TIDAL CONVERSION AND DISSIPATION POLEWARD OF THE CRITICAL LATITUDE

How channel width influences the fate of barotropic tidal energy

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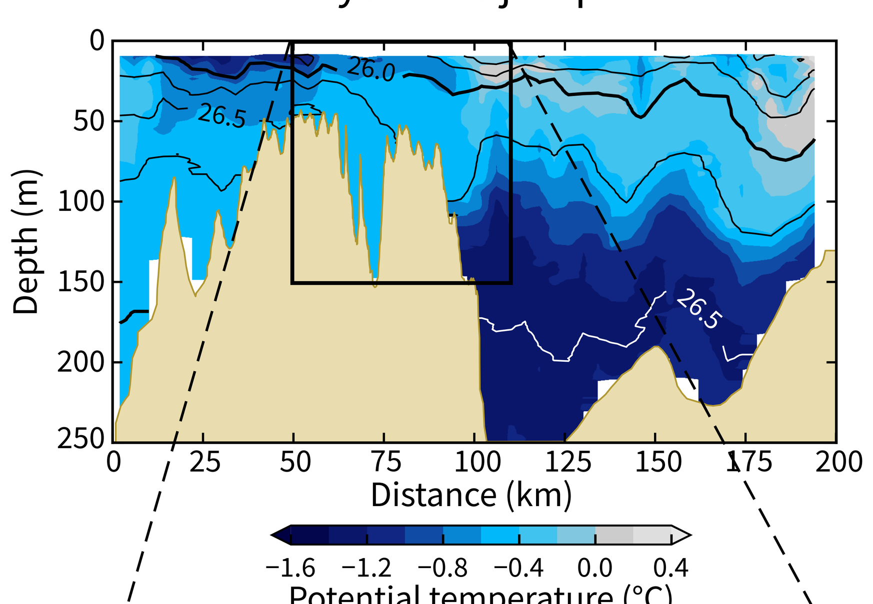
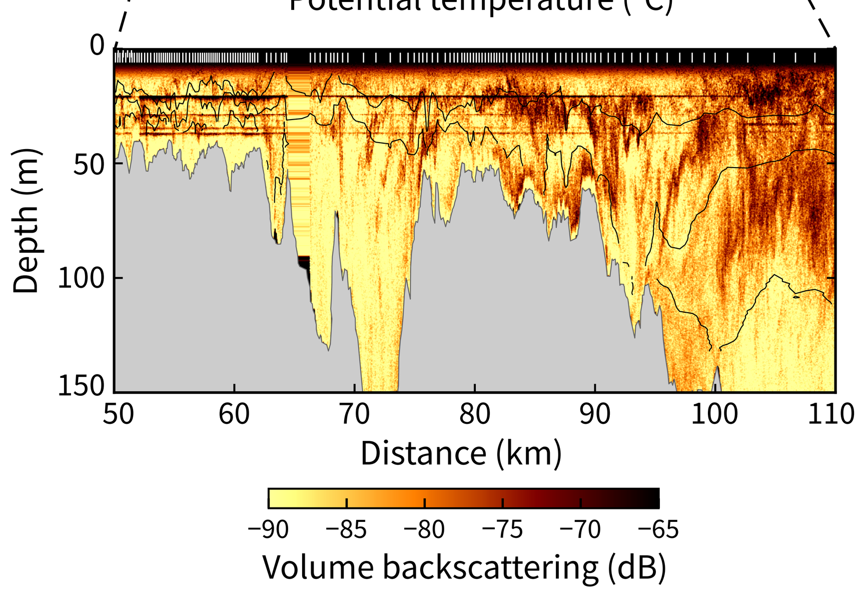
Subinertial tidal conversion in a channel with supercritical topography does not vary monotonically as the channel width increases, but rather displays peaks and nulls. The locations of these extrema are controlled by the wavelength of waves that travel along the flank of the obstacle.

