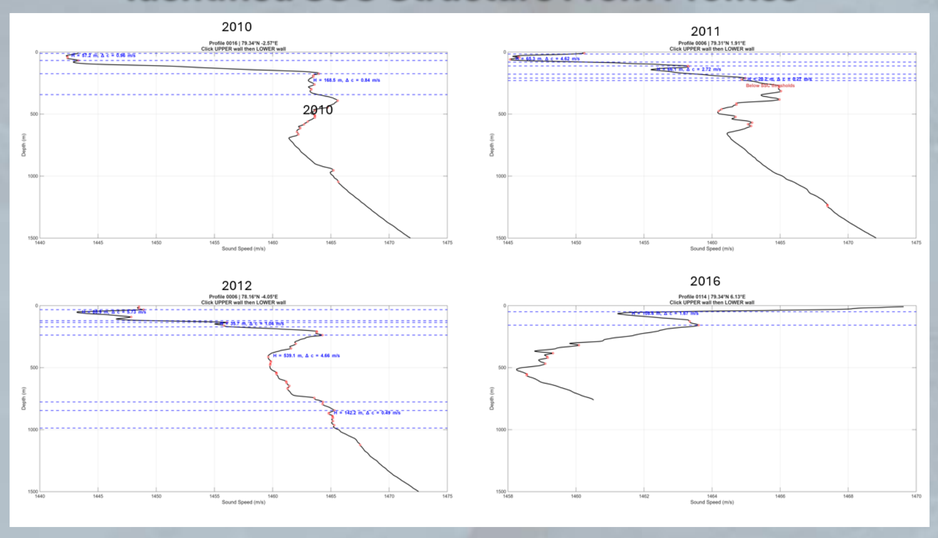


Fig. 3. Example sound speed profiles from 2010, 2011, 2012, and 2016 showing identified secondary sound channels (SSCs). Criteria for identification of an SSC was derived from the Navy Fleet Oceanographic and Acoustic Reference Manual (Naval Oceanographic Office, 2024). SSCs are defined by a local sound speed minima with minimum thickness ≥ 100 ft and strength ≥ 1 ft s^{-1}. Channels meeting these thresholds were classified as candidate sound channels and subsequently filtered to exclude deep sound channels.

Temperature-Salinity Characteristics

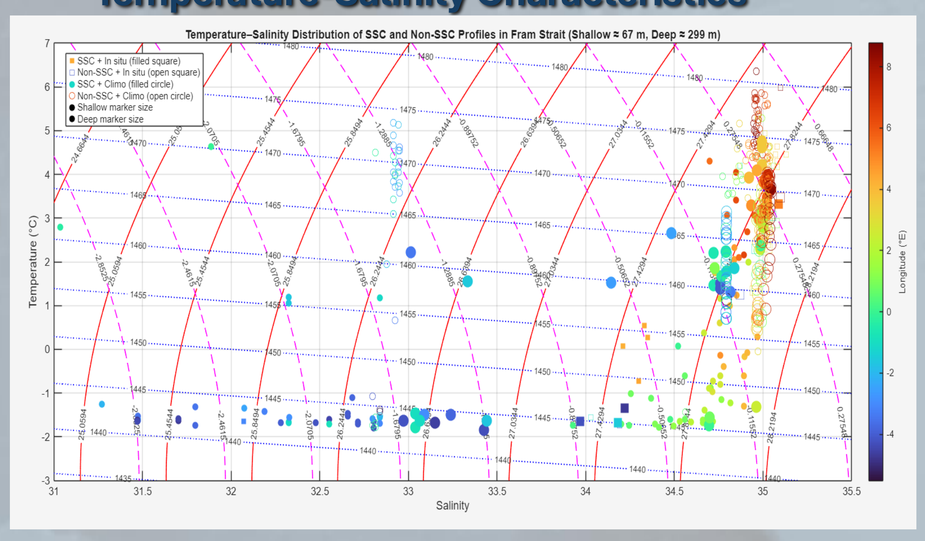


Fig. 4. Temperature–salinity diagram with spice and sound speed of profiles.

