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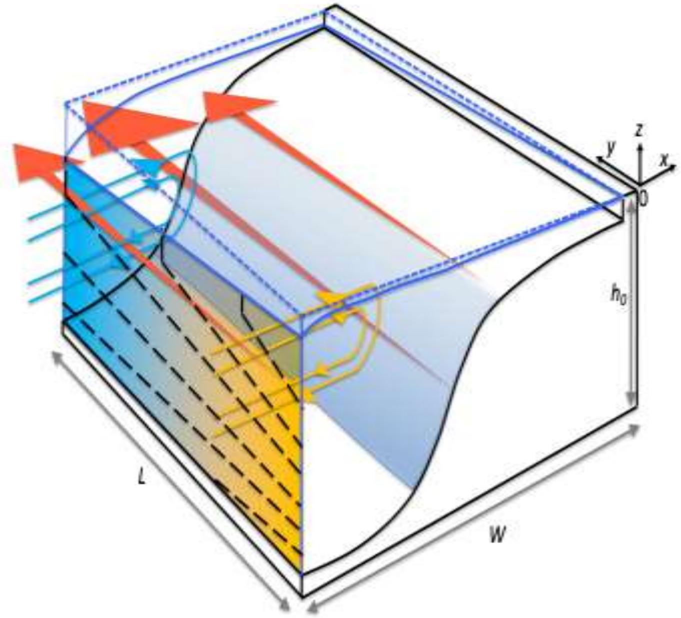
Oceanic density/pressure gradients and slope currents



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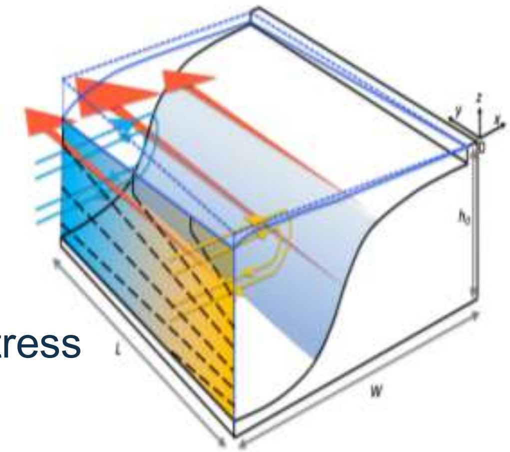
Summary and conclusions



- Analytic form of ocean slope current

    *equilibrated with oceanic density gradient “JEBAR” & wind stress

*steady, along-slope uniformity

(flow, depth, wind; gradients of density, surface elevation, pressure)

Simplified by equilibrium, along-slope uniformity, assumed linearity (JPO paper justifies)

- Direct relation between slope current strength, friction and along-slope forcing (e.g. wind) also between the total along-slope forcing and bottom Ekman transport

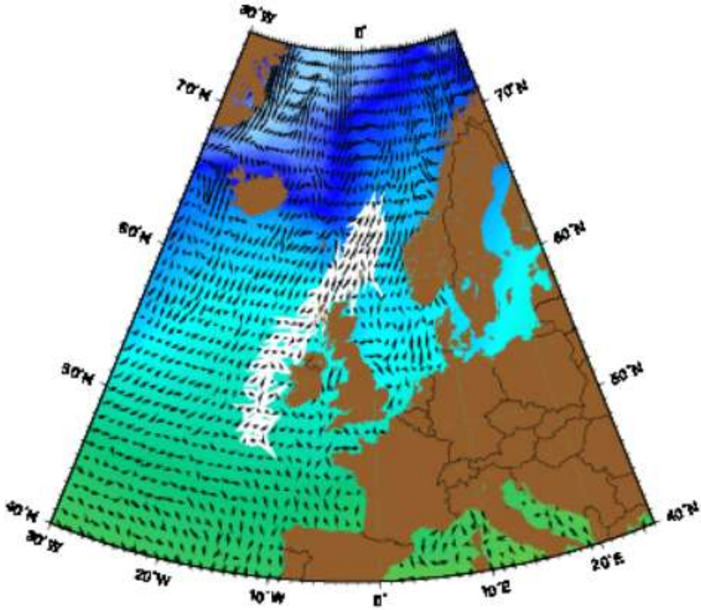
    → *any* forcing implies bottom stress (not “slippery”) and Ekman transport