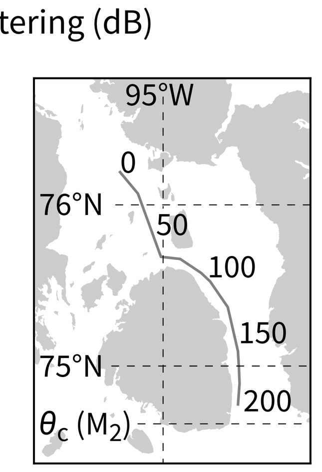
MOTIVATION

- Observations north of 75°N of flow over a sill display
  - Internal tides propagating from the sill
  - Evidence of strong turbulence
  - An internal hydraulic jump





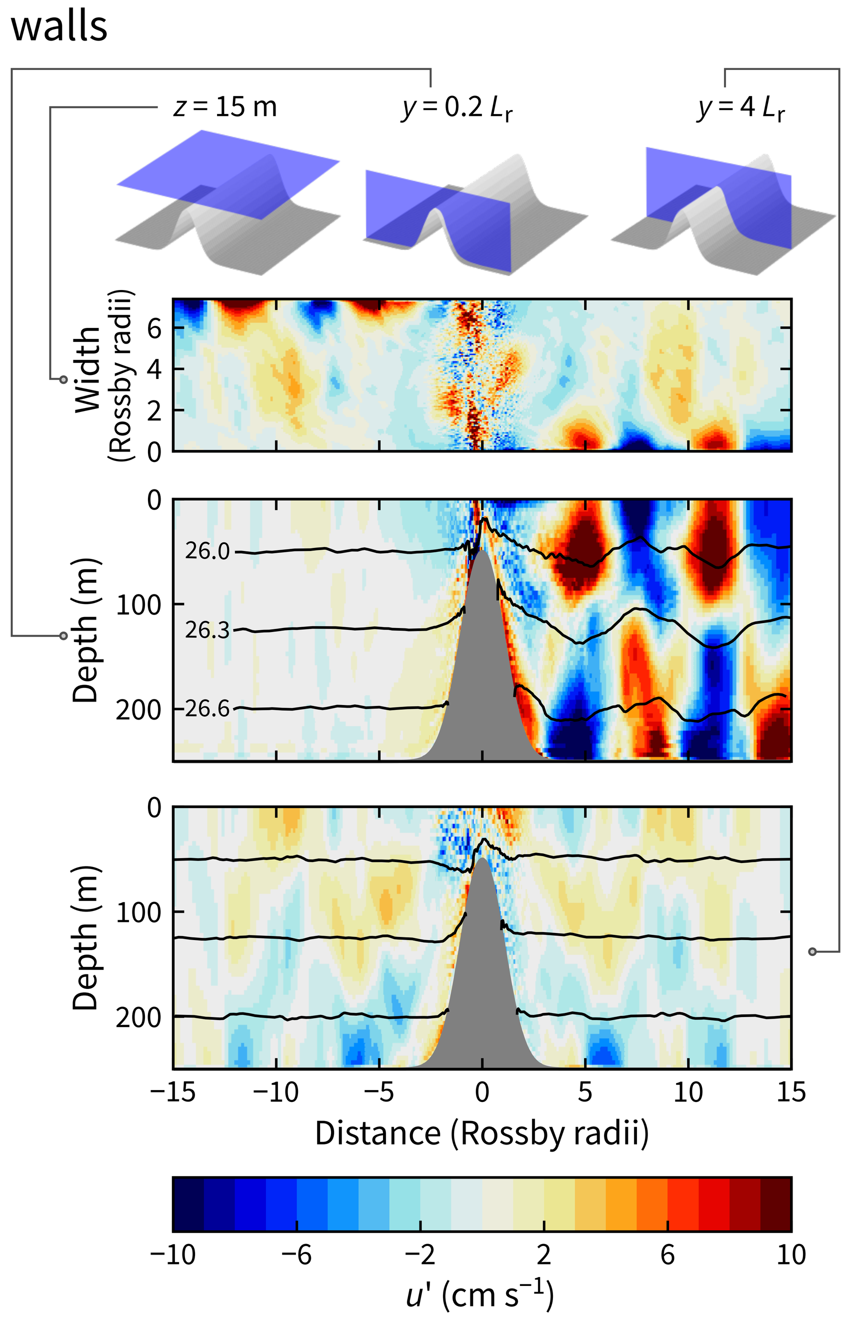
Observations from the central Canadian Arctic Archipelago
(top) Internal tides radiating southward (to the right)
(middle) Turbulent structures captured by an echosounder
(bottom) Much of the transect is approximately one internal Rossby radius from the coast of Cornwallis Island



