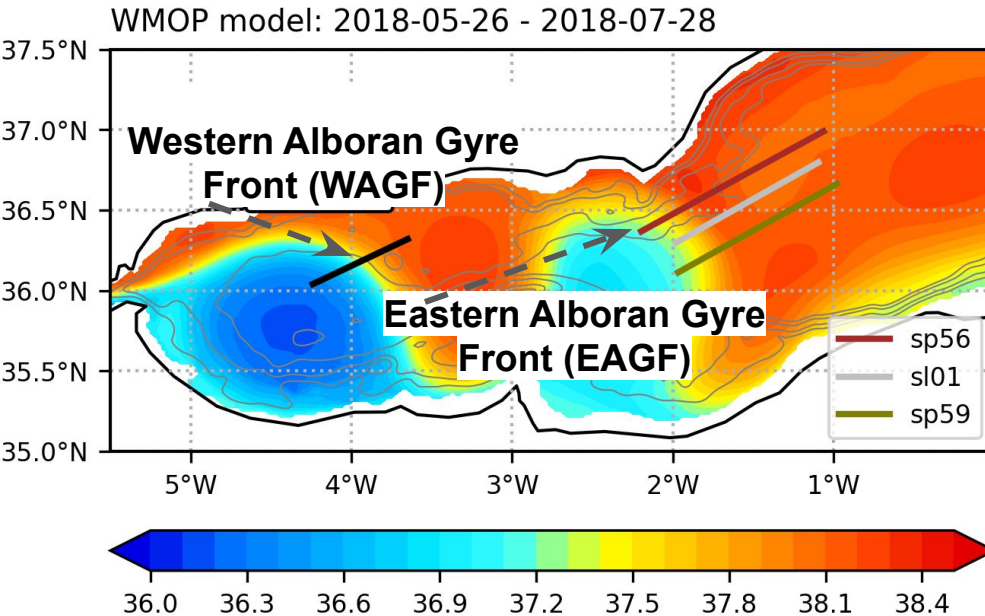


Analysis of Vertical Velocities Development through High-resolution Simulation and Glider Observations in the Alboran Sea



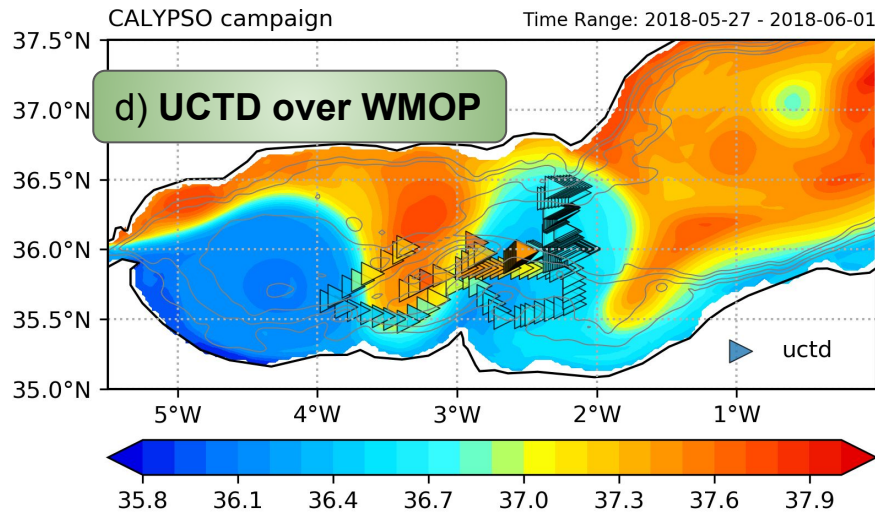
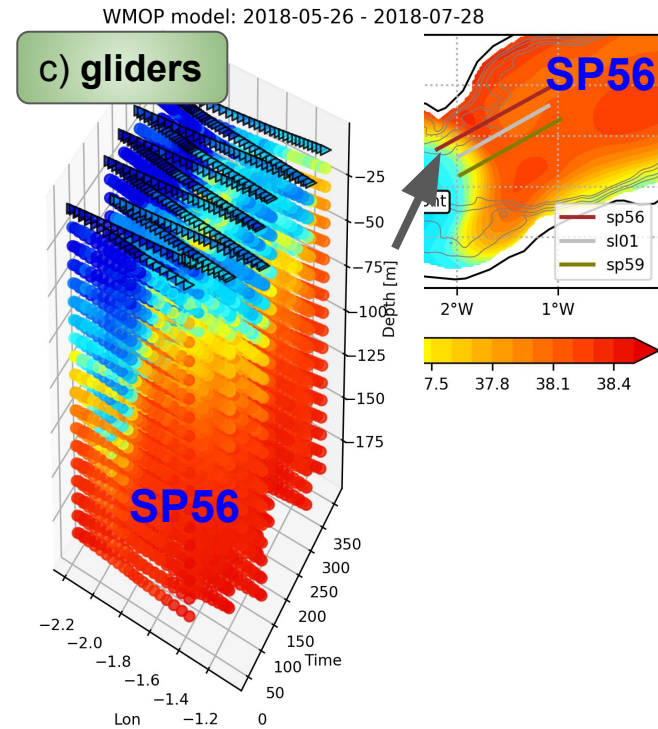
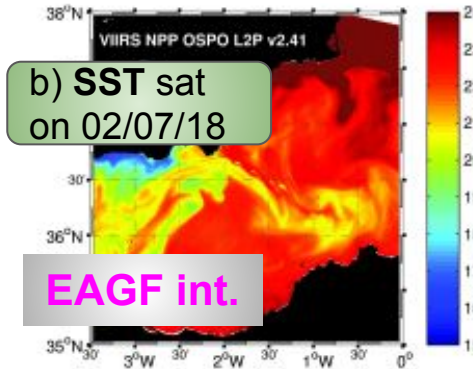
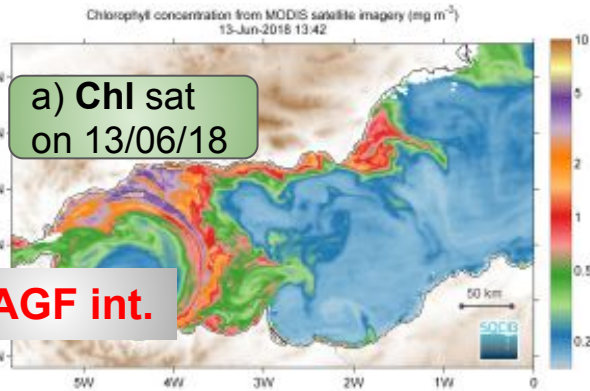
M. Garcia-Jove, B. Mourre,
N. Zarokanellos, P. Lermusiaux,
D. Rudnick, J. Allen, and J. Tintore



