Katabatic wind-driven exchange in fjords

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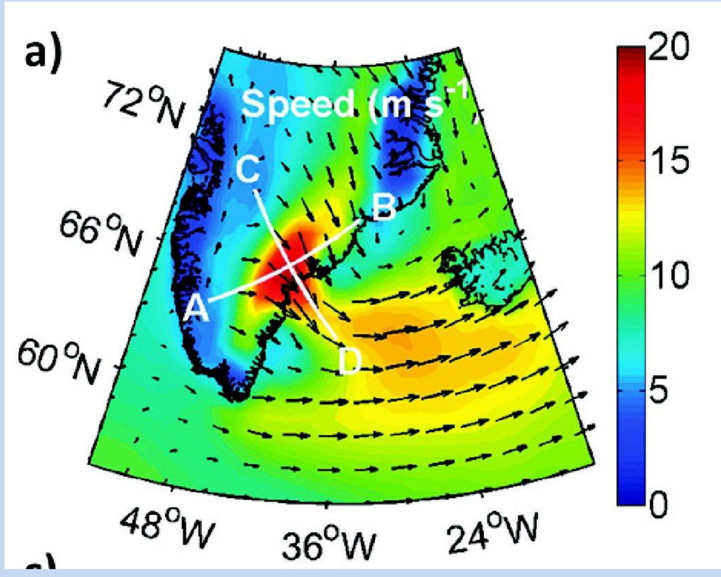
Introduction

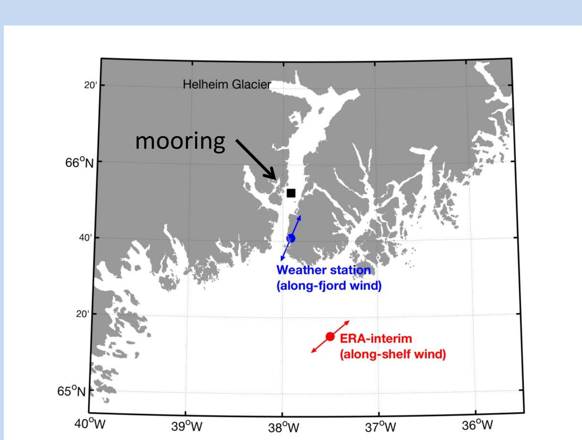


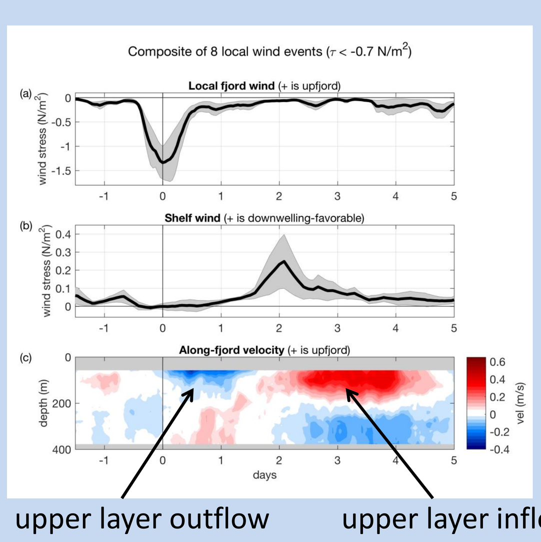
Katabatic winds are intense winds directed down fjord from glacier to open ocean.
In the Ammassalik region of SE Greenland wind speeds exceed 20 m/s, 1-2 days
4-8 events occur each year, primarily in winter (Oltmanns et al. 2014; Jackson, 2016)

Fjords are salt stratified and connect tidewater glaciers with the ocean shelf
The ocean is a source of heat to melt glaciers, glaciers are a source of fresh water for ocean

How do these winds events influence exchange between the fjord and shelf?

Observations





Mooring placed in Sermilik fjord from 8/2011-6/2012 and 9/2012 to 8/2013
T, S, velocity from ~ 50m to 500 m
(Jackson and Straneo 2016; Jackson 2016)

8 events over 2 years
Composite wind:
1 N/m^2 ~ 1 day duration

Fjord response:
upper layer outflow during wind followed by inflow after.
Exchange is baroclinc, ~ 4-6 x 10^{10} m^3 per event (About 15-30% of initial freshwater volume)

Theory: wide fjords

Transport:

$$\phi(t)=\frac{\tau_0 h_2}{\rho_0 H}\int_0^t\left[-\mathrm{H}(t'-y/C)+0.5\mathrm{H}(t'-(y+d)/C)-0.5\mathrm{H}(t'-(d-y)/C)+\mathrm{H}(t')\right]dt'$$

Farmer (1976) two-layer, inviscid, nonrotating theory, $H=h_1+h_2$ total depth; τ_0 steady wind stress; y distance from head of fjord; C is baroclinic wave speed, H is Heaviside function.