    → should not / cannot assume zero along-slope pressure gradient

- Boundary currents are energetic → significant meridional transports (water, heat. salt) but poorly resolved in models, sparsely measured, sparse literature on dynamics

- Analysis hopefully contributes to dynamical understanding, model testing and basis for further study of roles of friction, wind, changing oceanic density

Introduction



The Slope Current as represented by the Mariano Global Surface Velocity Analysis (MGSVA). The Slope Current is just off-shore of the British Isles and transports Northeast Atlantic water into the Norwegian Sea. Click here for
https://oceancurrents.rsmas.miami.edu/atlantic/slope.html

- Eastern ocean-boundary currents are common

  (e.g. W Europe, W USA, W Australia)

  and important,

  e.g. ~ ¼ of Atlantic inflow to the Nordic Seas

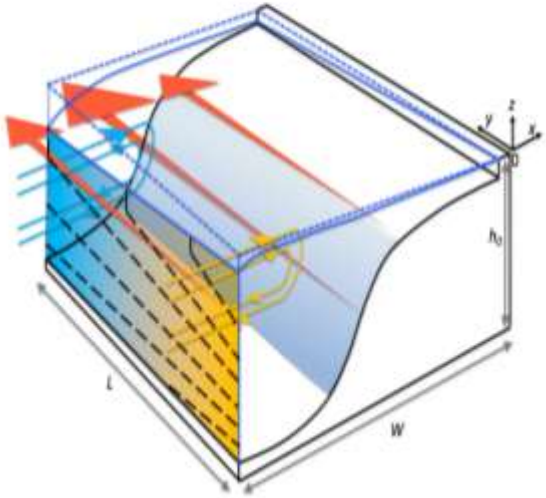
- No rest state if ∂ρ/∂y (along-slope ∇ density) and slope ∂h/∂x

- Literature analysis very restricted regarding form of density ρ

- Analysis here allows any $\rho = \rho_y(z)y + \rho_2(x,z)$ (y-uniform ∂ρ/∂y but wide scope to vary ρ)

- Wind stress also added, flow constrained by balancing bottom friction

Analysis (see JPO on-line for details)



- Assumptions:

  Hydrostatic pressure p, free surface $z = \eta(x, y)$

  Linear (justified in JPO paper;
  non-linear effects of eddies or tides are another forcing)

  Lateral viscosity = 0 (discussed separately)

  Surface wind stress, (turbulent) frictional stress (τ^x, τ^y)(x,z) through depth to bottom

  Steady, along-slope (y-) uniform context and flow

  No/small y-transport in adjacent deep ocean, sets $\frac{\partial \eta}{\partial y}$ there *and* over slope and shelf

  $$\left(\frac{\partial^2 \eta}{\partial x \partial y} = \frac{\partial^2 \eta}{\partial y \partial x} = 0\right)$$

- Resulting explicit formula for along-slope flow (from along-slope momentum)

$$\rho_s r v = \left(g \frac{h}{h_0} \int_{-h_0}^{0} \int_{z}^{0} \rho_y(z') dz' dz - g \int_{-h}^{0} \int_{z}^{0} \rho_y(z') dz' dz - \frac{h}{h_0} \tau_{s0}^{y} + \tau_s^{y} \right) - \frac{gr}{f} \int_{-h}^{z} \frac{\partial \rho_2}{\partial x} dz'$$

bottom friction | JEBAR relative to deep ocean | wind stress | geostrophic shear

Physical description

- E.g. density increases with y / poleward
- If no other forcing and deep-sea transport ~ 0

  then $\int_{-h_O}^{0} \frac{\partial p}{\partial y}\, dz = 0$

  (raised surface where less dense

  $\rightarrow$ upper $\frac{\partial p}{\partial y} < 0$ but lower $\frac{\partial p}{\partial y} > 0$)