Balearic Islands
Coastal Observing
and Forecasting
System

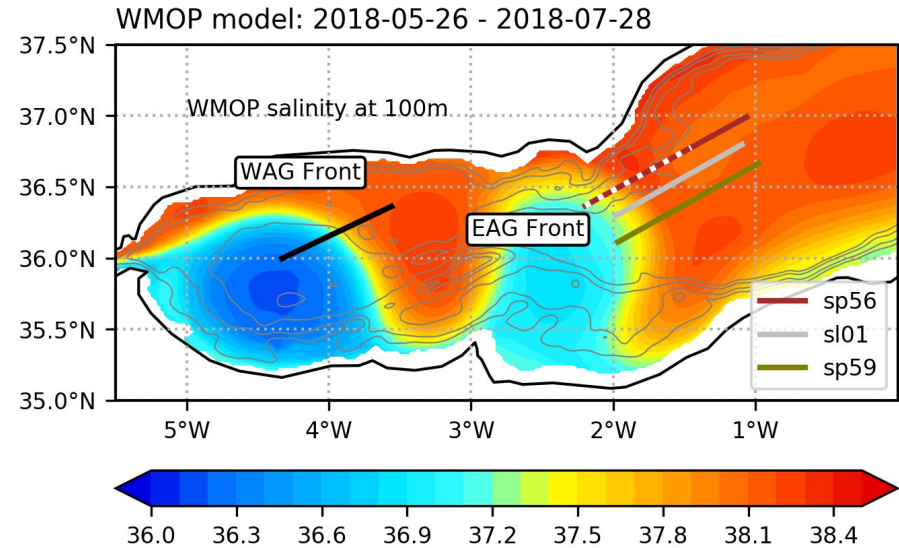


Observation: CALYPSO field campaign in 2018



Strong lateral salinity gradients, cold filament and frontal regions are observed in satellite images, UCTD and glider data.

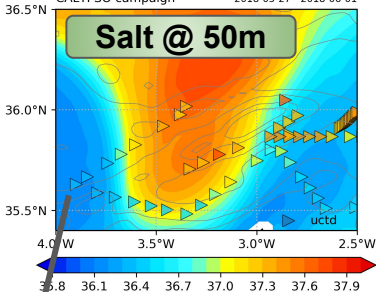
WMOP Simulation



WMOP free-run simulation over 2018 CALYPSO field campaign:

- 2-km horizontal spatial resolution,
- 2-month free-run simulation initialized from **WMOP data-assimilative real-time forecast** on 23 May 2018,
- Surface boundary from the hourly and 5-km spatial resolution HIRLAM atmospheric model (AEMET),
- Boundary condition from the CMEMS Mediterranean model.

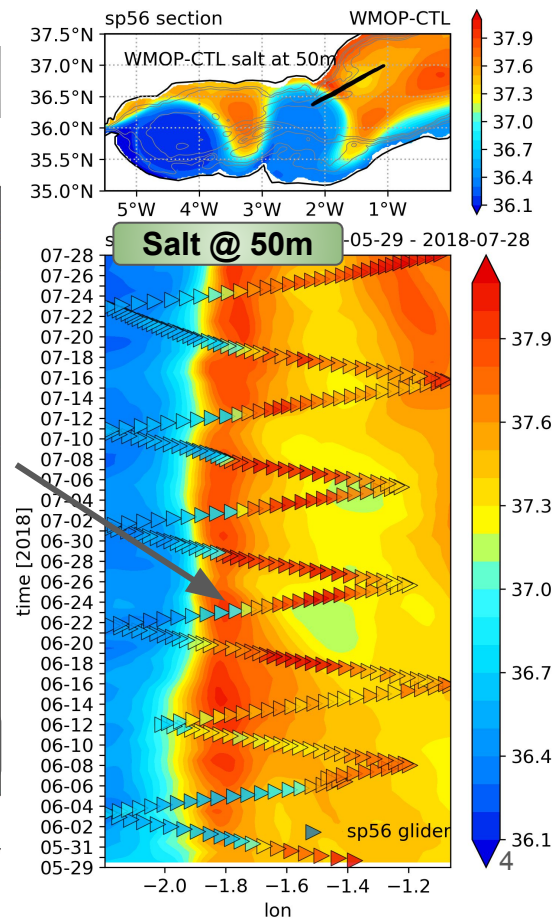
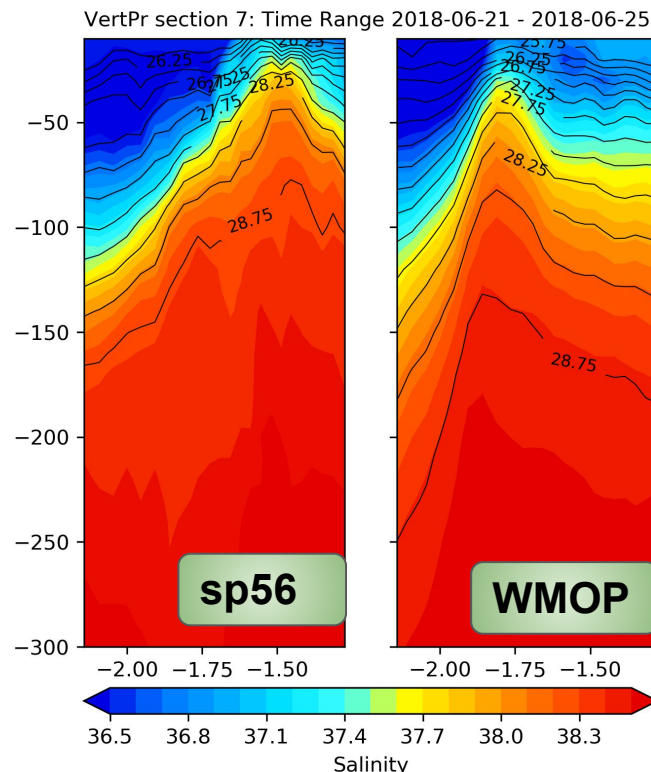
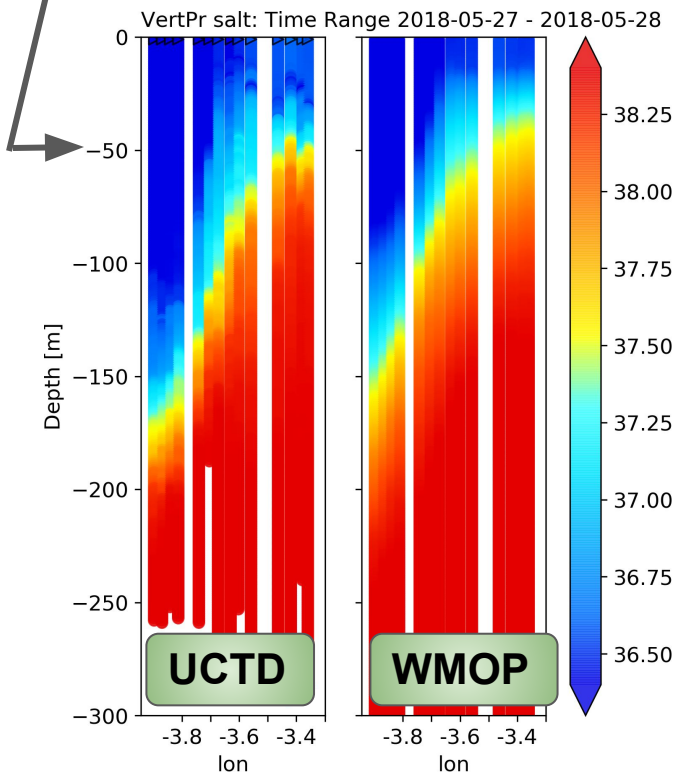
CALYPSO 2018 vs WMOP model