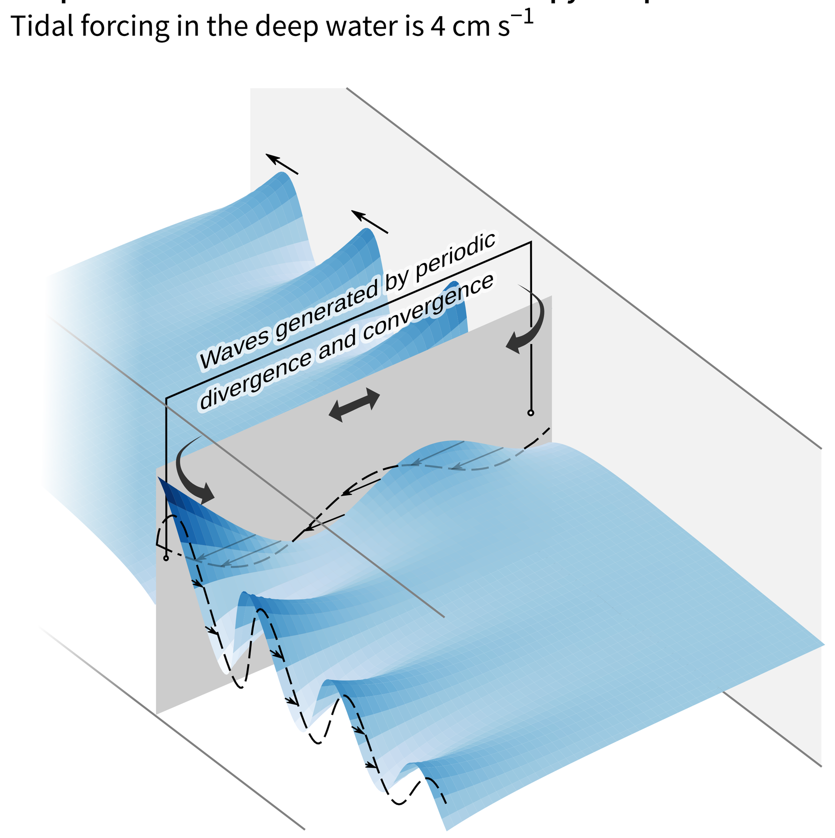
- Our measurements only enable back-of-the-envelope estimates of the fate of barotropic energy
- Using a suite of idealised simulations, we seek to explain and predict barotropic tidal losses in channels poleward of the critical latitude

PHENOMENOLOGY

- Near the walls, the fields resemble non-rotating internal tides
- Near-inertial waves dominate away from the walls



