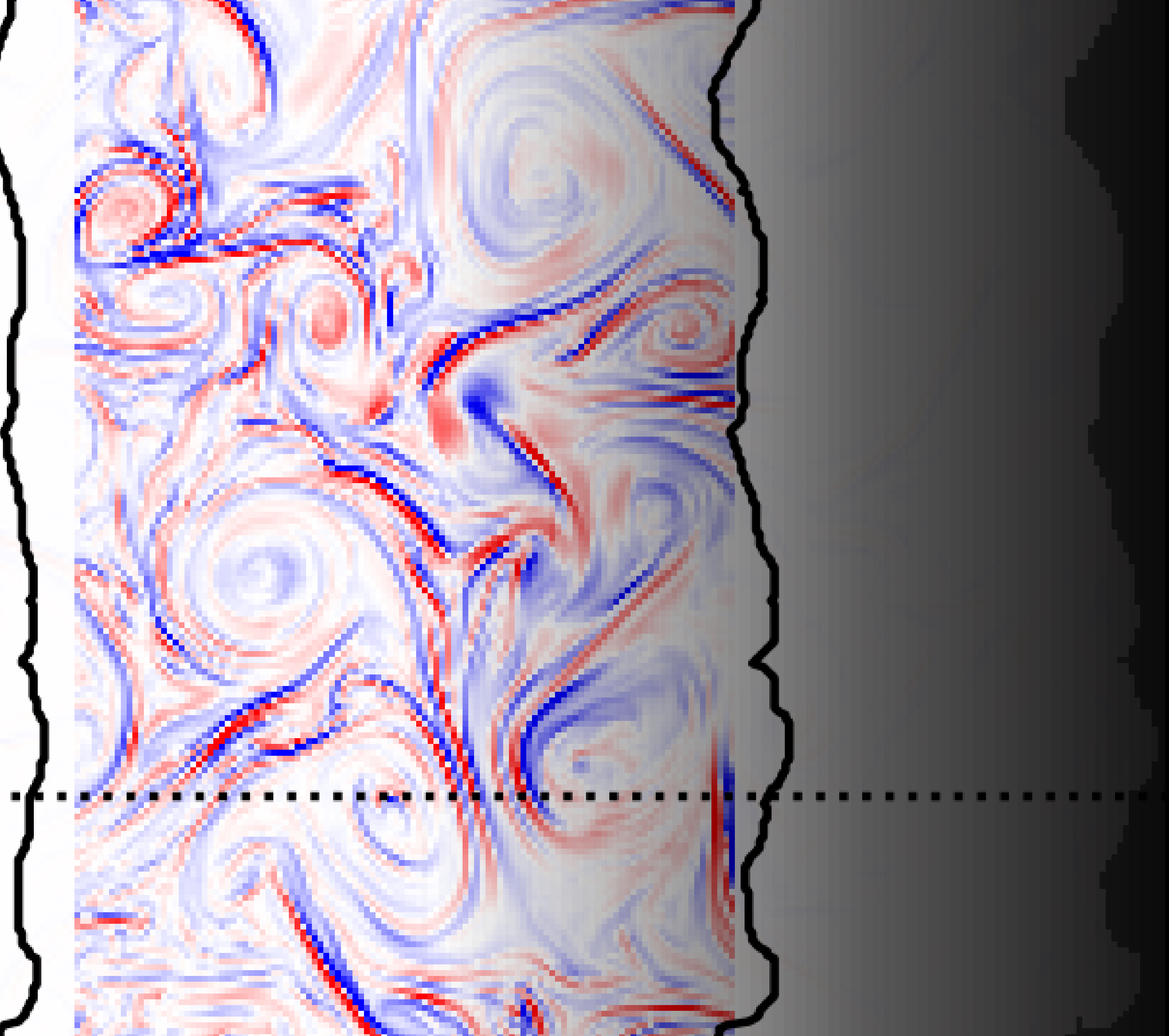
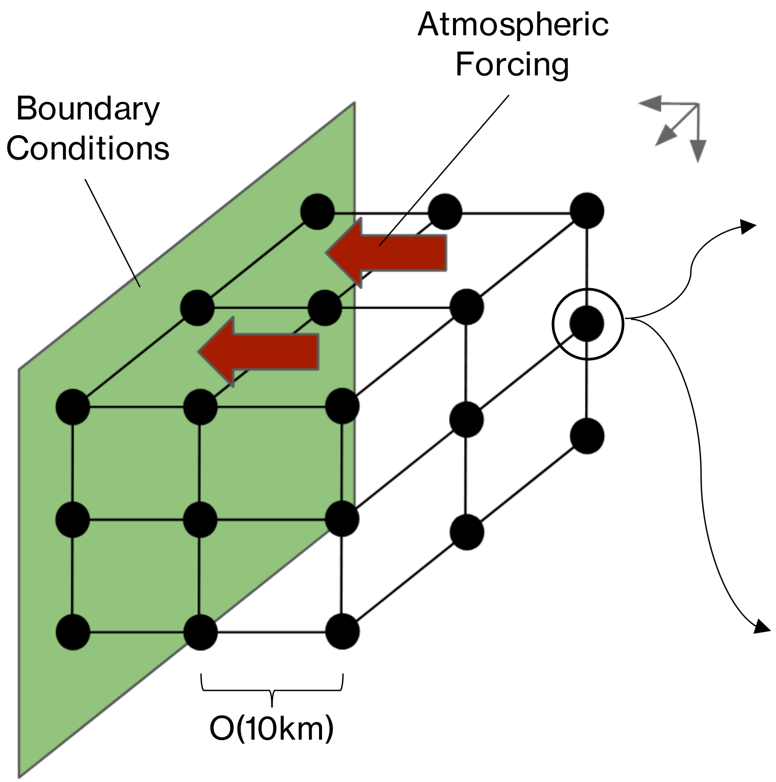


On the Impact of Submesoscale Fronts on Mesoscale Eddies and Biological Productivity in the California Current System

Masterthesis by Max Simon
at *Environmental Physics Group, ETH Zurich*

Computational Model Approach



Physics: Primitive Equations, Equation of State for u, p, S, T, ρ using ROMS

Biology: Biogeo-chemical tracers (e.g. NO3) and dynamics (NPP, carbon sinking) using ROMS-BEC (coupled to physics)