SSCs occur in Polar Water, Atlantic Water, and mixed water masses in the Fram Strait. Western SSCs are associated with cold, fresh Polar Water (−2 to −1°C, 31–34 psu) and negative spiciness, while eastern SSCs occur in warm, saline Atlantic Water (2 to 5°C, ~35 psu) with neutral to positive spiciness. Central detections reflect mixing between these water masses. Across all regions, SSCs are linked to strong salinity variability, indicating temperature sets the background sound speed structure while salinity modulates SSC formation and persistence.

Abstract

Secondary sound channels (SSCs) are subsurface acoustic ducts formed by localized sound speed minima that can significantly influence underwater acoustic propagation. While SSCs have been observed in various ocean environments, their occurrence, structure, and environmental drivers in high-latitude regions remain poorly understood. The Fram Strait, a key gateway between the Arctic Ocean and the North Atlantic, provides a dynamically complex environment where strong thermohaline gradients and mesoscale processes create favorable conditions for SSC formation.

This study investigates the spatial distribution, vertical structure, and environmental controls of SSCs in the Fram Strait using a combination of in situ observations (2010–2012, 2014, 2016) and high-resolution output from the Regional Arctic System Model (RASM). Sound speed profiles were analyzed using Navy defined detection criteria to identify SSC occurrences and characterize their properties. Additional analyses, including temperature–salinity relationships, spiciness, density structure, eddy kinetic energy (EKE), and sea surface height (SSH), were used to evaluate the thermohaline and dynamical environments associated with SSC formation.

Results show that SSCs are a recurrent and widespread feature of the Fram Strait, occurring across multiple water masses rather than being confined to a single regime. A bimodal vertical distribution of SSC axis depths is identified, with shallow channels occurring most often near 67 m and deeper channels centered around 299 m, corresponding to distinct stratification regimes within the water column. Spatially, SSCs are most frequently observed along the eastern and western margins of the strait and are notably absent in regions of strong variability, such as the Molloy Deep circulation area.

Temperature is found to control the background sound speed structure, while salinity variability plays a critical role in modulating SSC strength and persistence. Temperature–salinity analysis further demonstrates that SSCs occur within both cold, fresh Polar Water of the East Greenland Current and warm, saline Atlantic Water of the West Spitsbergen Current, as well as within intermediate mixing regions. These findings support the hypothesis that SSC formation is governed primarily by persistent thermohaline stratification rather than localized or transient processes.

This study demonstrates that SSCs are a robust and recurring acoustic feature of the Fram Strait that can be resolved in high-resolution ocean models, particularly within the upper water column. Improved understanding of SSC formation and variability enhances environmental characterization of Arctic acoustic conditions and supports more accurate prediction of sound propagation in a region of increasing strategic and operational importance.

Conclusions

- ❖SSCs are a recurrent and widespread feature of the Fram Strait.
- ❖SSCs occur in both Atlantic and Polar water masses.
- ❖Exhibit a robust bimodal vertical structure (~67 m and ~299 m).
- ❖Salinity variability modulates SSC strength, while temperature controls background sound speed.
- ❖SSCs represent a key acoustic feature of the Fram Strait and must be considered for accurate prediction of sound propagation in Arctic environments.