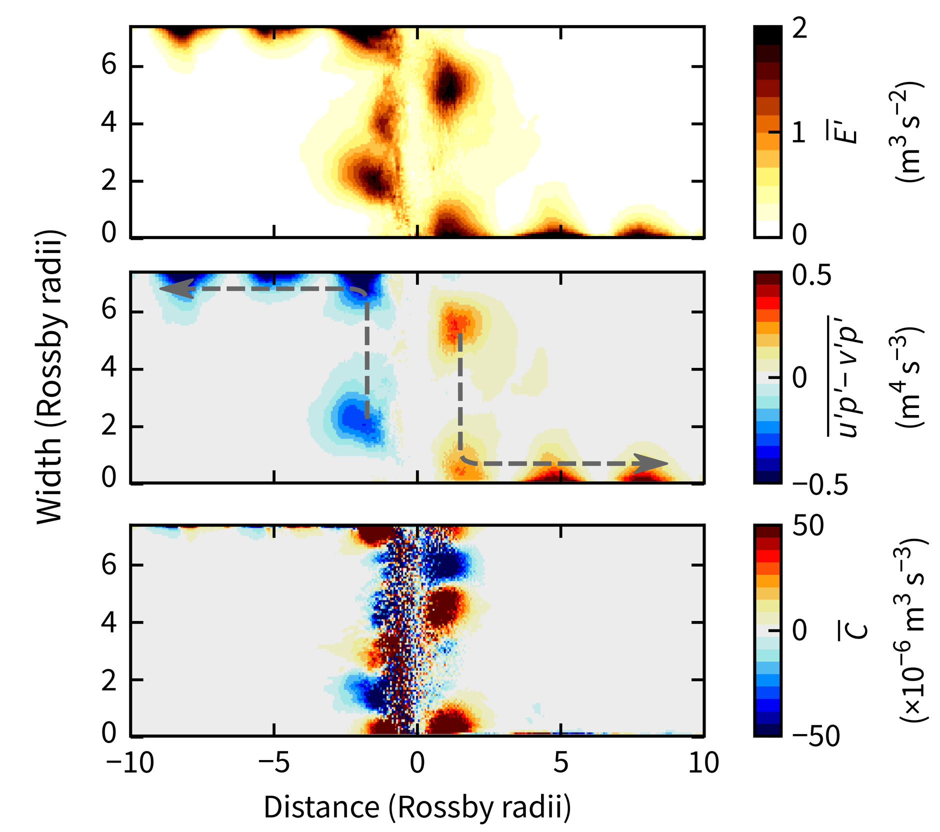
Snapshots of baroclinic velocities and isopycnal perturbations
Tidal forcing in the deep water is 4 cm s^{-1}



A simplified depiction (based on the above figure) of an isopycnal surface below the crest of the obstacle

RADIATION AND CONVERSION

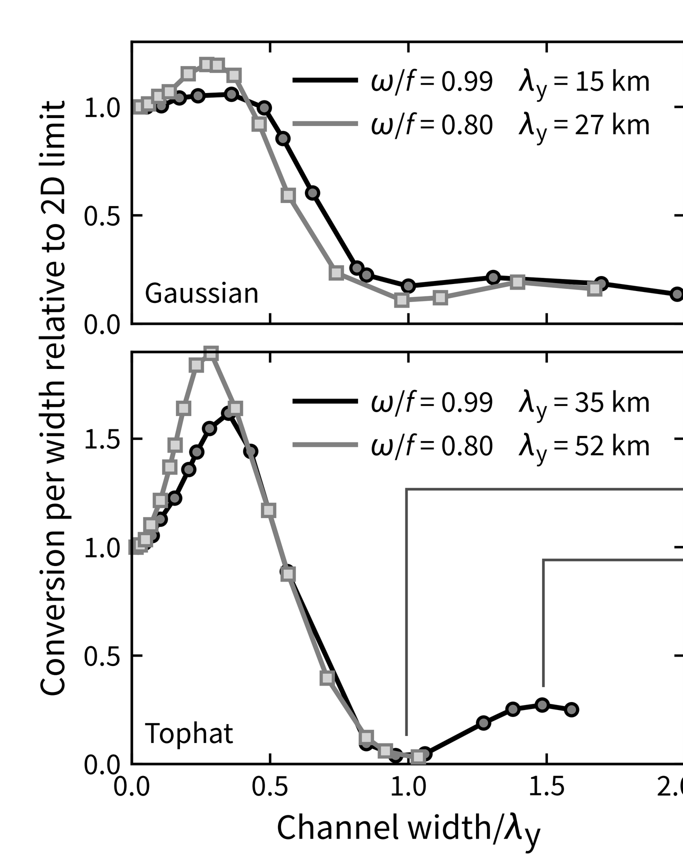
- The energetics display a simpler picture than the velocity fields by filtering out near-inertial motions
- Internal waves travelling in the y direction along the obstacle's flanks are clearly evident