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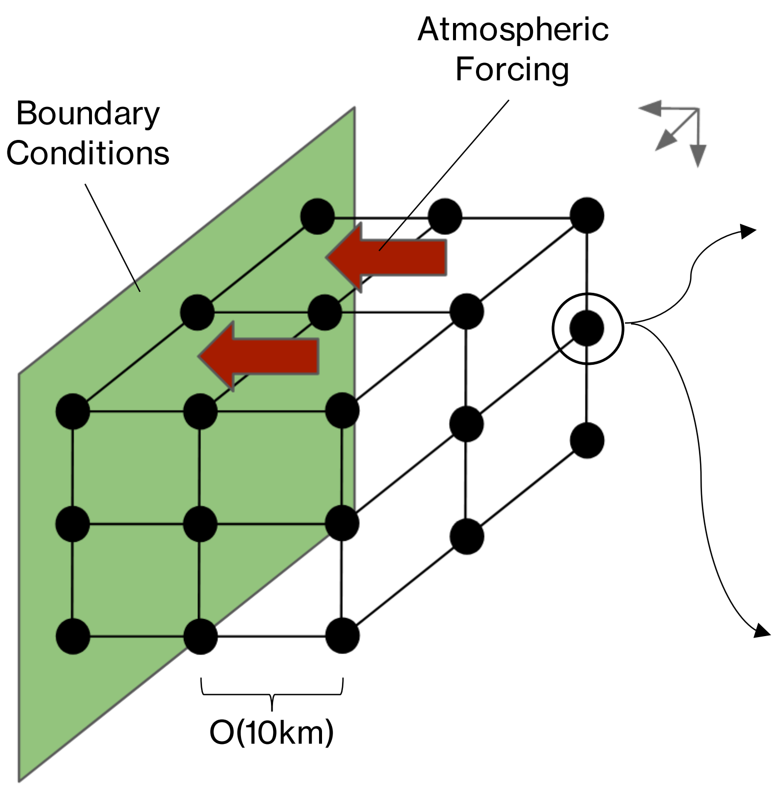

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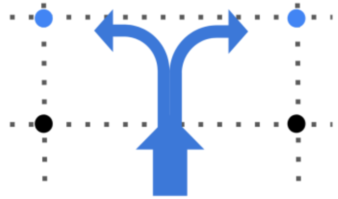
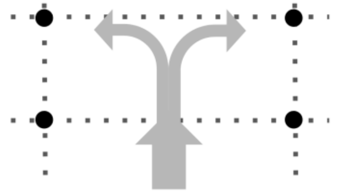
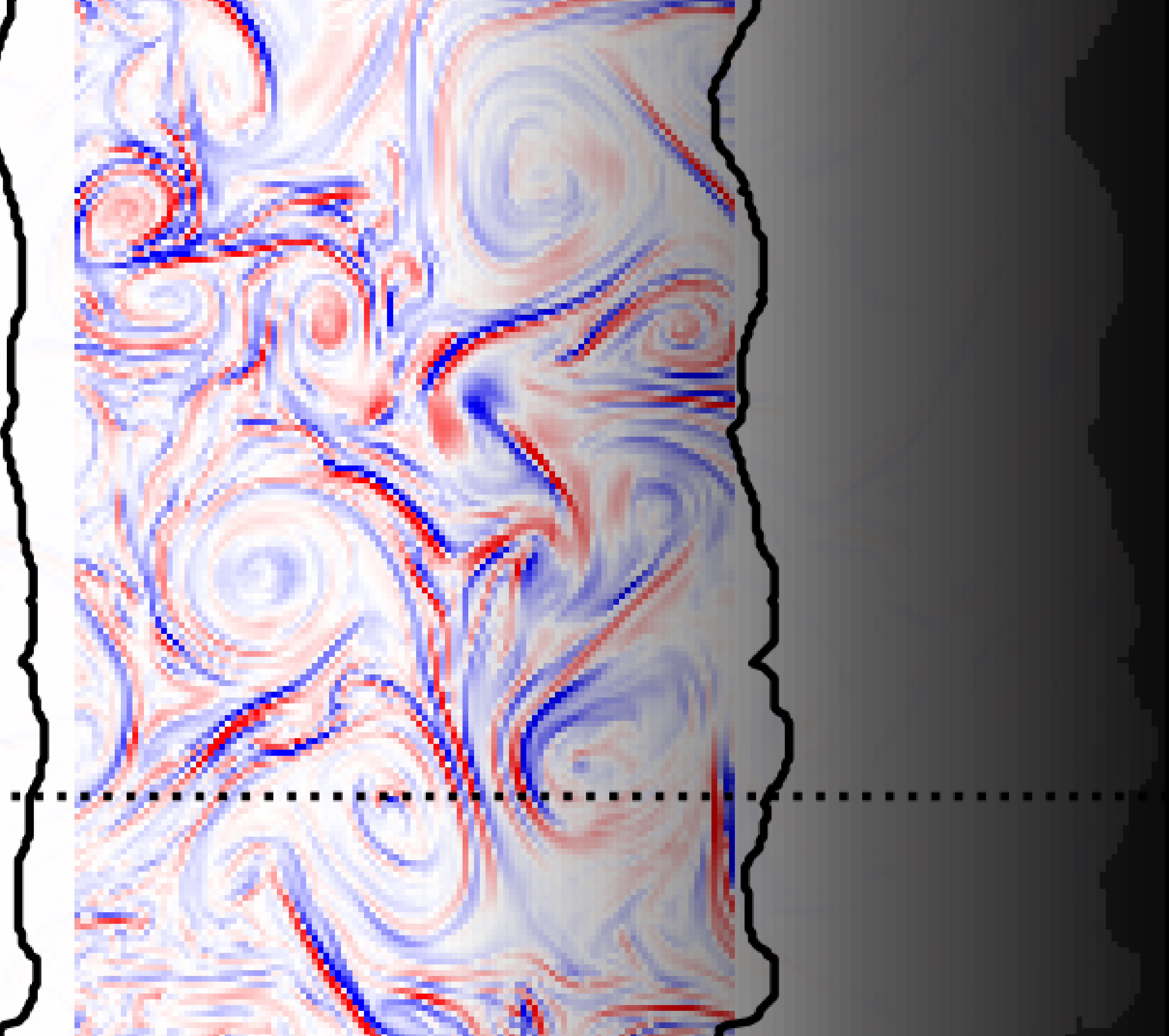
Discretization



