Momentum fluxes across the air-ice-ocean interface in the Beaufort Sea

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Abstract

Increasing extent and duration of seasonally ice-free area in the western Arctic Ocean suggests increased air-sea coupling, specifically fluxes of momentum and heat between the lower atmosphere and the upper ocean. The dependence of these fluxes on ice concentration and its dynamical characteristics is still uncertain. As part of the Stratified Ocean Dynamics of the Arctic (SODA) project, year-long time series of upper-ocean velocity profiles were obtained across a range of ice conditions and are used to infer momentum fluxes. We consider the structure of observed current profiles as a function of sea state and ice cover. During the summer and in open water with minimal stratification, the wind forcing is in local equilibrium with surface gravity waves, and there is a direct transfer of momentum from the atmosphere to the upper ocean. The presence of ice modifies the momentum budget through both the inclusion of ice-atmosphere and ice-ocean stresses, and by damping short surface gravity waves and thus changing the surface roughness that the atmosphere acts upon. Ice presence is also associated with increased near-surface stratification, which can act to decouple the sub-surface ocean from atmospheric forcing. Our observations show frequent decoupling of a thin surface layer (<10 m depth), including case studies in which the relatively fresh surface waters formed by "ice puddles" have entirely different motion from the relatively salty water a few meters below. Ice formation in the fall affects both the ocean stratification and the ice characteristics, leading to competing effects affecting momentum transfer. Initial results across the annual cycle are presented.

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How does ice cover mediate momentum transfer into the Arctic Ocean?

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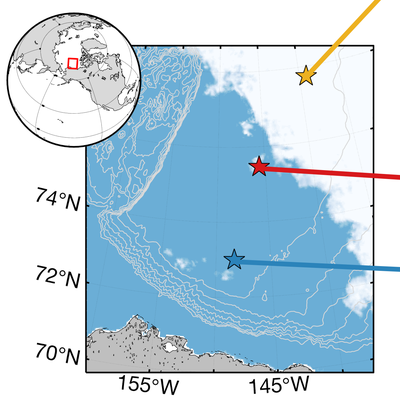
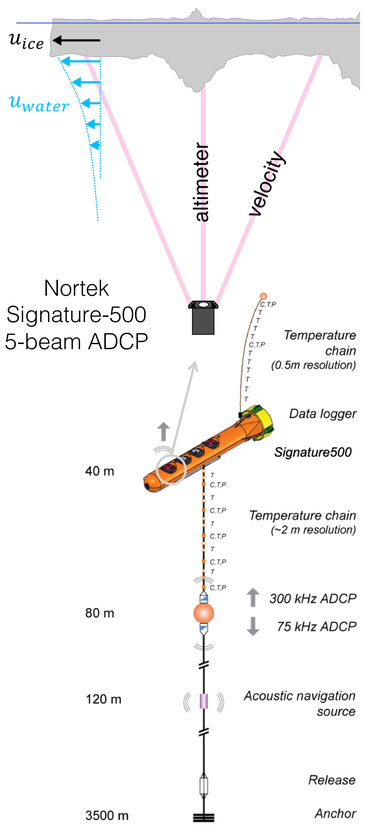
Key ideas