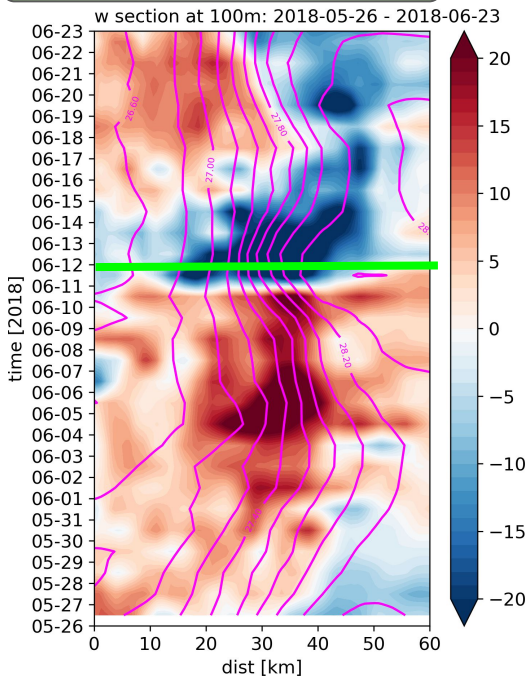
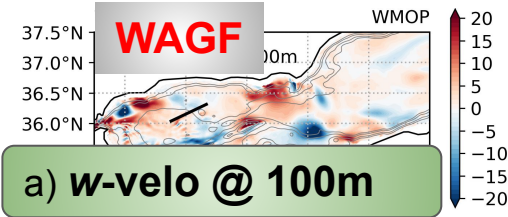
WAGF

Salinity

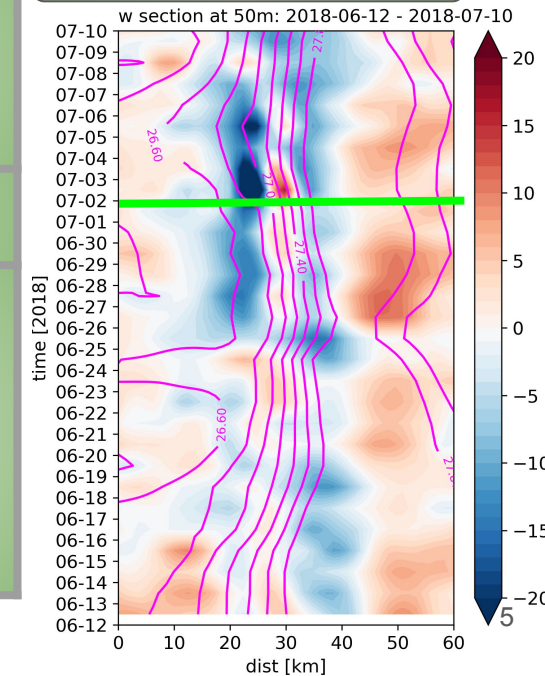
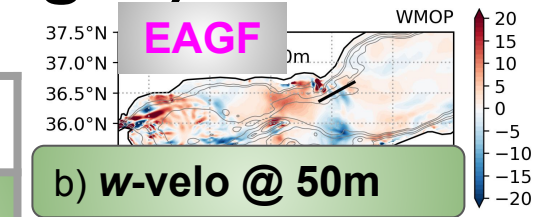
EAGF



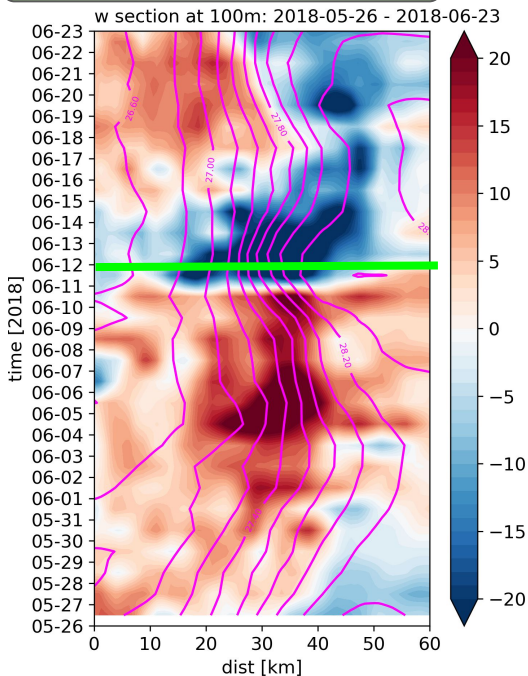
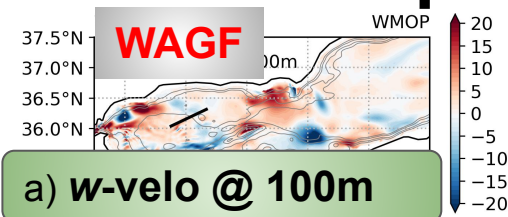
Temporal variability of vertical velocities on WAGF and EAGF (daily averages)