Observations: all processes contribute to observations



Model: only resolved processes can contribute



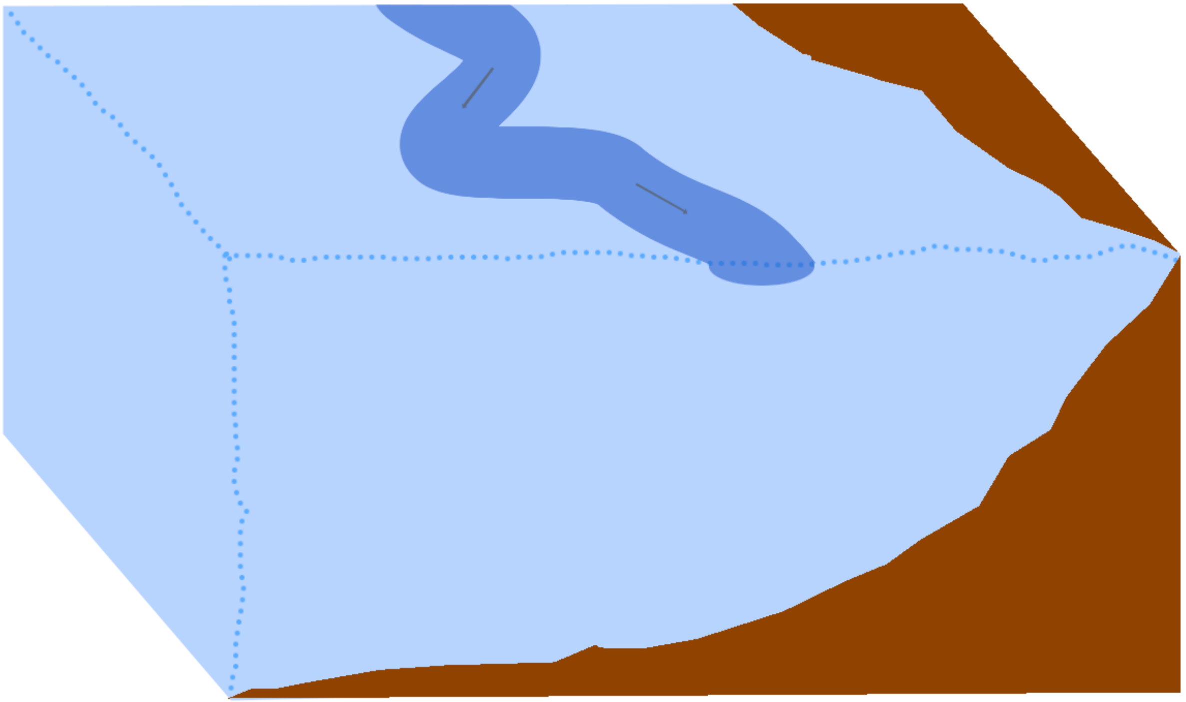
What is the difference between a model that resolves submeso-scale fronts and a model that does not?

Structure

1. Domain & Model Data
2. Submesoscale Fronts
3. Impact on Mesoscale Eddies
4. Biological Productivity
5. Summary

Domain & Model Data

Domain: Eastern Boundary Upwelling System



(based on Nagai et al., 2015)

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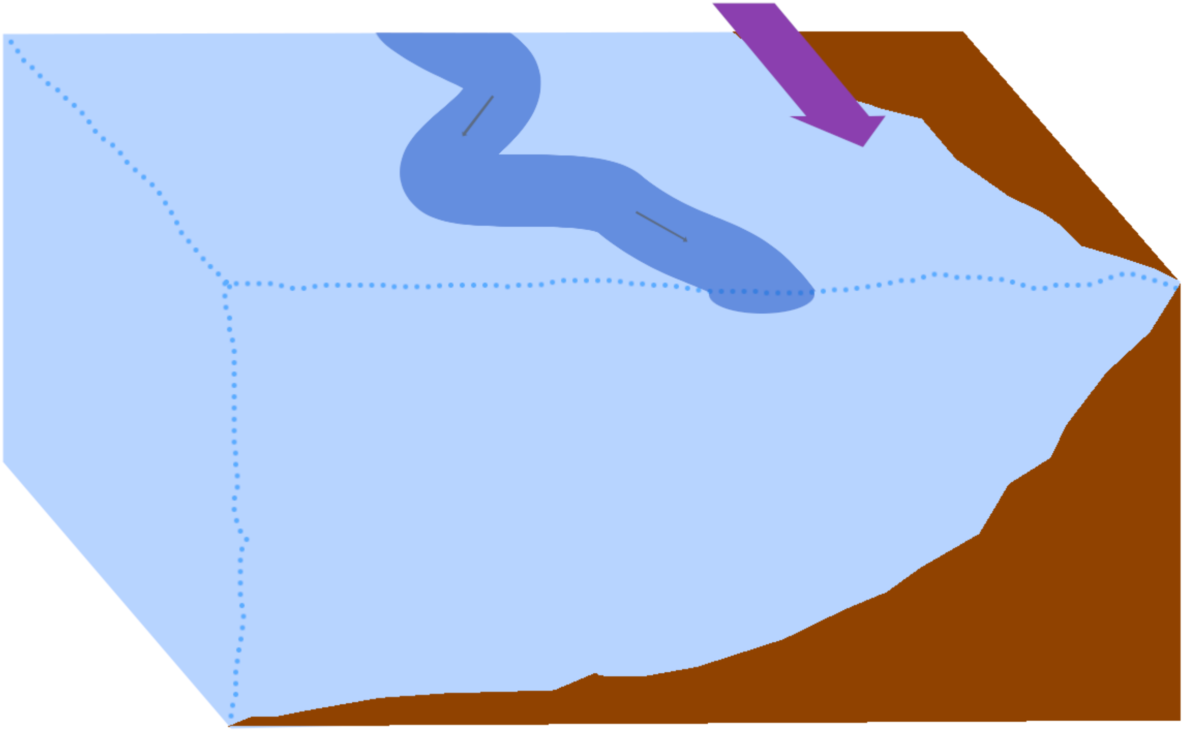