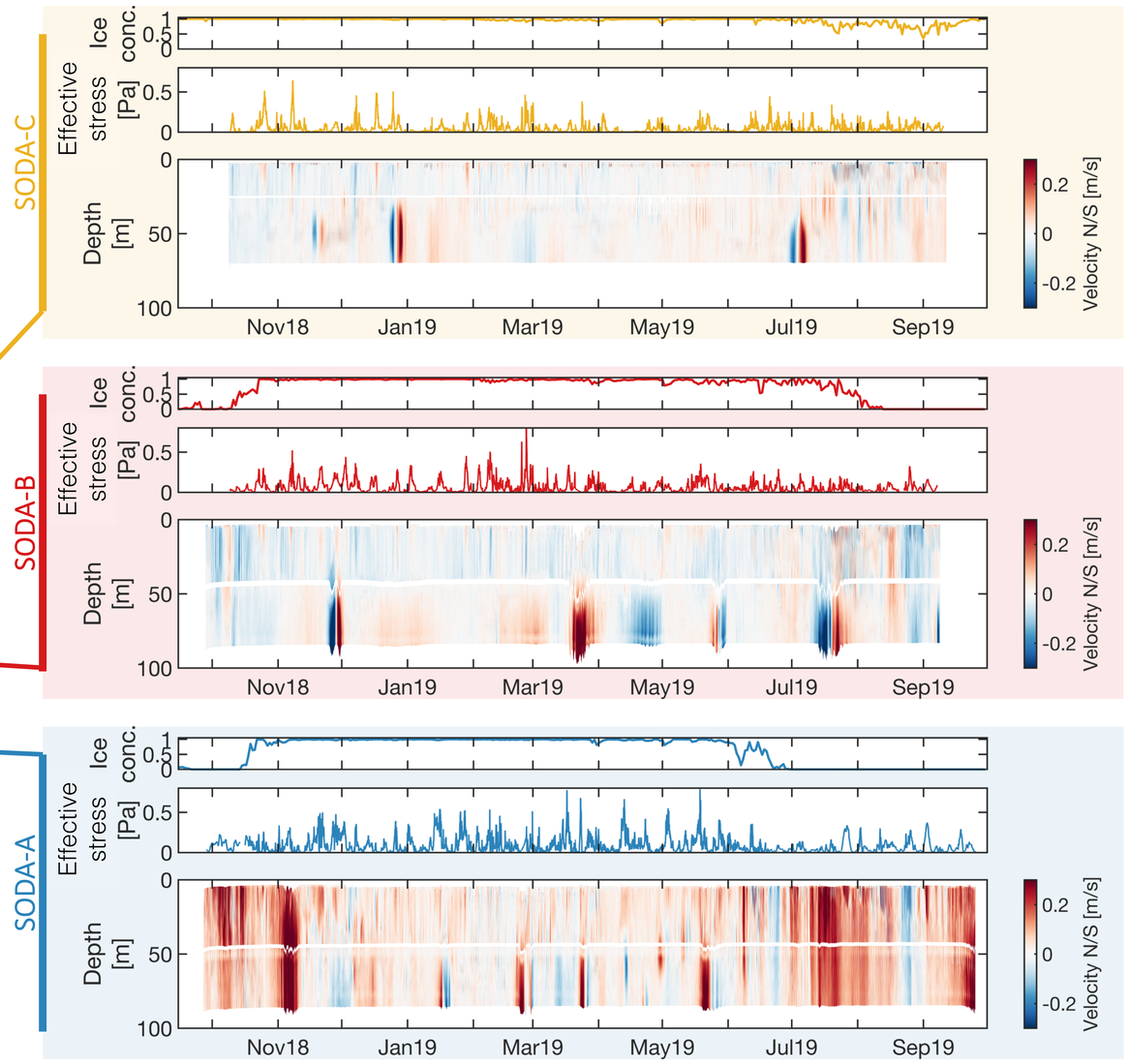
1. We can recover estimates of ice-ocean drag from moorings
2. Ice draft bursts allow ice geometry characterization for use in parameterizations
3. Differences in the upper-ocean momentum match differences in surface stress

Study description

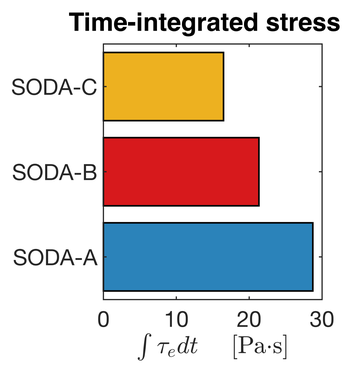
The Stratified Ocean Dynamics of the Arctic (SODA) program took place in the Beaufort Sea, including 3 moorings deployed for a year from Sept. 2018 to Sept. 2019.







Effective surface stress input



Changes in effective stress are driven by both the individual atmosphere and ice stresses and sea ice concentration (A):

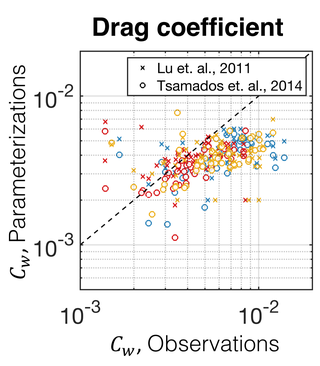
$$\boldsymbol{\tau_e} = (1-A)\boldsymbol{\tau_{ao}} + A\boldsymbol{\tau_{io}}$$

Differences in upper-ocean momentum across moorings matches with differences in effective surface stress input

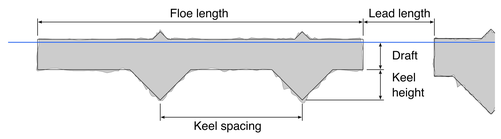
Ice-ocean stress: $\boldsymbol{\tau_{io}} = \rho_w C_w(\boldsymbol{u_i} - \boldsymbol{u_w})|\boldsymbol{u_i} - \boldsymbol{u_w}|$