For steady winds, velocity increases to max at time=d/C before decreasing back to zero.

$$V_m=\frac{\tau_0 h_2}{2\rho_0 h_1 H}\frac{d}{C}$$

Theory: narrow fjords

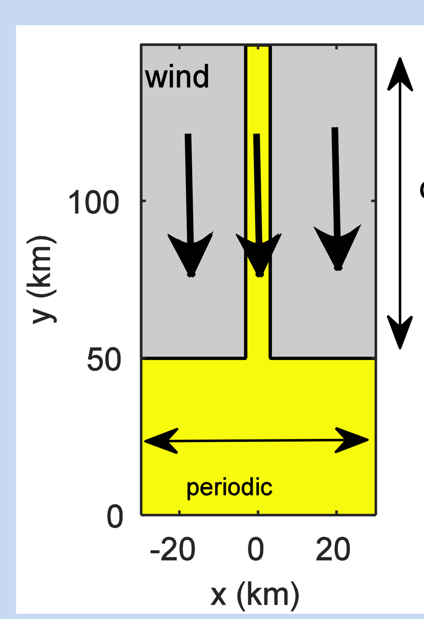
For narrow fjords balance is between wind and friction. For Smagorinsky viscous parameterization, scaling: boundary layer width δ with steady max velocity V_0

$$\delta=\left[\left(\frac{\nu\Delta}{2\pi}\right)^2\frac{\tau_0}{\rho_0 h_1}\left(\frac{d\,h_2}{CH}\right)^2\right]^{1/3}\qquad V_0=\left[\left(\frac{\pi}{\nu\Delta}\right)^2\frac{\tau_0}{\rho_0 h_1}l^3\right]^{1/2}$$

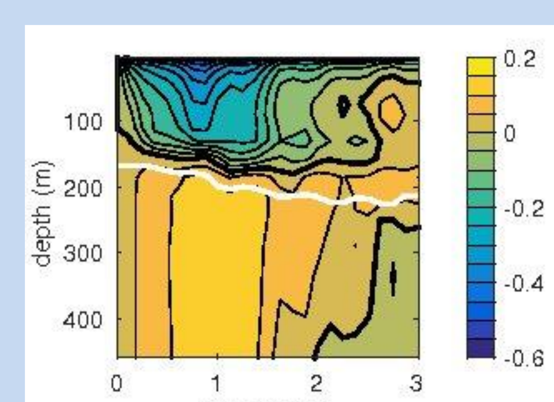
Δ grid spacing
l fjord half-width
ν nondim constant

Numerical model (MITgcm)

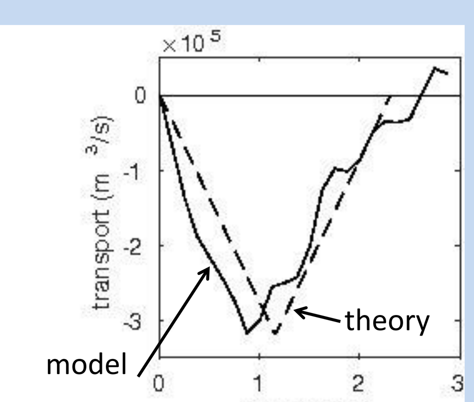
(Marshall et al, 1997)



Flat bottom domain with rectangular fjord of width 2*l*
Steady, spatially uniform wind applied for 3 days
Grid spacing 250 m
Initial two-layer stratification