Distribution of SSC Axis Depths

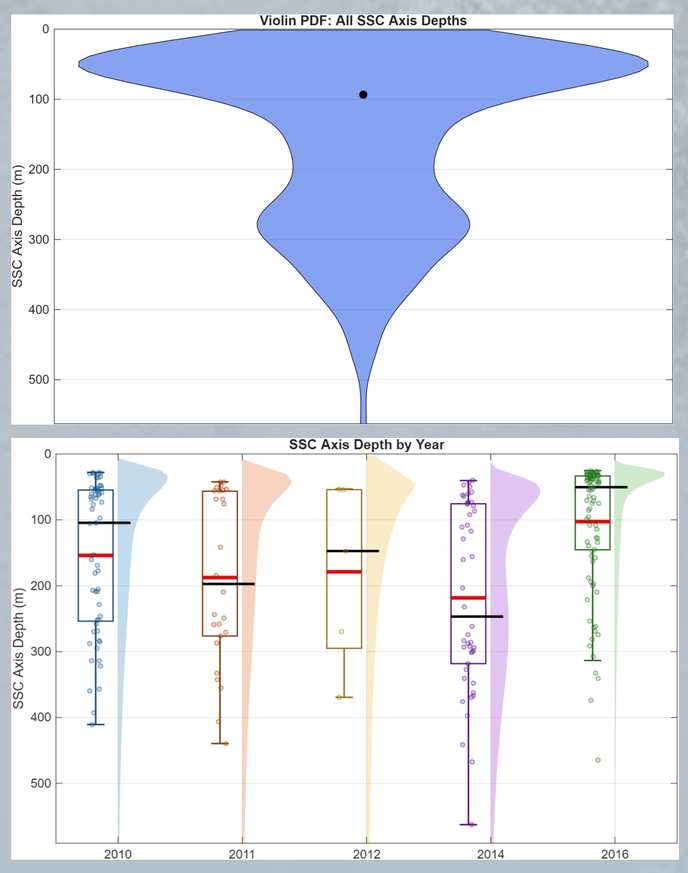
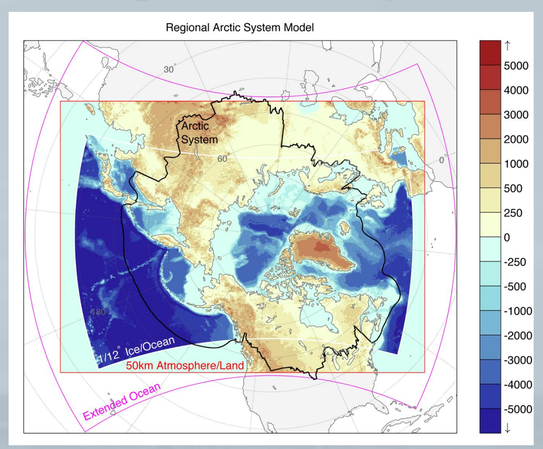


Fig. 5. Distribution of SSC axis depths for all data (upper panel) and by year (lower panel).

SSC axis depth shows a bimodal structure. Shallow channels occur near ~67 m, while deeper channels occur near ~299 m, representing two distinct stratification regimes. Note, there is a significant variation in sample size causing individual years to appear skewed.

Regional Arctic System Model (RASM)



Component	Code	Configuration
Atmosphere	WRF3	50km, 40 levels
Land	VIC	50km, 3 soil layers
Ocean	POP2	1/12° (~9km), 45 levels
Sea Ice	CICE6	1/12° (~9km), 5 thickness categories
Coupler	CPL7x	Flux exchange every 20 min

← We utilize results from the Regional Arctic System Model (RASM) to examine the effects of increasing the flow through Bering Strait. RASM is a high-resolution atmosphere-ice-ocean-land regional model with a domain encompassing the entire marine cryosphere of the Northern Hemisphere, including the major inflow and outflow pathways, with extensions into the North Pacific and Atlantic oceans. RASM has been developed over the past 15 years, and each component, as well as the fully coupled system, has been evaluated substantially.

←Details on the components of RASM including the code and configuration for each component. While this table shows the RASM setup for this study, multiple configurations are available.