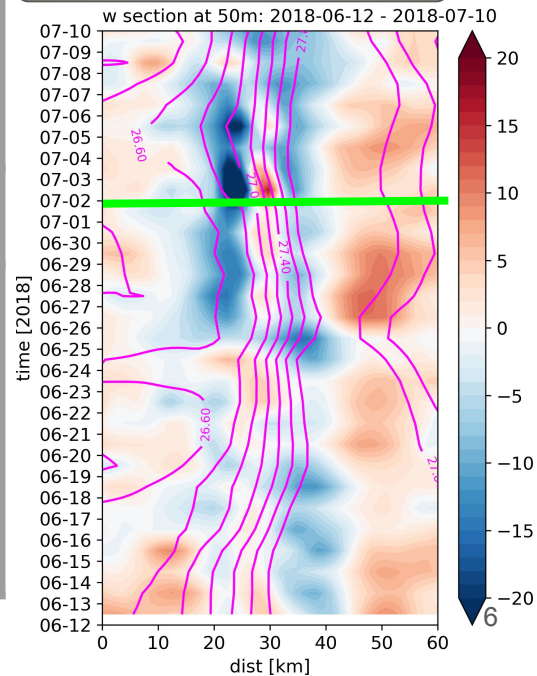
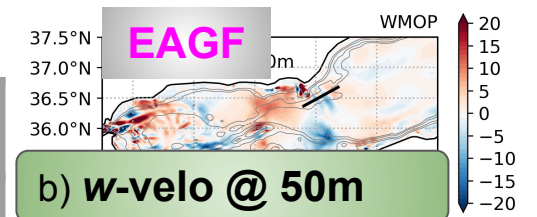
WAGF	EAGF
$L \approx 100 \text{ km},$ $W \approx 50 \text{ km},$ $D \approx 180 \text{ m}$	$L \approx 100 \text{ km},$ $W \approx 20 \text{ km},$ $D \approx 120 \text{ m}$
$T \approx 7 \text{ days}$	$T \approx 4 \text{ days}$
$w_{\text{max}}^+ = +18$ m/day @57 m	$w_{\text{max}}^+ = +15$ m/day @56 m
$w_{\text{max}}^- = -55 \text{ m/day}$ @156 m	$w_{\text{max}}^- = -38 \text{ m/day}$ @41 m



Motivation: Why are vertical velocities development different on WAGF and EAGF?

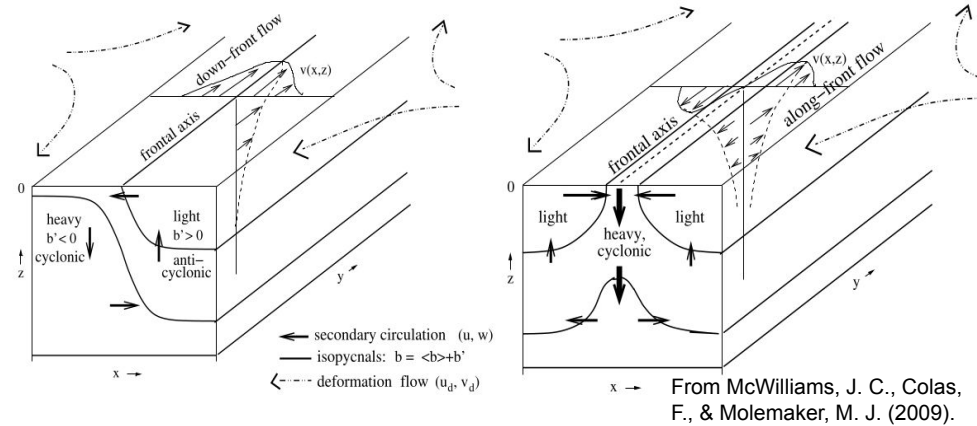


WAGF	EAGF
$L \approx 100$ km, $W \approx 50$ km, $D \approx 180$ m	$L \approx 100$ km, $W \approx 20$ km, $D \approx 120$ m
$T \approx 7$ days	$T \approx 4$ days
$w_{\max}^+ = +18$ m/day @57 m	$w_{\max}^+ = +15$ m/day @56 m
$w_{\max}^- = -55$ m/day @156 m	$w_{\max}^- = -38$ m/day @41 m

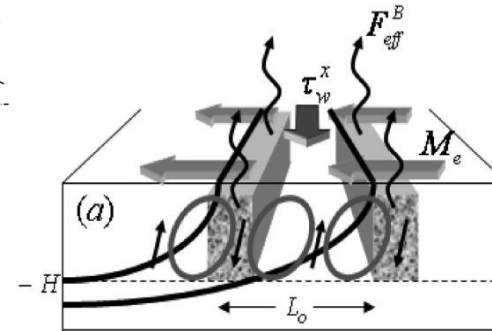


Theoretical Background

Frontogenesis vs Filamentogenesis



Frontogenesis induced by Ekman transport



From Thomas, L. N., & Lee, C. M. (2005).

Nonlinear Ekman transport

$$\mathcal{M}_{\mathbf{E}} = -\frac{\mathbf{k} \times \tau^h}{\rho_0(f + \xi)}$$

Ekman pumping velocity

$$\mathcal{W}_E = \frac{1}{\rho_0} \nabla_h \cdot \mathcal{M}_{\mathbf{E}}$$

Vertical velocities are developed by:

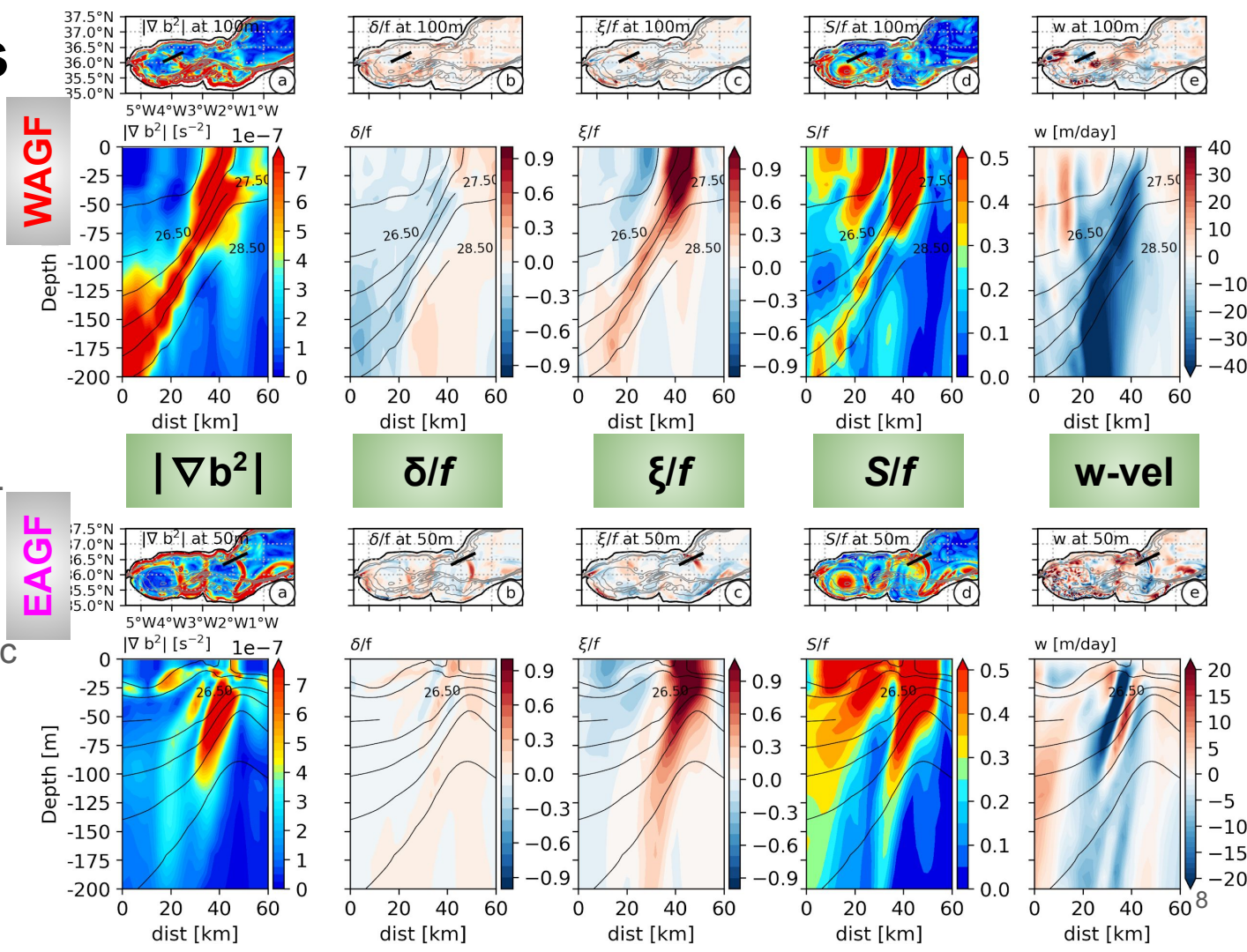
- Frontogenesis mechanism,
- Ekman pumping front winds,
- Instabilities processes,
- Front intensification by cold filament.

Frontogenesis mechanism

WAGF more intense than **EAGF**: Intense buoyancy gradient $\Rightarrow$ large convergence, horizontal strain, and cyclonic vorticity.

Vertical velocities cell:

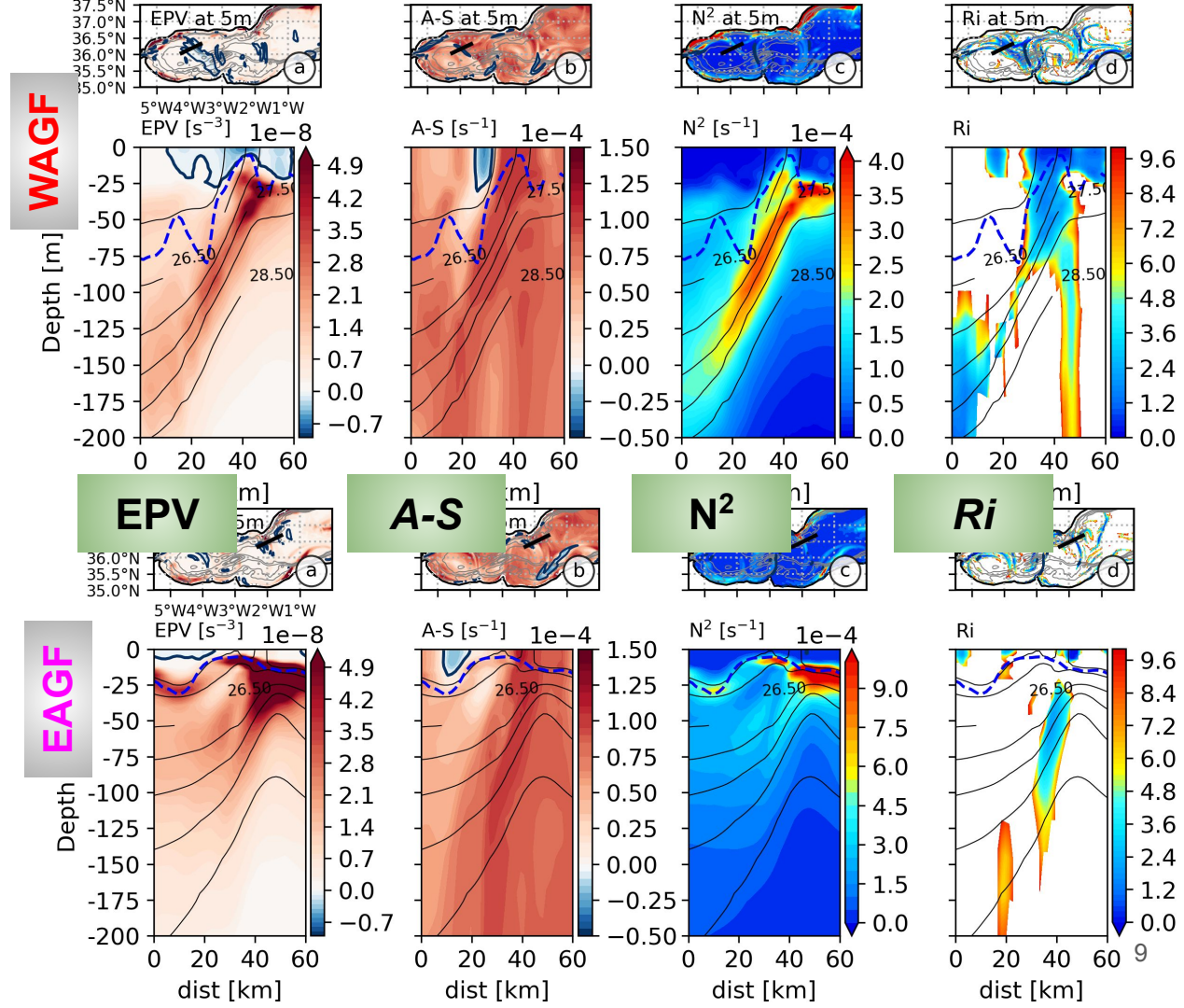
- **WAGF** $\Rightarrow$ ageostrophic secondary circulation,
- **EAGF** $\Rightarrow$ complex structure.