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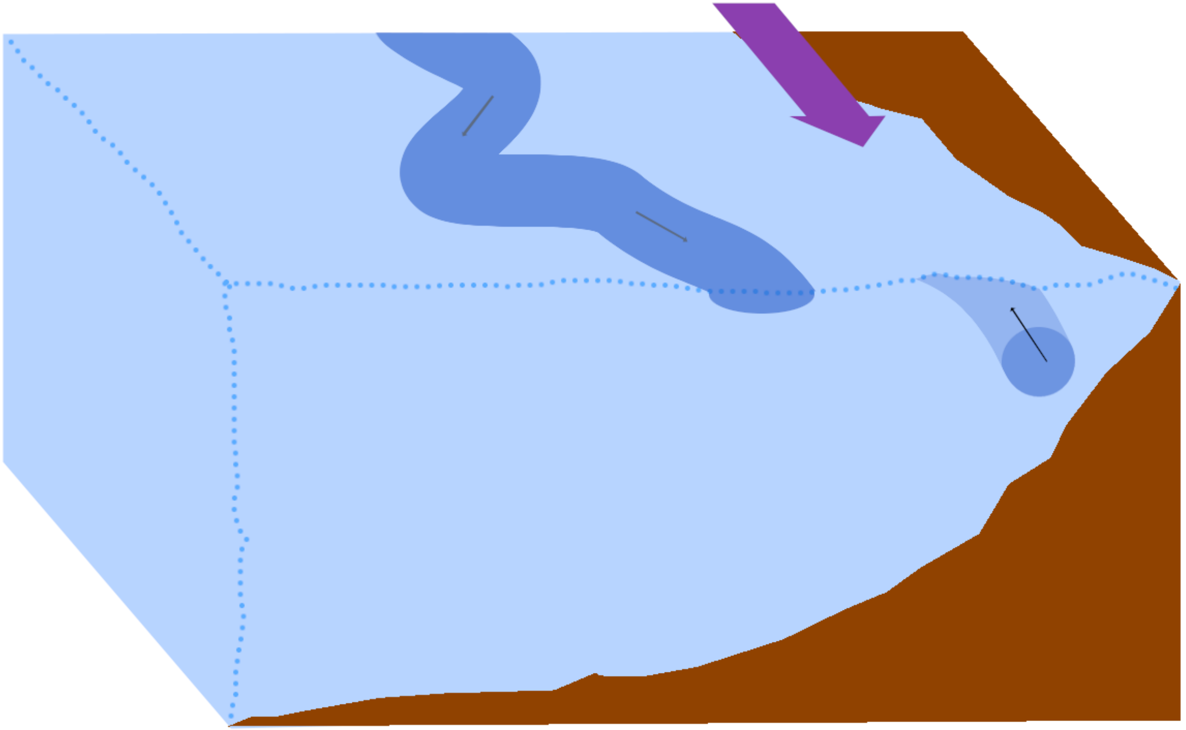

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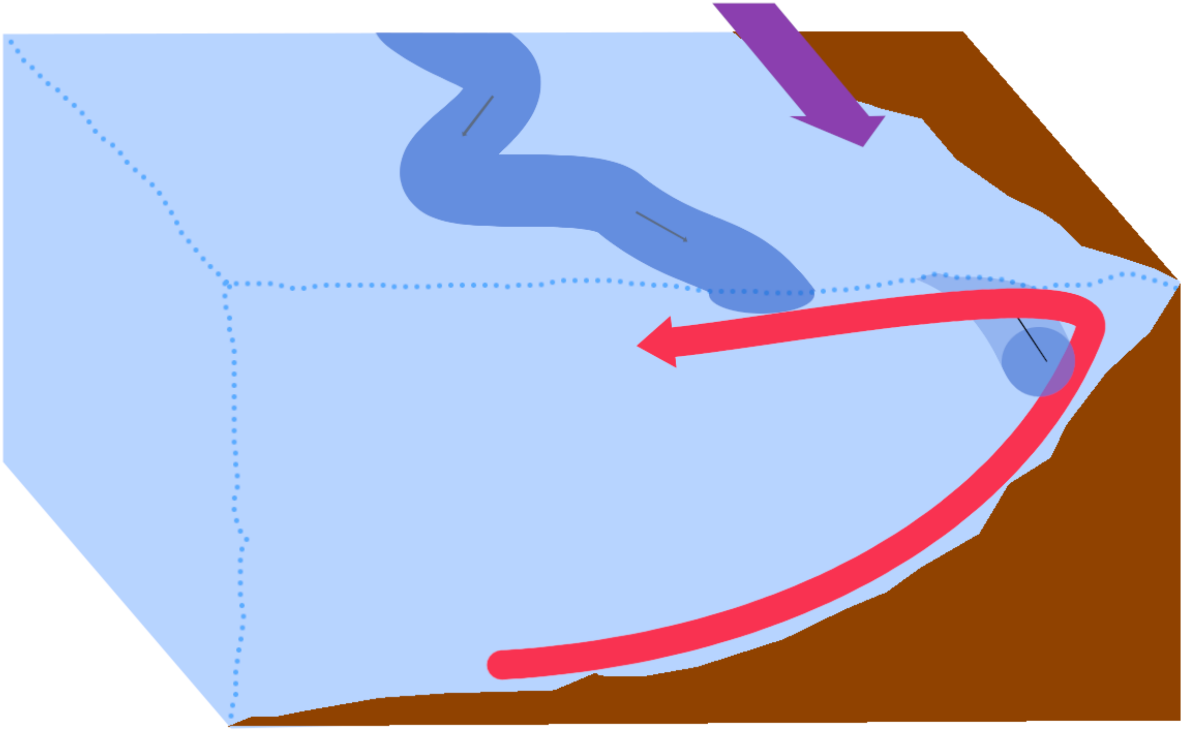

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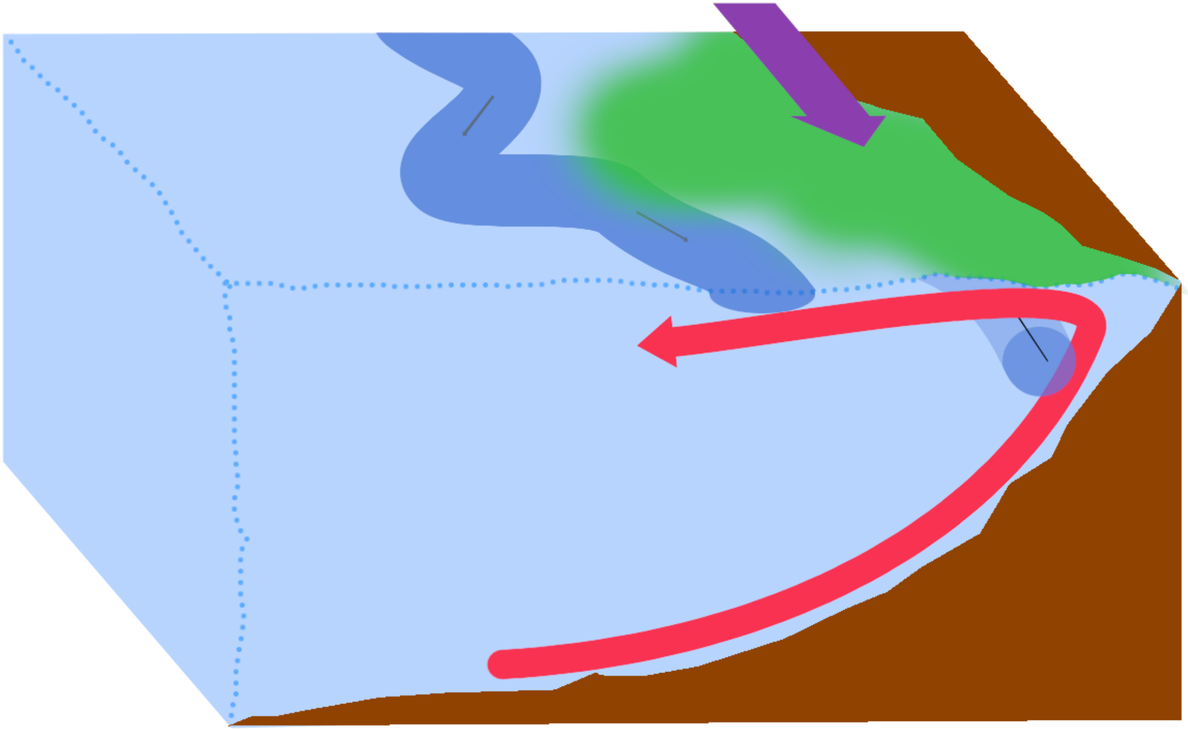

