What explains the Seasonal cycle of mesoscale instability of the West Spitsbergen Current?

Wilken-Jon von Appen (AWI)
Ursula Schauer (AWI)
Tore Hattermann (AVKVAPLAN, AWI)
Agnieszka Beszczynska-Möller (IOPAN, AWI)

submitted to Journal of Physical Oceanography

FAMOS Meeting 2015, Session 3
November 5th, 2015
Flow separation in Fram Strait: some enters Arctic, some recirculates west and then south.

Figure from Beszczynska-Möller et al ICES 2012
West Spitsbergen Current: warm northward flow

Figure from Beszczynska-Möller et al ICES 2012
Atlantic Water temperature trends

Atlantic Water: $>2^\circ$C

Figure from Beszczynska-Möller et al ICES 2012
Instability of the West Spitsbergen Current

- Teigen et al JGR 2010: WSC is barotropically unstable; idealized model fitted to 1 year of mooring data
- Teigen et al JGR 2011: WSC is baroclinically unstable; more unstable conditions seen in winter; no attribution
Moorings of the AWI physical oceanography section and the AWI deep sea section (Hausgarten)
Moorings of the AWI physical oceanography section and the AWI deep sea section (Hausgarten)

Summer ship sections along 78°50’N
Data

- Moorings of the AWI physical oceanography section and the AWI deep sea section (Hausgarten)
- Summer ship sections along 78°50’N
- Argo floats
Moorings of the AWI physical oceanography section and the AWI deep sea section (Hausgarten)

Summer ship sections along 78°50’N

Argo floats

AVISO ENVISAT along-track sea surface height
Warm surface water leads to strong stratification in summer

Stratification much reduced in winter
Temperature and density yearly cycle

- Temperature increase in \( \approx 75 \) m leads to density decrease
- Warming signal weaker and delayed in \( \approx 250 \) m
Mesoscale EKE in upper ocean across FS

(a) EKE at 75m

Maximum in winter in boundary current
Energy propagates westward with the recirculation
Less energetic in summer, EKE has baroclinic structure
EKE from along-track SSH and moorings

- $\eta'(x)$ sea surface height anomaly in along-track direction
- surface geostrophic velocity: $v_g = \frac{g}{f} \frac{\partial \eta'}{\partial x}$
- assume isotropy: $|v_g| \approx |u_g| \Rightarrow EKE = v_g^2$
**EKE from along-track SSH and moorings**

- $\eta'(x)$ sea surface height anomaly in along-track direction
- surface geostrophic velocity: $v_g = g \frac{\partial \eta'}{\partial x}$
- assume isotropy: $|v_g| \approx |u_g| \Rightarrow EKE = v_g^2$

![August EKE](image_url)
EKE from along-track SSH and moorings

- moorings bandpass filtered, SSH 10 km horizontal resolution → mesoscale responsible for EKE
- boundary current along slope: band of elevated EKE
- south of 78°N: EKE does not leave boundary current
Can we explain the seasonal cycle of EKE by local processes?

- Strong vertical shear supports baroclinic instability (related to strong horizontal density gradients)
- Strong stratification suppresses baroclinic instability
Seasonal cycle of the Richardson number

$$N^2 = -\frac{g}{\rho_0} \frac{\Delta \rho}{\Delta z}$$

Mean stratification increases by a factor of 5
Seasonal cycle of the Richardson number

\[ N^2 = \frac{-g}{\rho_0} \frac{\Delta \rho}{\Delta z}, \quad S^2 = \left( \frac{\Delta u}{\Delta z} \right)^2, \quad Ri = \frac{N^2}{S^2} \]

Mean stratification increases by a factor of 5
Seasonal cycle of the Rossby radius

\[ L_d = \int \frac{N(z')}{\pi f} \, dz' \approx \frac{N}{f} H \]

Mean stratification increases by a factor of 5, \( L_d \approx 3-6 \) km
Strength of baroclinic instability

- Eady (1949) problem, modified by Stone (1972), rewritten using thermal wind: e-folding growth rate of baroclinic instability \( \omega = 0.3f \sqrt{\frac{1}{1+R_i}} \)

- Instability grows by factor \( e \approx 2.7 \)
  - in \( \approx 12 \) hours (winter)
  - in \( \approx 2 \) days (summer)

- Boundary current unstable (but less unstable) in summer
- Increased stratification in summer stabilizes the WSC
- Increased shear in winter destabilizes the WSC
Amplitude of the EKE

- Observed: \( EKE = \frac{1}{2}(u'^2 + v'^2) \)
- Consider how long a linear small amplitude instability can grow: until it is non-linear and large amplitude
- Assume:
  - Instability has grown to final amplitude
  - No EKE has been lost from boundary current
- Stone (1972) parametrization: \( v' \sim \bar{v} \);
  \( EKE \approx a * v'^2; \ a = \frac{1}{2} \)
Amplitude of the EKE

- Observed: $EKE = \frac{1}{2}(u'^2 + v'^2)$
- Consider how long a linear small amplitude instability can grow: until it is non-linear and large amplitude
- Assume:
  - Instability has grown to final amplitude
  - No EKE has been lost from boundary current
- Stone (1972) parametrization: $v' \sim \bar{v}$; $EKE \approx a \cdot v'^2; a = \frac{1}{2}$
- Killworth (1997) parametrization: $v' \sim \omega L_d$; $EKE \approx b \cdot v'^2; b = \frac{1}{4}$
- $a, b \lesssim 1 \rightarrow$ Some energy lost from boundary current
Summary

- In winter WSC is baroclinically unstable
- In summer WSC is less baroclinically unstable
- Increased stratification stabilizes boundary current in summer

Discussion

- Stronger wind stress curl over Nordic Seas in winter: → stronger flow in WSC
- Stronger air-sea heat fluxes over Nordic Seas in winter: → weaker stratification in WSC
- Explanation for mesoscale variability in Fram Strait: → locally generated by oceanic processes → indirectly forced by atmosphere