Instabilities processes

WAGF stronger and deeper signal of instabilities processes and ML deeper than **EAGF**:

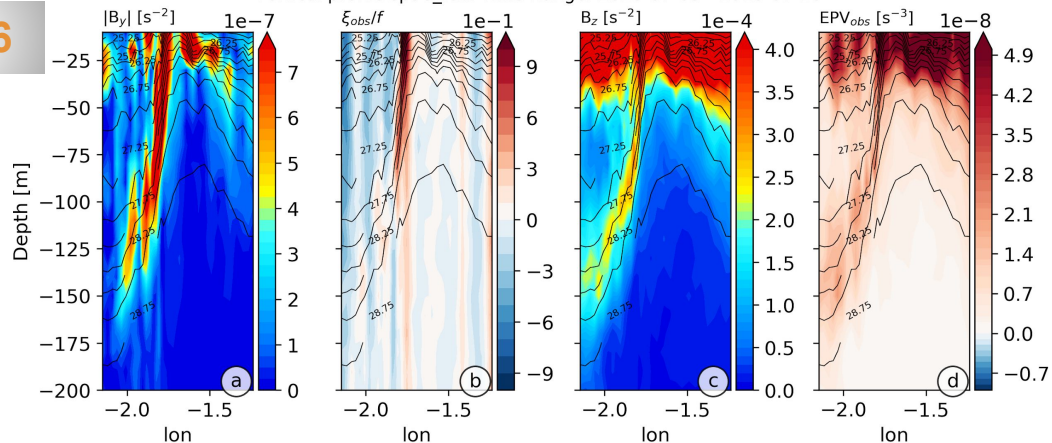
- **WAGF**: Ri small and instabilities processes until 30 m ($EPV < 0$),
- Symmetric instability ($0 < Ri < 1$),
- Unbalanced ageostrophic instability ($A-S < 0$),
- No evidence of gravitational instabilities ($N^2 > 0$),
- **EAGF** shallow ML and increased stratification.



Frontogenesis & Instabilities processes in the Gliders

Vertical profile sp56_raw Time Range: 2018-07-05 - 2018-07-10

SP56



$|\nabla b^2|$

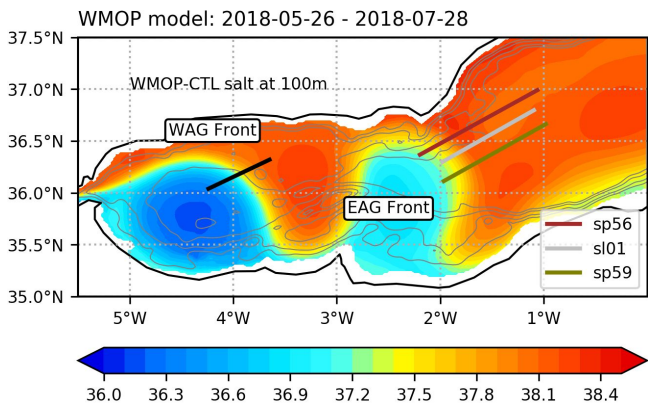
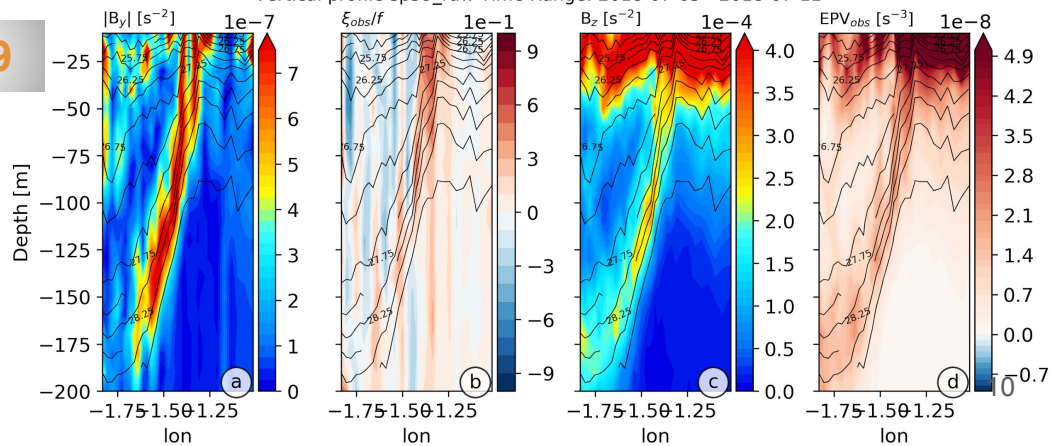
ξ/f