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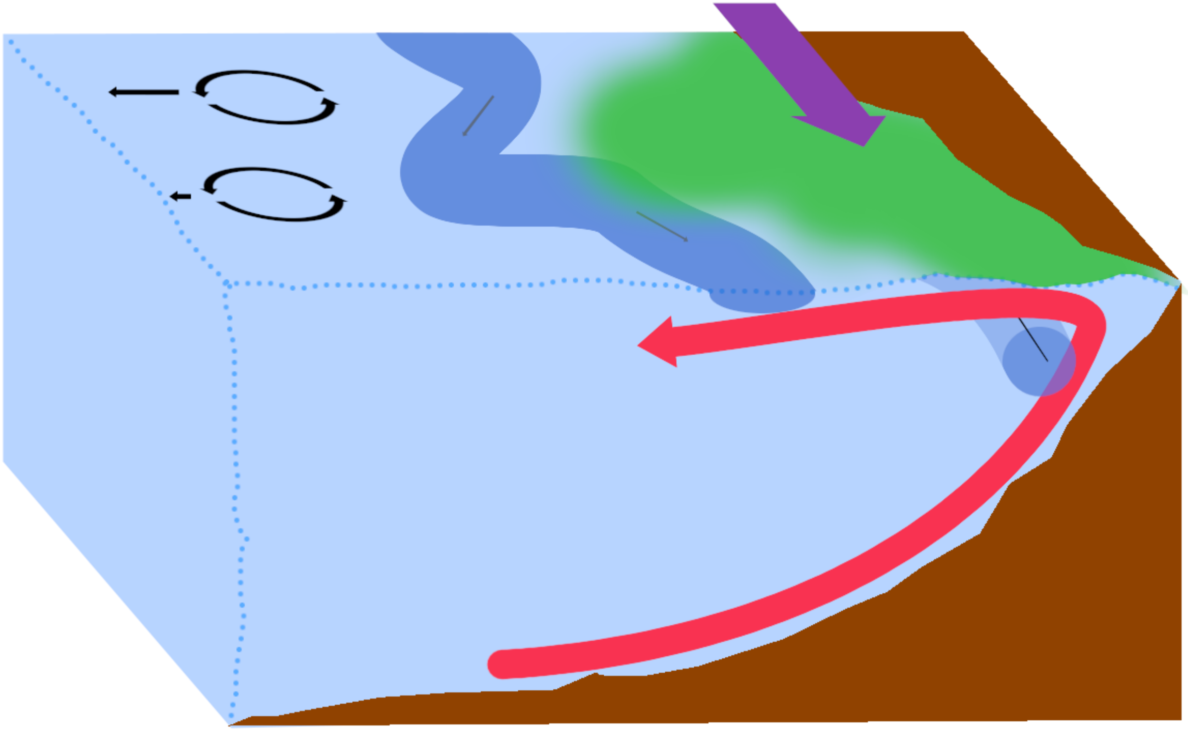

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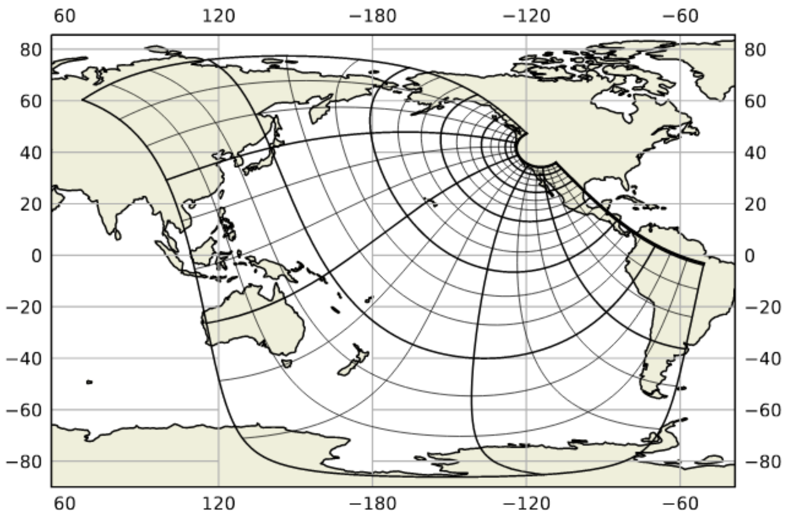
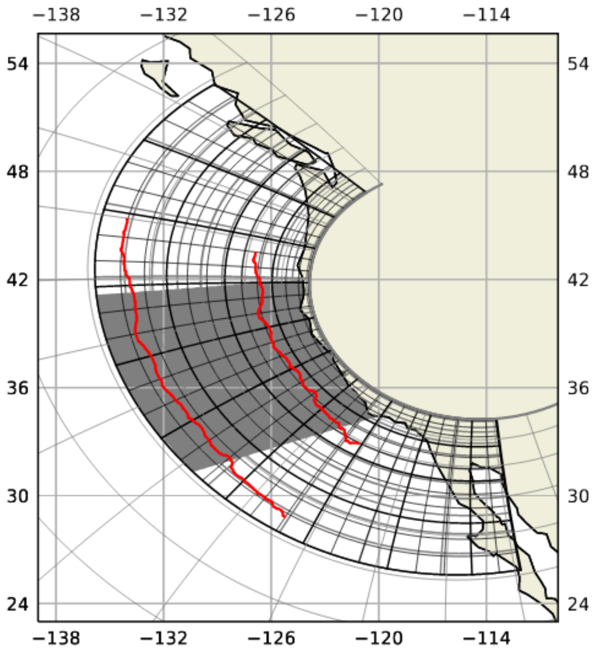
Model data