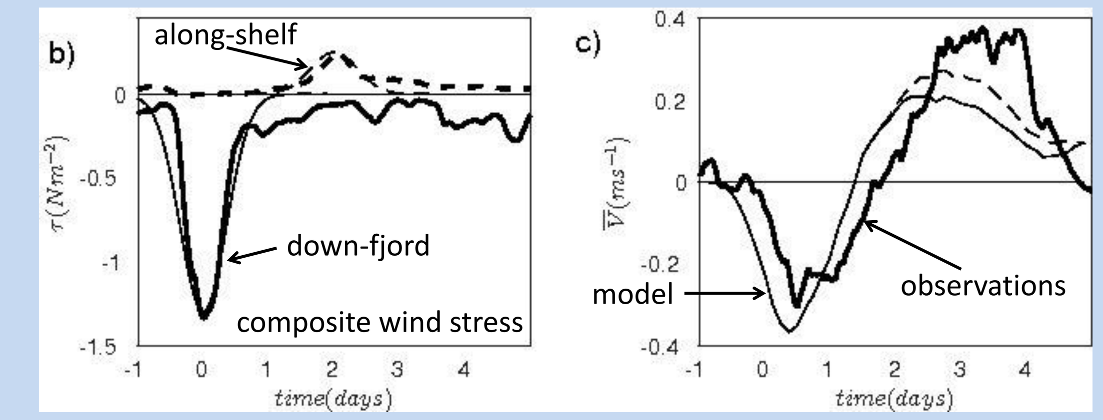
Along-fjord velocity



outflow transport

Outflow in upper layer, inflow in lower layer.
Max outflow at 1 day, decreases to zero (even with continued wind forcing)
In good agreement with Farmer theory (dashed line)

Compare model with observations



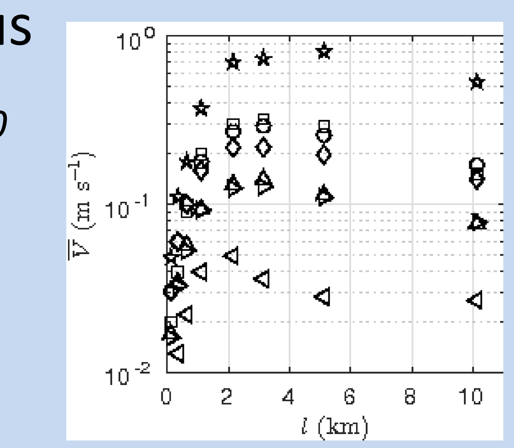
bold: observations
thin: model with and without along-shelf wind

Wind stress — velocity at 50 m

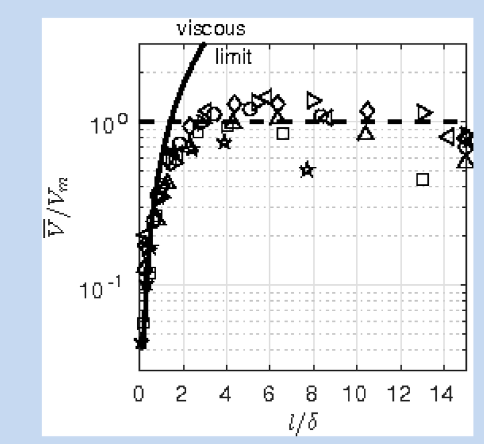
Close agreement between model and observations

Compare model with theory

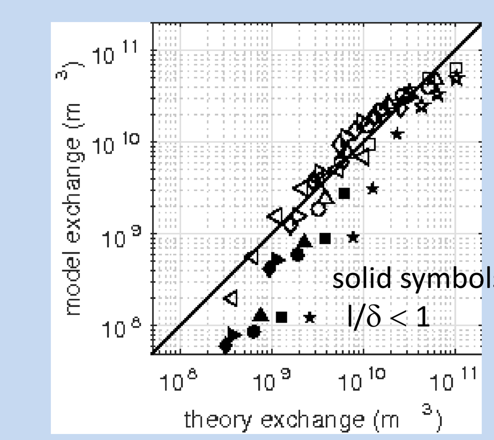
Vary: wind, stratification, layer thickness, fjord width



max velocity (m/s)



nondimensionalized



volume exchanged

Max outflow velocity between 2 and 80 cm/s
Velocity is scaled by V_m and fjord width by δ results collapse
When fjord width < δ the frictional boundary layer dominates

Summary

1. 4-8 katabatic wind events occur each year
2. For wide fjords, O(20%) of the initial volume of upper layer fluid gets flushed out per event
3. For narrow fjords, exchange is limited by friction
4. Idealized numerical model compares favorably with mooring observations in Sermilik Fjord
5. Katabatic wind events represent an important exchange mechanism between fjord and shelf

Spall, M. A., R. Jackson, F. Straneo, 2017: Katabatic wind-driven exchange in fjords, submitted to J. Geophys. Res.
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Jackson, R., 2016: Dynamics of Greenland's glacial fjords. Ph.D. thesis Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution
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