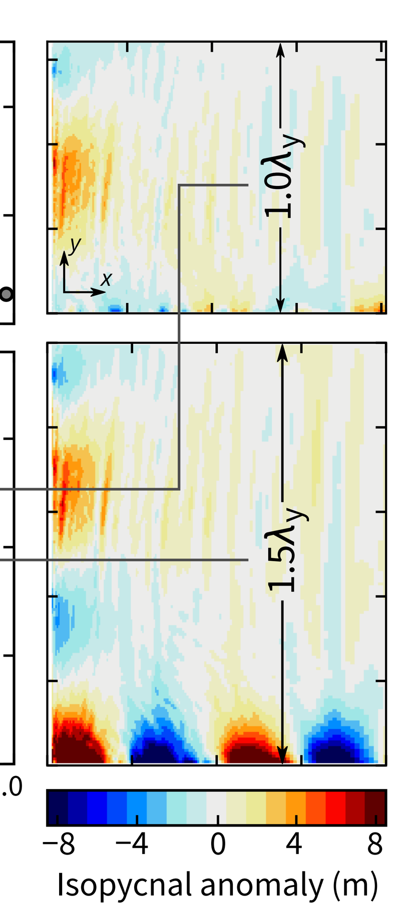
Snapshots of depth-averaged energy terms
Baroclinic energy density, baroclinic energy flux, and barotropic-to-baroclinic conversion

λ_y CONTROLS CONVERSION

- The along-obstacle wavelength λ_y is the controlling parameter
- Longer tidal periods (smaller ω) equate to longer along-obstacle waves
- Surprisingly, rotation can lead to conversion rates larger than the non-rotating limit



Curves of conversion vs channel width collapse closely when scaled by λ_y



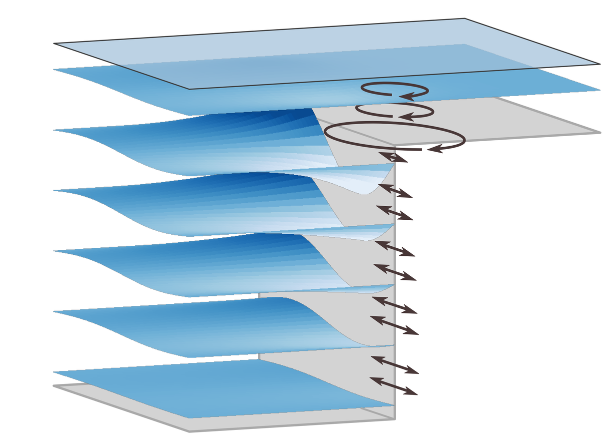
Snapshots of the differing response for channels with large and small tidally averaged conversion
Fields are taken from the deep eastern part of a tophat simulation at 80 m deep, where a large response is expected

PREDICTING λ_y

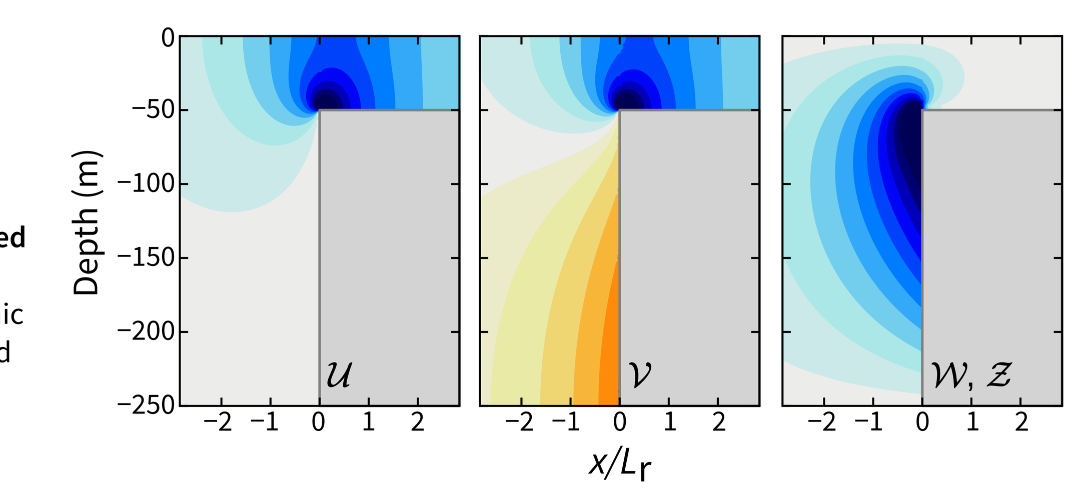
- Step-trapped Kelvin waves are a simple model for the along-obstacle wave
- Solutions are not separable in x and z unlike Kelvin waves
- Mode-matching methods give mode shapes (Chapman, 1982, *DAO*):

$$[p', u', v', w, \rho'] = [\mathcal{P}, \mathcal{U}, \mathcal{V}, \mathcal{W}, \mathcal{Z}](x, z)\, e^{i(\omega t - k_y y)}$$