Observations of SSCs with modeled SSH Anomalies

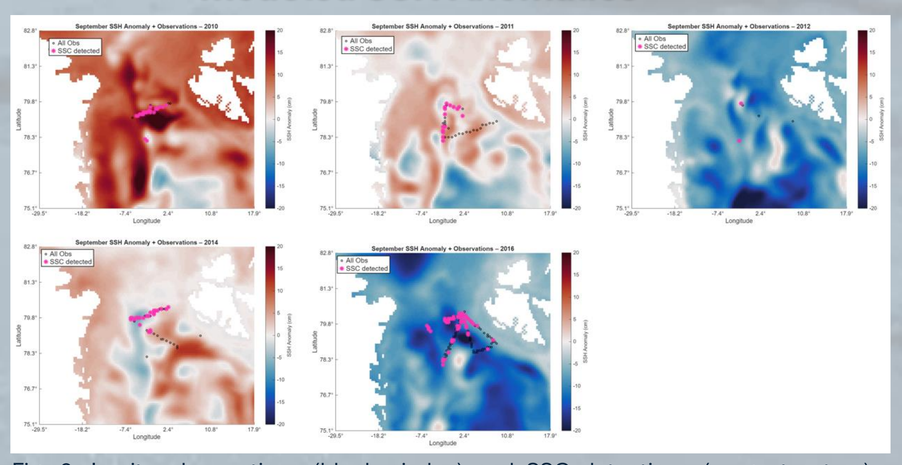


Fig. 6. In-situ observations (black circles) and SSC detections (magenta stars) overlaid on modeled sea surface height (SSH) anomalies across all years.

SSCs occur primarily in regions of moderate SSH variability and are largely absent in strongly positive or negative SSH regions associated with enhanced mesoscale activity, indicating a preference for more stable environments.

SSC Detection in RASM

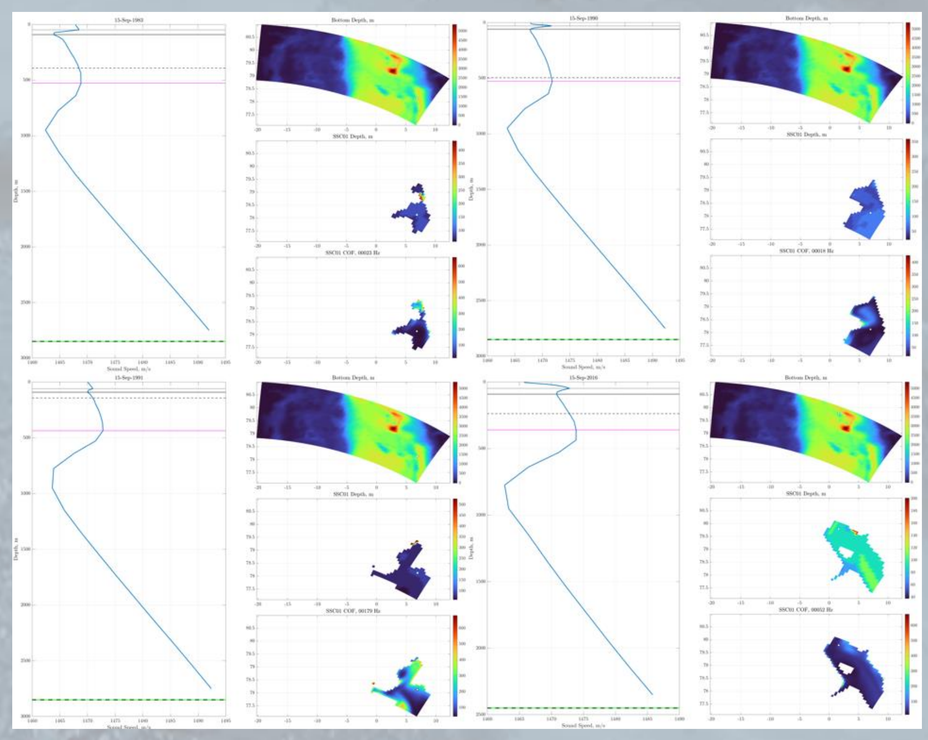


Fig. 7. Monthly mean SSPs extracted at represented locations (white dots on Bathy plot) across Fram Strait. Each panel shows SSC depth, regional occurrence by year, and corresponding cutoff frequencies, illustrating the recurrent and variability of SSC structure in climatological model output.

References

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