

SPATIAL SCALES OF SHELF-BASIN EXCHANGE OBSERVED IN THE CHUKCHI, BEAUFORT, AND MACKENZIE SLOPE REGIONS

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Introduction

Levin (1992) argues elegantly "... that the problem of pattern and scale is the central problem in ecology ..." and states further that "... the prediction of the ecological causes and consequences of global climate change, require the interfacing of phenomena that occur on very different scales of space, time, and ecological organization..." These statements certainly relate to the objectives of the shelf-basin interaction program. Its observational second phase constitutes a fine opportunity to significantly advance understanding of pattern and scale in the Arctic Ocean. In order to succeed in this goal, however, we as a community must address scaling issues explicitly, thoroughly, and honestly in studies with bio-physical objectives.

Modeling ecosystem behavior in a global change scenario requires that the scales of both biological and physical processes are known, resolved, and properly parameterized. Generally insurmountable problems in predictive capability occur when (a) the dominant scales are unknown, (b) the scales are known but a metric does not exist that matches the often diverse scales of biological and physical systems, and (c) known dominant scales are not resolved in observational programs. I suspect that the dominant scales of the physical processes in the Arctic are known with less uncertainty than those of the biological processes. Stommel (1963) and Haury et al. (1978) present early conceptualizations on how variance is distributed in time and space for physical and biological variables, respectively. I here present observational evidence on those physical scales.

I specifically emphasize the importance of the internal radius of deformation L_d that constitutes a fundamental length scale of physical processes on shelves, slopes, and deep ocean basins. L_d is the length scale where the earth rotation becomes an important and often dominant contributor to the dynamics in a stratified rotating fluid (Gill, 1982). Such systems adjust to perturbations with motions at the scale of L_d . It is the scale of most eddies in the ocean and most weather systems in the atmosphere. Most of the variance resides at L_d in non-tidal regimes such as the Arctic Ocean. The scale depends both on the latitude and the strength of vertical stratification. In the Arctic Ocean L_d varies between 5-10 km. It increases towards the south, increases with vertical density differences, and increases with the vertical scale of motion. Any experimental design must consider how processes at this fundamental scale are resolved, parameterized, or, if L_d is ignored, what the consequences of this ignorance may be. These considerations become particularly prudent if a geometric length scale L associated with variable bottom topography or coastline orientation approaches L_d . For many Arctic shelves, slopes, straits, and canyons L_d and L are similar and the ratio L/L_d constitutes an important parameter that can suggest dynamical similarity across scales.

Methods

Through international collaborations and ships-of-opportunity I collected direct velocity observations using acoustic Doppler current profilers (ADCPs) and drifters every year from 1993 through 1997.

Collaborating with Canadian scientists aboard Canadian icebreakers, I towed or mounted ADCPs. The 6-week expedition aboard the CCGS Henry Larsen in 1993 revealed a spatial shift of the boundary between Atlantic and Pacific water mass assemblies that caused Atlantic layer warming in the Canada Basin (Carmack et al., 1995 and McLaughlin et al., 1996). Furthermore, it provided snapshots of the delicate current and density pattern in all three spatial dimensions within Barrow Canyon and across the Chukchi and East Siberian slope (Münchow and Carmack, 1997; Münchow et al., 2000). Signorini et al. (1997) modeled the physical flow through Barrow Canyon with a three-dimensional general circulation model to investigate eddy formation. Neither the model nor the observations revealed the generation of the submesoscale eddies that D'Asaro (1988) hypothesized would form near Point Barrow at a rate of about once every two days.

Collaborating with U.S., Japanese, and Russian scientists, I deployed surface drifters in the summer of 1995 into ice-free coastal waters off Siberia and Alaska. The 39 drifters revealed surface currents and ice drift during summer and winter seasons, respectively. For the open water season these data unexpectedly revealed a generally westward surface flow from the Chukchi to the East Siberian shelf (Münchow et al., 1999) rather than the expected freshwater-driven eastward flow from the Kolyma River discharge region towards the Chukchi Sea (Weingartner et al., 1999). Values for horizontal mixing coefficients resembled mid-latitude open ocean rather than coastal values.

More recently, ONR funding facilitated the processing, screening, and calibration of historical ADCP data. The data were collected along with 204 discrete CTD casts aboard the R/V Alpha Helix in the summer 1996 during a 3-week long survey of the eastern Chukchi and western Beaufort shelf and slope regions that included Barrow Canyon. The data are posted in sections at <http://newark.cms.udel.edu/~muenchow/hx96.html> as jpeg, postscript, and ASCII text files for public access.

Applications

The horizontal length scales of physical processes in the Arctic Ocean span more than 6 orders of magnitude from individual ice floe and lead sizes at about 1-m to the entire ocean basin exceeding 1000 km. Vertical scales extend this range by at least another two orders of magnitude to include microstructure and turbulent exchange processes. It is impossible to resolve all these scales in a single experiment and, luckily, this is not necessary. What is necessary, however, is that the signals with the largest amplitudes are resolved by the measurements in order to minimize aliasing of the processes of primary interest. For example, if an ice-algae bloom takes place within a week, daily productivity measurements will be required to properly resolve even interannual changes. There is no way to obtain a meaningful annual productivity cycle under these conditions from samples collected, say, once a month. The situation is similar to that of sampling seasonal variations of sea level when tidal variations are dominant. It is essential to resolve the tidal cycle with hourly measurements, say, even if one is interested in monthly values

only. The same argument made for temporal variability applies equally to spatial variability: if we believe in prior observations and models that indicate current fields whose variance peaks at the scale of the internal radius of deformation L_d , then this length scale must be resolved in order to reveal the pattern even if the much larger scales are the primary interest. Hence there is no way to obtain a meaningful estimate of shelf-basin exchange if L_d is not resolved.

I will present selected ADCP velocity sections to emphasize the importance of L_d in the slope regions from the date line at 75N latitude to the Canadian Mackenzie Canyon. The most dramatic flows occur near Barrow Canyon at the intersection of the Chukchi and Beaufort shelves with the deep Canada Basin offshore. The data are published in Münchow and Carmack (1997), Signorini et al. (1997), Münchow et al. (2000), and at <http://newark.cms.udel.edu/~muenchow/hx96.html>. I hope to demonstrate that the total integrated across-shelf mass flux through Barrow Canyon at scales $L \sim L_d$ rivals the total integrated flux of an along-slope section with $L \sim 30 L_d$. Much less is known about Mackenzie Canyon, where only a single 1994 ADCP section is available. This wide canyon ($L \sim 5 L_d$) appears more typical of Arctic canyons than Barrow Canyon since it features a nearby source of riverine freshwater, that is the Mackenzie River. It is also the locale of much enhanced upwelling (Carmack and Kulikov, 1998) that prominently supports large schools of feeding bowhead whales adjacent to the coast at the head of the canyon.

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