Mid resolution (7.0 km)
pactcs30



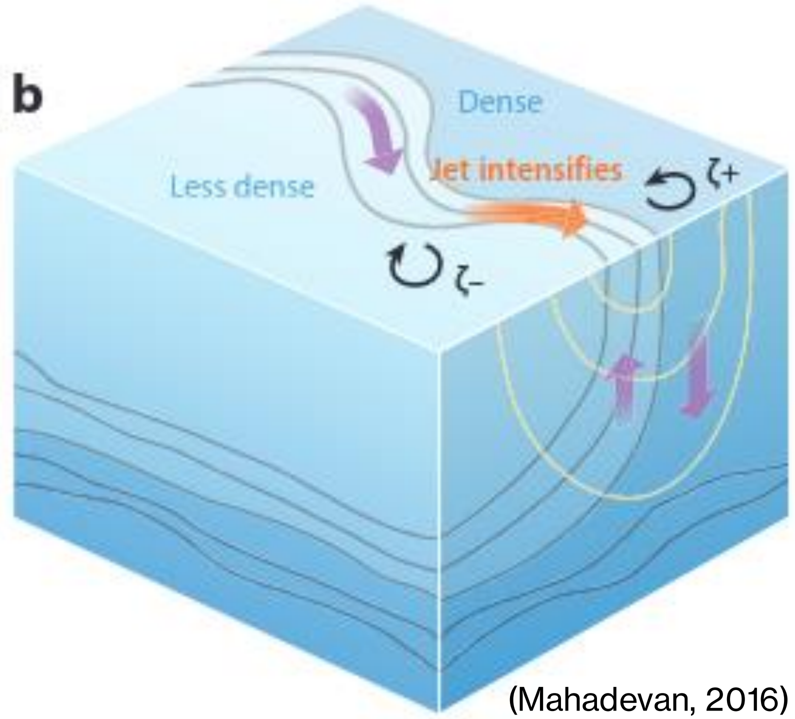
High resolution (2.8 km)
uswtcs



- climatological forcing (normal year, ERA5)
- MR integrated on full domain, used as boundary condition for HR
- five years integration time, last three years used for analysis
- data saved as bidaily averages

Submesoscale Fronts

Submesoscale Fronts: Frontogenesis



(Mahadevan, 2016)

- emerge at horizontal density fronts, driven by mesoscale eddy strain or atmospheric forcing

(Thomas et al., 2008; Mahadevan, 2016)

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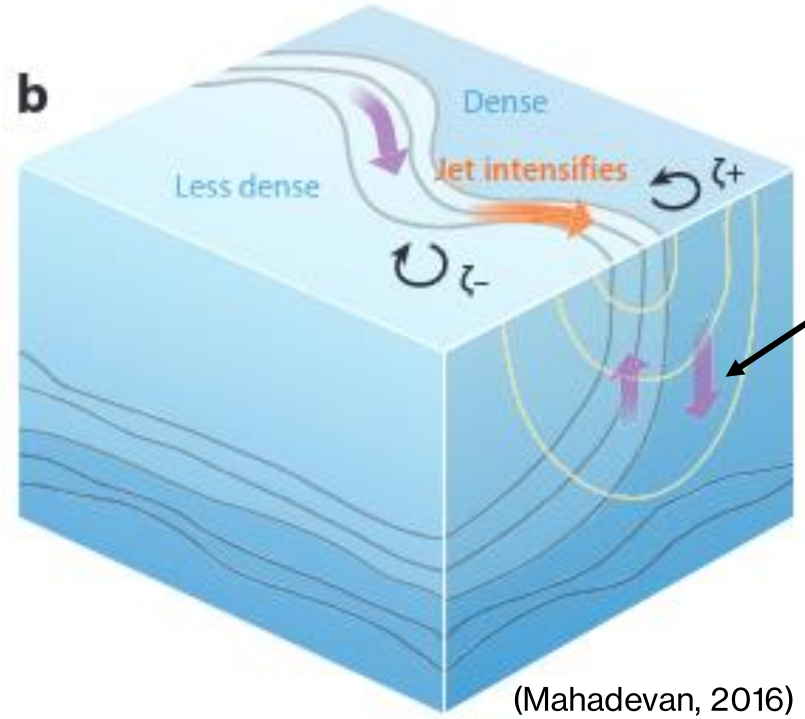

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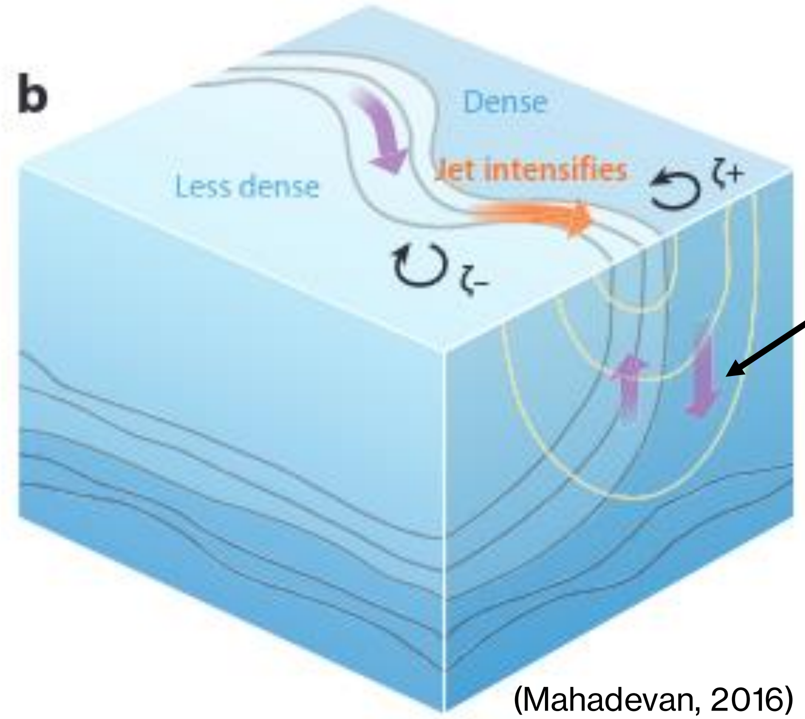