N^2

EPV

Vertical profile sp59_raw Time Range: 2018-07-05 - 2018-07-11

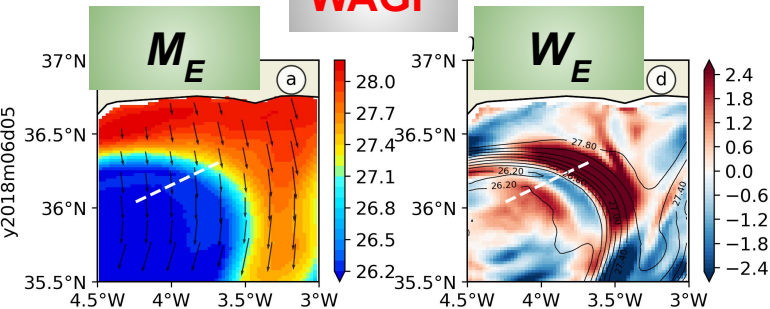
SP59



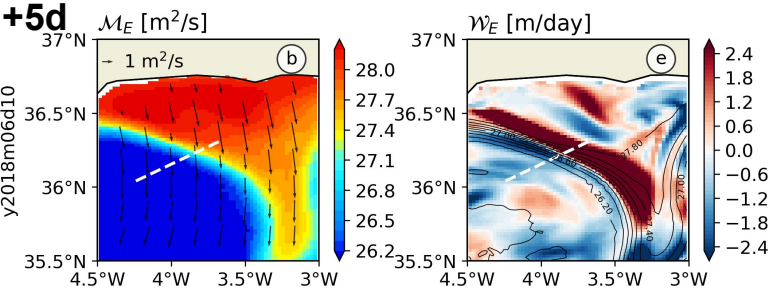
- **EAGF**'s intensification period (according to **WMOP**)
- Increase of frontogenesis diagnostic values up to 100 m
- No evidence of instabilities due to the strong summer stratification.

Nonlinear Ekman transport & pumping velocity at different days

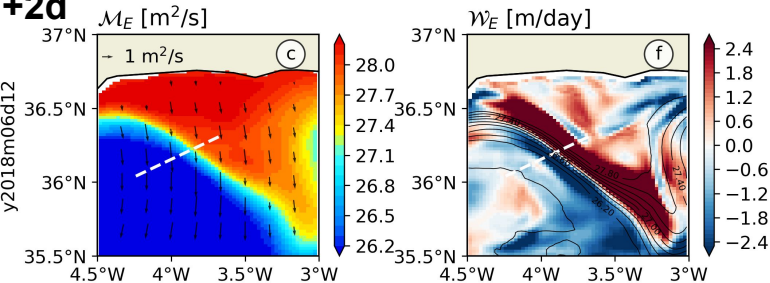
WAGF



+5d



+2d

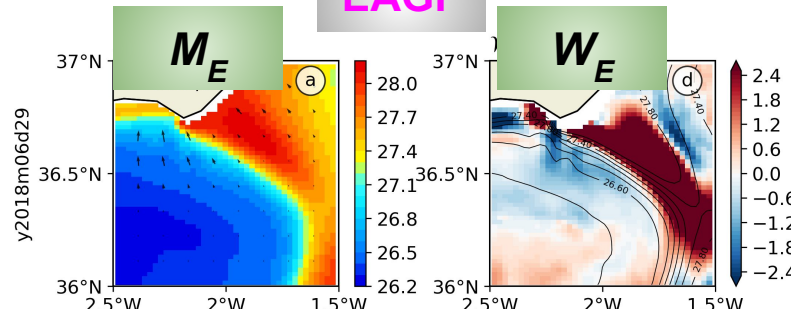


WAGF:
down-front
winds $\Rightarrow$
destruction of
EPV and
stratification.

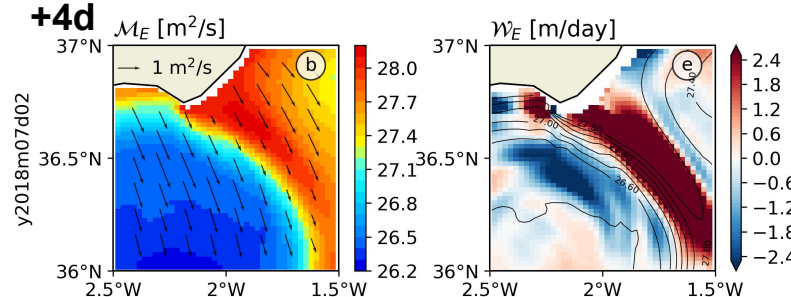
Ekman
transport: water
from the dense
side over the
light side