- $\frac{\partial p}{\partial y}$ geostrophically balances zonal flow u

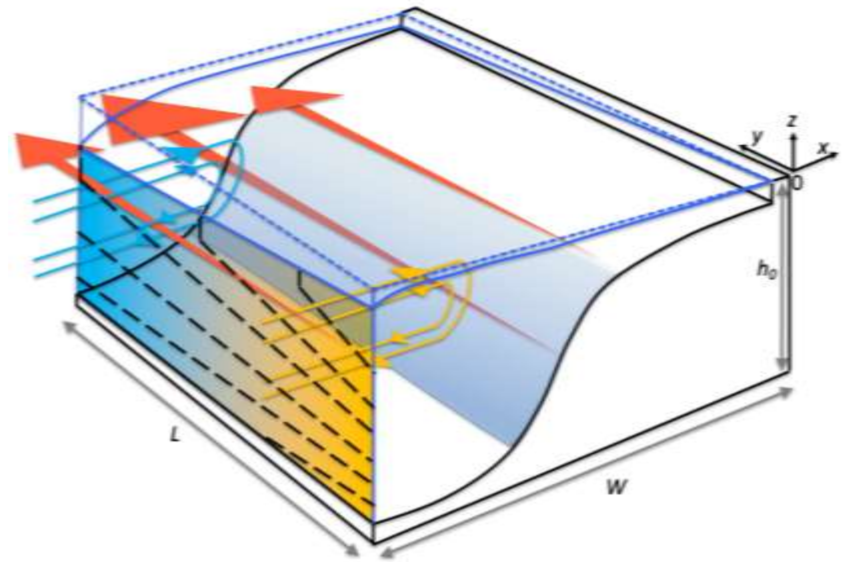
  with deep-sea $\int_{-h_O}^{0} u\, dz = 0$

- Over shallower slope, less "lower"

  $\rightarrow \int_{-h}^{0} \frac{\partial p}{\partial y} dz < 0, \quad \int_{-h}^{\eta} u_{geostrophic}\, dz > 0$

  "excess" u returns in bottom Ekman layer

  $\leftrightarrow$ friction on along-slope $v \leftrightarrow \int_{-h}^{0} \frac{\partial p}{\partial y} dz < 0$



ΔPressure contours (Δp increases up)

Along-slope flow

Cross-slope flow

Bottom stress and Ekman transport

- From depth-integrated along-slope momentum

  with $\frac{\partial}{\partial y}$ (along-shore transport) = 0 and coast $\Longrightarrow$ zero onshore transport

$$0 = \rho_r f \int_{-h}^{\eta} u dz = -gh\rho_s \frac{\partial \eta}{\partial y} - g \int_{-h}^{0} \int_{z}^{0} \frac{\partial \rho}{\partial y} dz' dz + \tau_s^y - \tau_b^y$$

onshore transport — pressure gradient (z) generally ≠ 0 ! — wind — bottom stresses

Bottom stress almost certainly not zero if there is any forcing or density y-gradient
→ not "slippery", Ekman transport ≠ 0

Along-slope evolution

- Velocity evolves along slope (and in time) towards equilibrium

- Coastal-trapped waves (CTW) carry information about initial/"upstream" conditions

→ evolution scale set by decay distance of CTWs: days / 100s – 1000s km

depends strongly on context & forcing pattern

forcing match to higher-mode CTWs → shorter scales

strong friction or narrow shelf with weak stratification → shorter scales

- Density fields approximating $\rho = \rho_y(z)y + \rho_2(x,z)$ over distance > evolution scale