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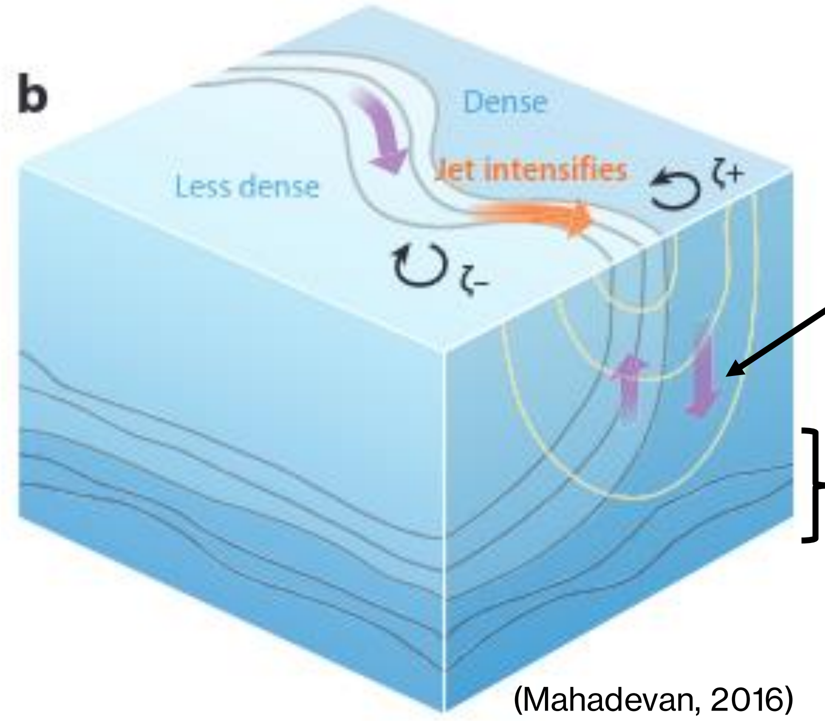

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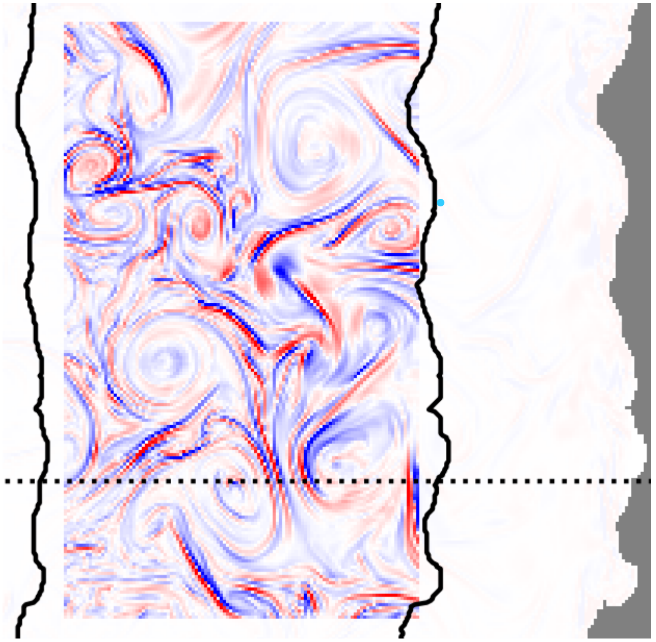
- ageostrophic secondary circulation to restore geostrophic balance of jet
- upwelling at less dense side, downwelling at dense side ($\mathcal{O}$(m/day))
- modulated by mixed layer depth

(Thomas et al., 2008; Mahadevan, 2016)

Submesoscale Fronts: Characteristics

Vertical velocity field at 25m depth



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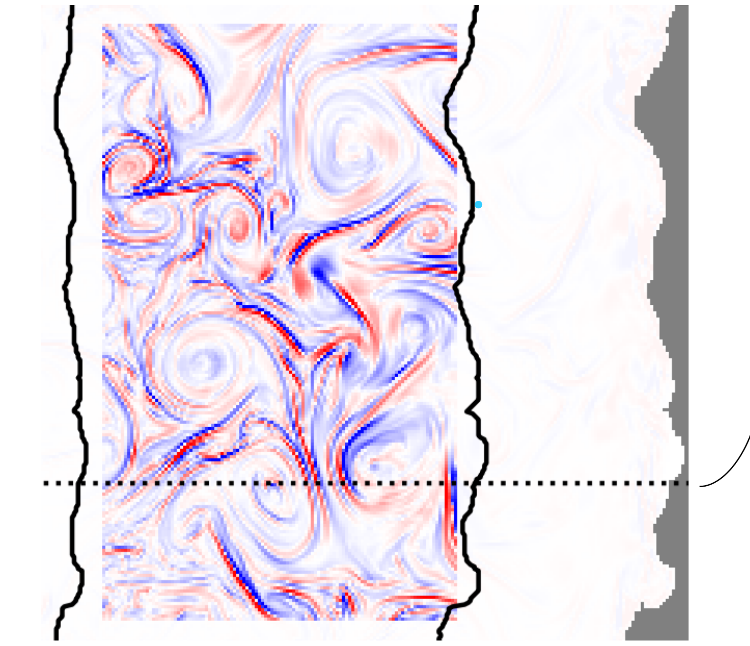
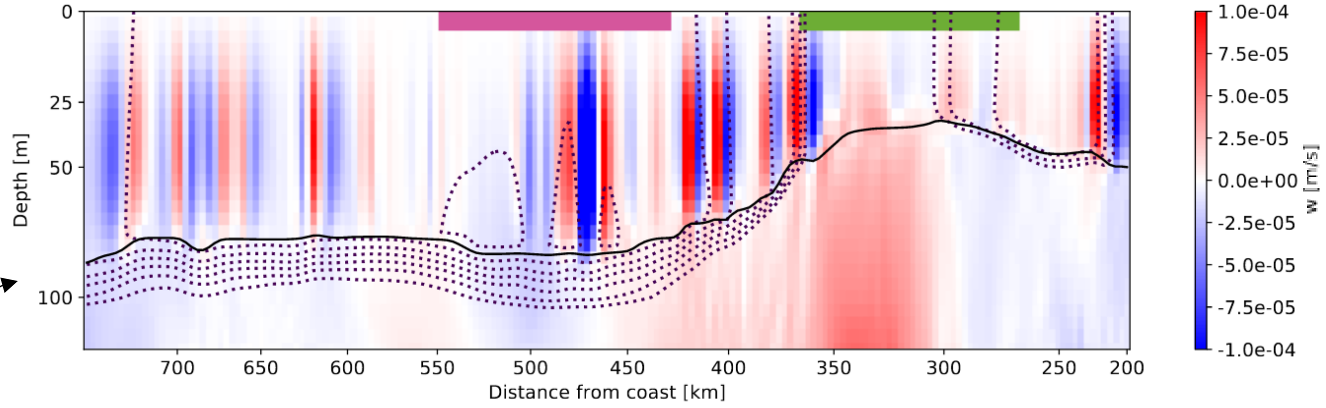