EAGF:
intermittent
winds regime

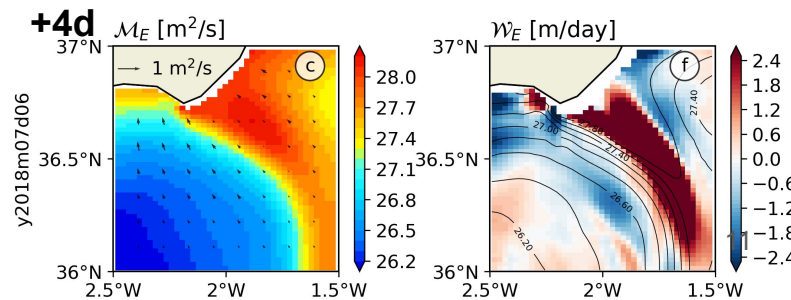
EAGF



+4d

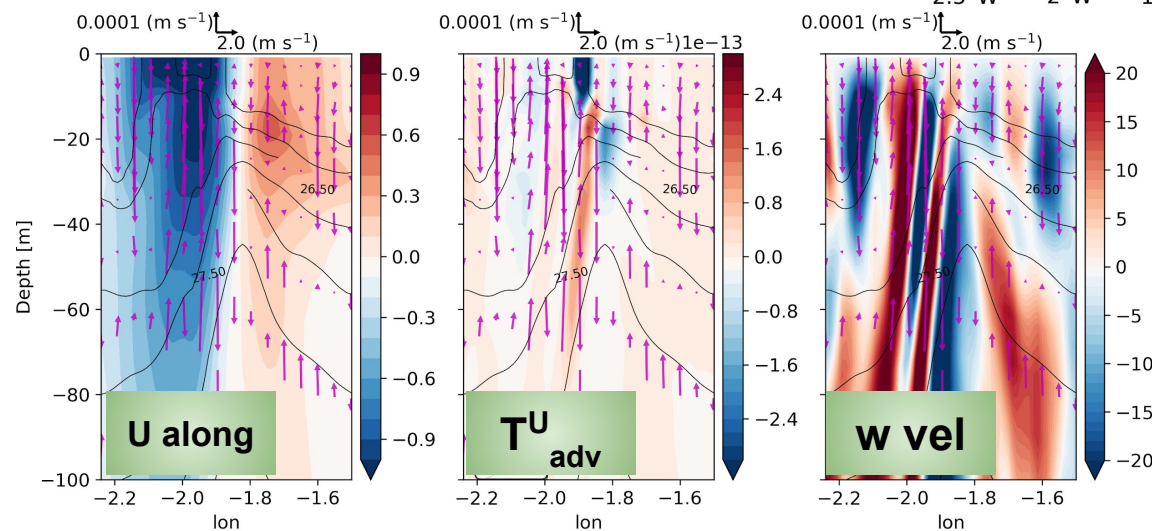
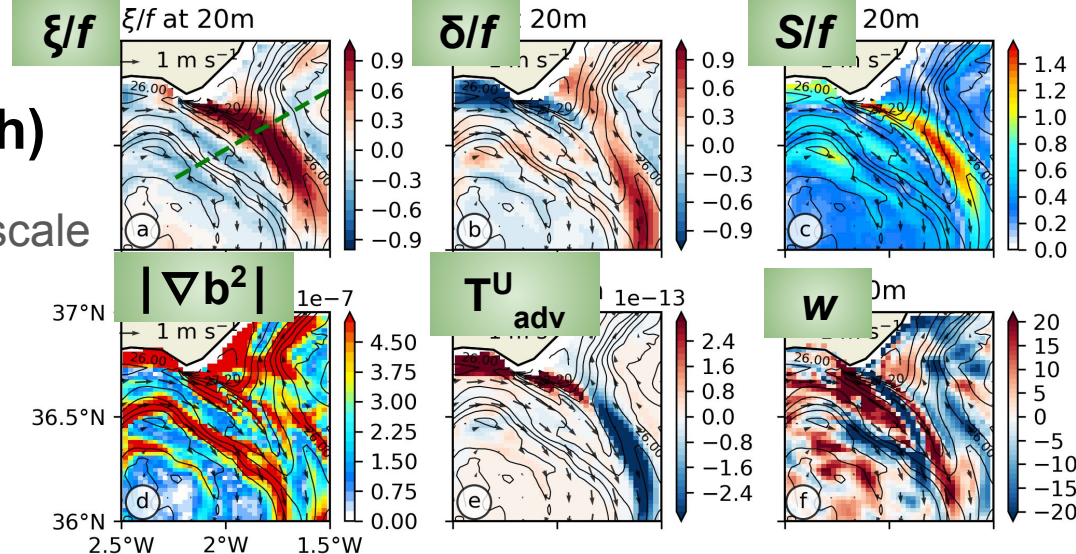


+4d



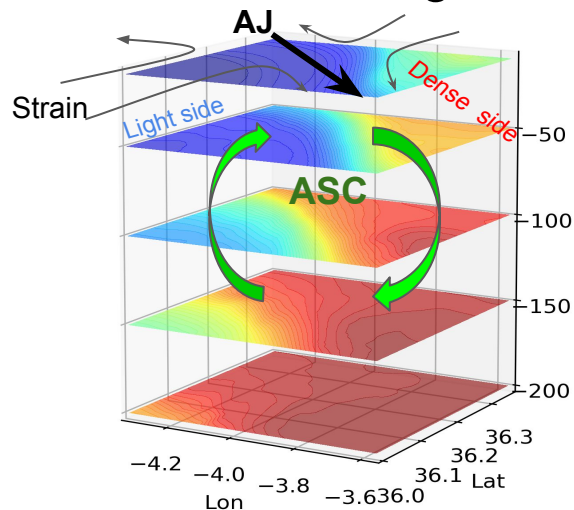
Filamentogenesis process in **EAGF** snapshot (18/07/02-06h)

- **EAGF** intensification by a cold mesoscale filament & coherent submesoscale structures.
- Advective frontal tendency term ($T^U_{adv} > 0$) $\Rightarrow$ filamentogenesis.

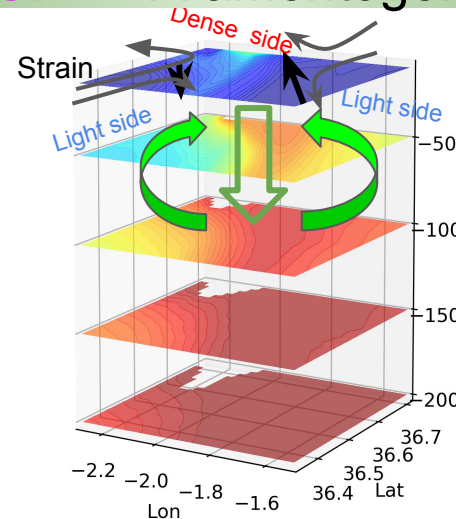


- Along front velocity contour $\rightarrow$ two regions centered in the filament.
- $T^U_{adv} > 0$ at pointy isopycnals.
- W -velocities: ageostrophic secondary circulation $\rightarrow$ 2 re-circulation cells.

WAGF → Frontogenesis



EAGF → Filamentogenesis



Deeper, longer, and stronger front → intense frontogenesis

Weaker stratification, deeper ML → instabilities processes

Down-front winds → Ekman transport → pumping velocities

Horizontal strain and convergence flow mechanisms → high cyclonic vorticity → single cell ageostrophic secondary circulation

Shallower, shorter, and weaker front → weak frontogenesis

Stronger stratification, shallower ML → weak instabilities processes

Intermittent winds → no destruction stratification & EPV → weak pumping velocities

Cold filament mechanisms → advective frontal tendency term → 2 cells ageostrophic secondary circulation

Thanks and Questions?

 https://socib.es/?seccion=modelling&facility=calypso_assim

<https://calypsodri.who.edu/projects>

@ mgarciajove@socib.es

References

1. McWilliams, J. C., Colas, F., & Molemaker, M. J. (2009). Cold filamentary intensification and oceanic surface convergence lines. *Geophysical Research Letters*, 36(18), L18602. <https://doi.org/10.1029/2009GL039402>.
2. Thomas, L. N., & Lee, C. M. (2005). Intensification of ocean fronts by down-front winds. *Journal of Physical Oceanography*, 35(6), 1086–1102. <https://doi.org/10.1175/JPO2737.1>.
3. Mahadevan, A., & Tandon, A. (2006). An analysis of mechanisms for submesoscale vertical motion at ocean fronts. *Ocean Modelling*, 14(3–4), 241–256. <https://doi.org/10.1016/j.ocemod.2006.05.006>.