expected to give near- equilibrated velocity

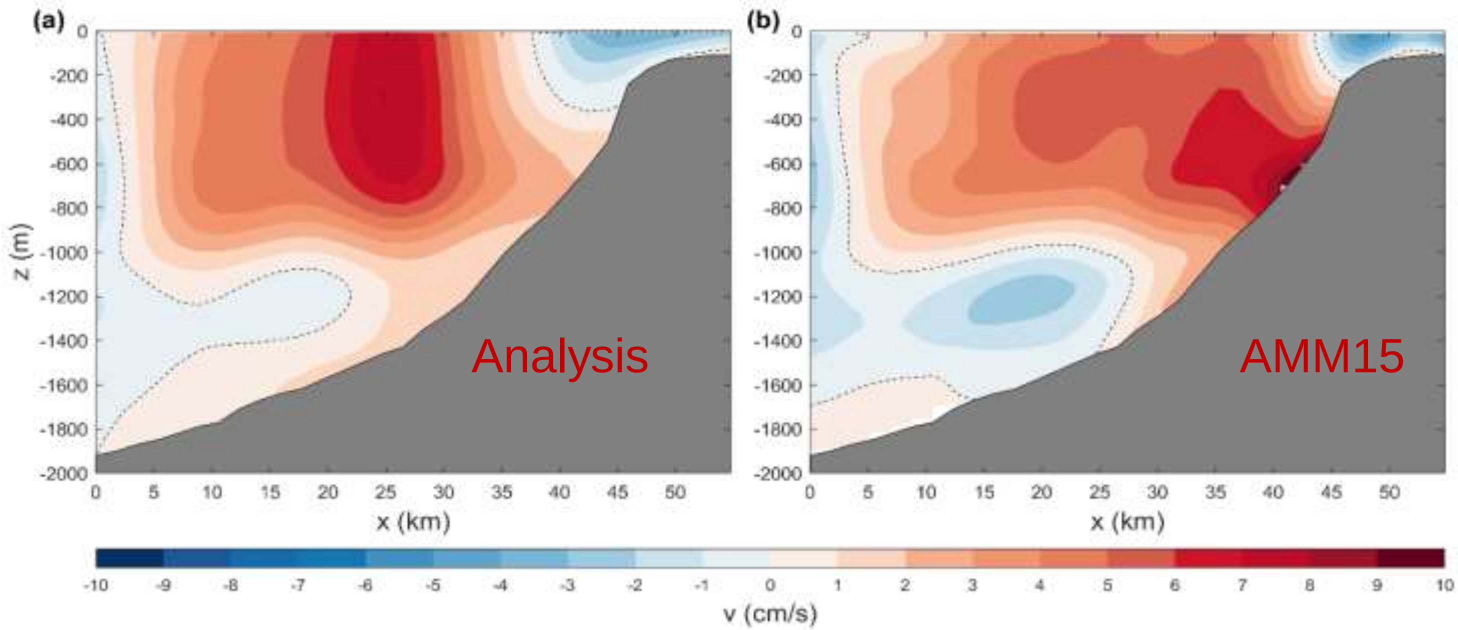
- Oceanic eddies impinging on the slope, and storms,

likely to cause departure from analysis owing to short scales.

Comparison with AMM15 (numerical model; Graham et al. 2018)

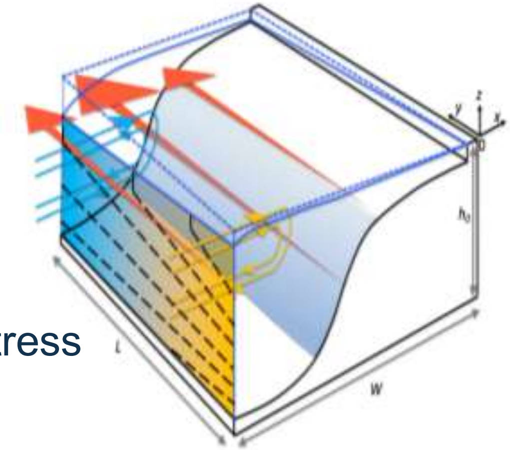
- $\rho = \rho_y(z)y + \rho_2(x,z)$ fitted to February 2018 in AMM15 (1.5 km NEMO) over 100 km along-slope x (200 – 1700 m cross-slope) at 56°N west of Scotland

- Analysis with bed friction factor $r = 0.01$ ms^{-1}, $\tau_s = 0.1$ Pa (mean February wind stress)
  Plots show along-slope flow: along-slope (100 km) and February average
  "Analysis" laterally smoothed (15 km window) for estimated lateral "diffusion"



- Northward flow mostly from JEBAR and "thermal wind"
- Discrepancies! Factors might be uniform r and wind stress (analysis); on/off-shelf tidal currents and tidal rectification, irregular topography, variability in time and **space** (AMM15)

Summary and conclusions



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