- Work in progress: behaviour of waves beside knife-edges and gaussian bumps



Isopycnals (vertically exaggerated) and particle orbit cycles in a step-trapped Kelvin wave



Mode shapes for a step-trapped Kelvin wave
Cross- and along-step baroclinic velocities, vertical velocity, and isopycnal perturbation

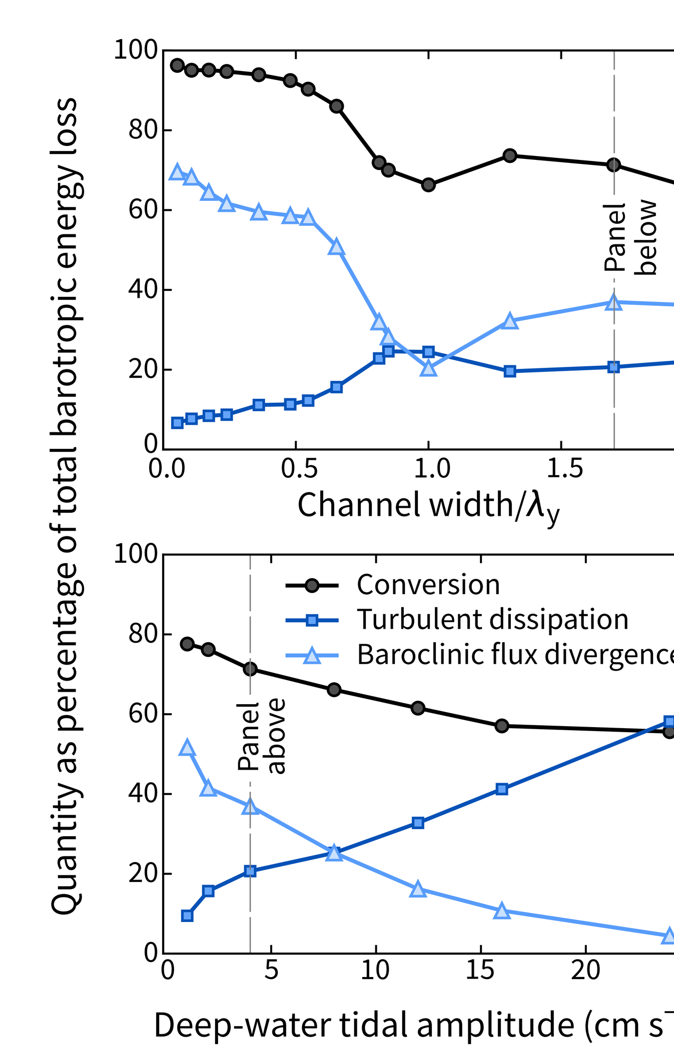
EFFICIENT REMOVAL OF BAROTROPIC ENERGY

- In the weak forcing limit, the barotropic tide in a channel loses far more energy than the equivalent 2D (infinite ridge) scenario in which energy loss occurs only via local dissipation
- Even in wide channels, internal tide generation is typically a stronger barotropic energy sink than dissipation
- Preliminary empirical scalings for a wide channel:

$$C \propto U^{2.1}, \varepsilon \propto U^{2.7}$$

2D theories predict
$C \propto U^2$ and $\varepsilon \propto U^3$
(St Laurent et al., 2003, *DSR*; Llewelyn Smith and Young, 2003, *JFM*; Klymak et al., 2010, *JPO*)

- Nonlinear lee waves are of comparable importance for wide channels with internally supercritical flow: $G > 1$ (cf. Rippeth et al., 2017, *GRL*)



Partitioning of the barotropic tidal energy loss with varying channel width and tidal forcing

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