Atmosphere-ocean stress: $\boldsymbol{\tau_{ao}} = \rho_a C_{ao} \boldsymbol{U_{10}}|\boldsymbol{U_{10}}|$

Ice-ocean drag parameterization



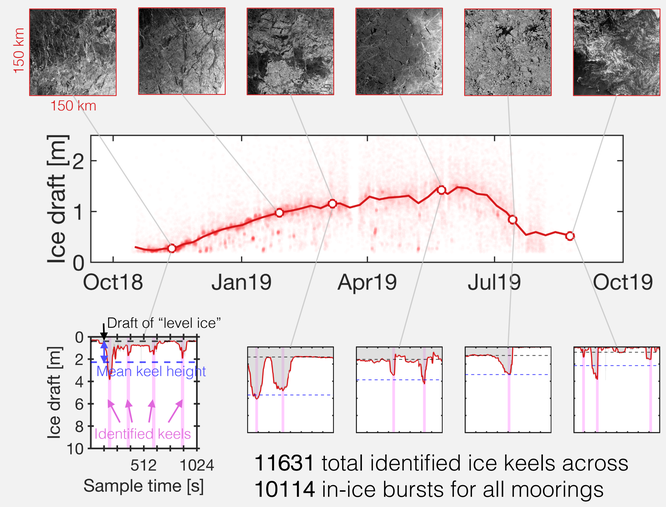
Tsamados et. al. (2014), and Lu et. al. (2011) parameterize the ice-ocean drag coefficient, C_w, in terms of idealized geometric features. We test the parameterizations against estimates from our observations with known ice geometry.



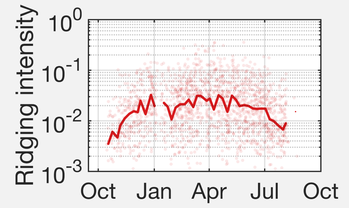
Methods

Ice Geometry

- Burst altimetry data from Signature-500 ADCPs (1024 s @ 2Hz collected every 2 hours) allows for identification and assessment of ice keels and leads
- SAR imagery provides additional context



- Bursts give temporal variation in keel height & spacing, and can be used to derive additional geometric properties



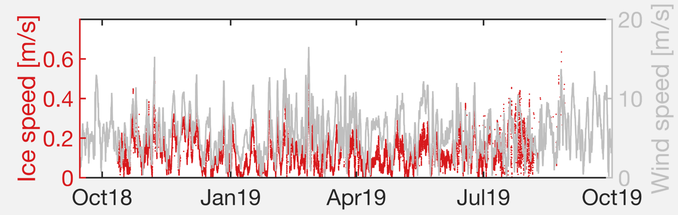
Ice-ocean momentum transfer

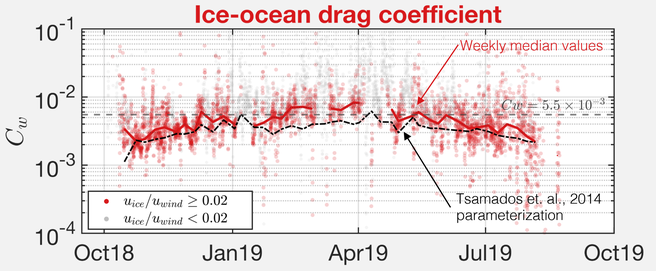
Ice momentum equation: $\rho_i h_i \left[\frac{d\boldsymbol{u_i}}{dt} + \boldsymbol{f}\times\boldsymbol{u_i}\right] = \boldsymbol{\tau_{ai}} + \boldsymbol{\tau_{oi}} + \nabla\cdot\boldsymbol{\sigma}$ if $u_{ice}/u_{wind} \geq 0.02$

Ocean-ice stress: $\boldsymbol{\tau_{oi}} = \rho_w C_w e^{i\beta}(\boldsymbol{u_w} - \boldsymbol{u_i})|\boldsymbol{u_w} - \boldsymbol{u_i}|$

- We estimate the ice-ocean drag coefficient by inverting ice momentum in terms of the ocean-ice stress
- This is only valid if internal ice stresses are negligible, which we assume occurs for a high enough ice/wind speed ratio
- Results are sensitive to the inclusion of water velocity $\boldsymbol{u_w}$

Ice-ocean drag coefficient: $C_w = \left|\frac{\boldsymbol{\tau_{ai}} - \rho_i h_i(\boldsymbol{f}\times\boldsymbol{u_i})}{\rho_w(\boldsymbol{u_w} - \boldsymbol{u_i})^2}\right|$





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