Vertical velocity field as vertical section



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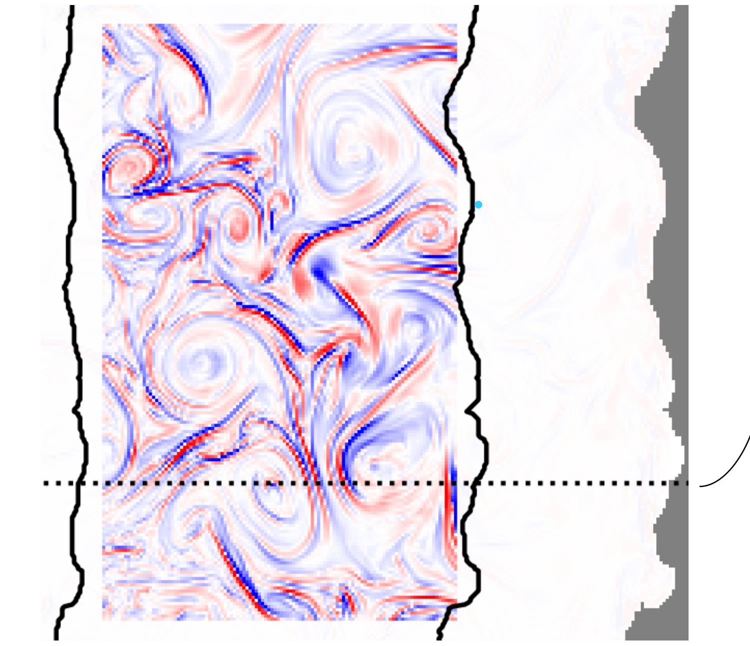

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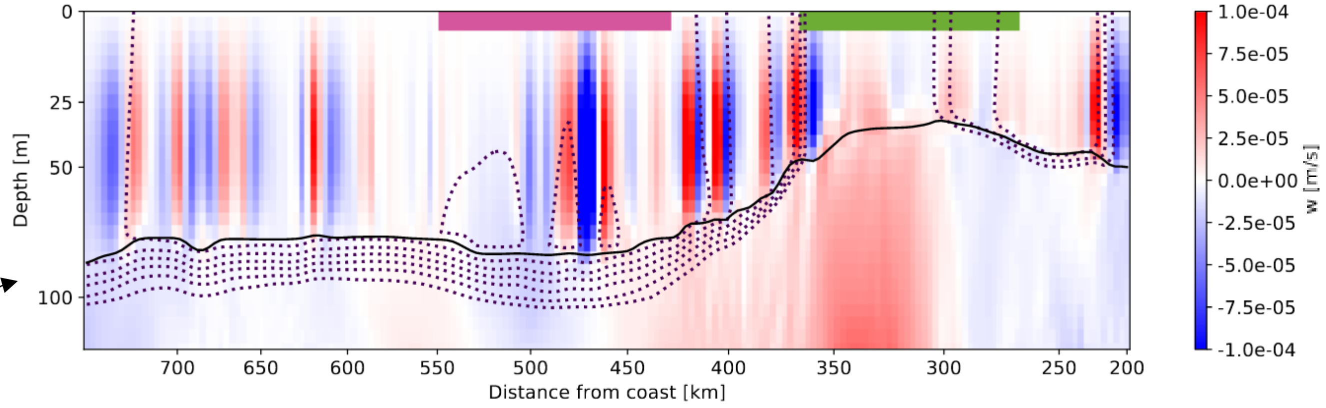

Submesoscale fronts shape vertical velocities in the mixed layer

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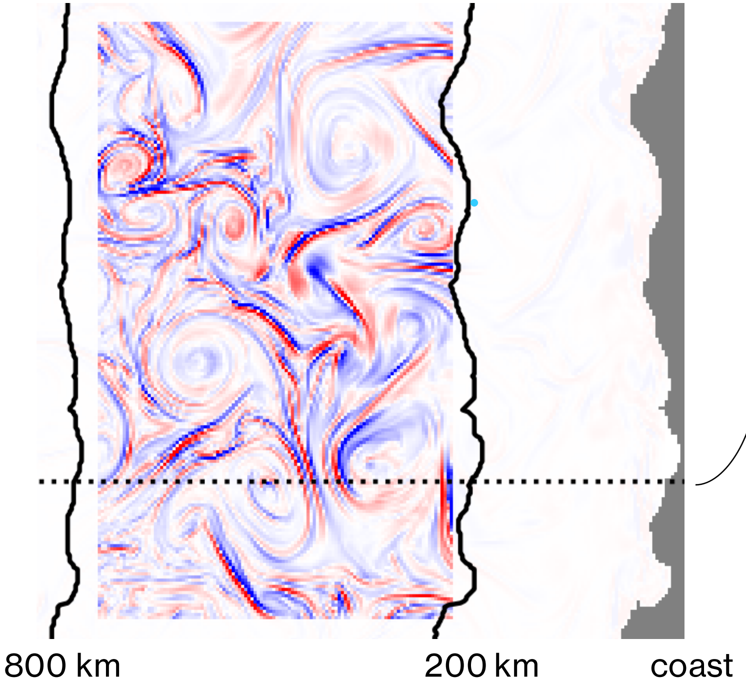

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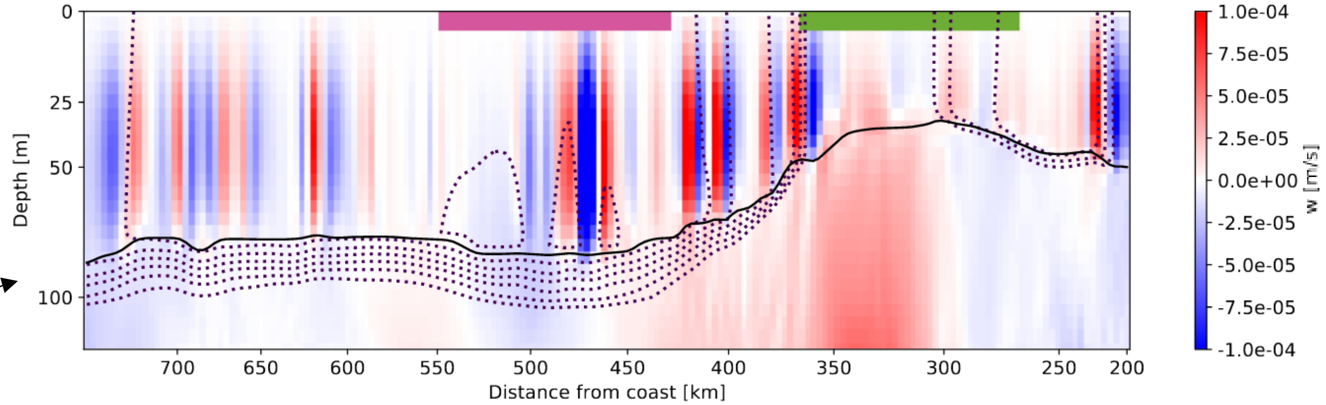

Characteristics:

- strong vertical velocities
- elongated features
- horizontally & vertically coherent

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Submesoscale Fronts: Characteristics

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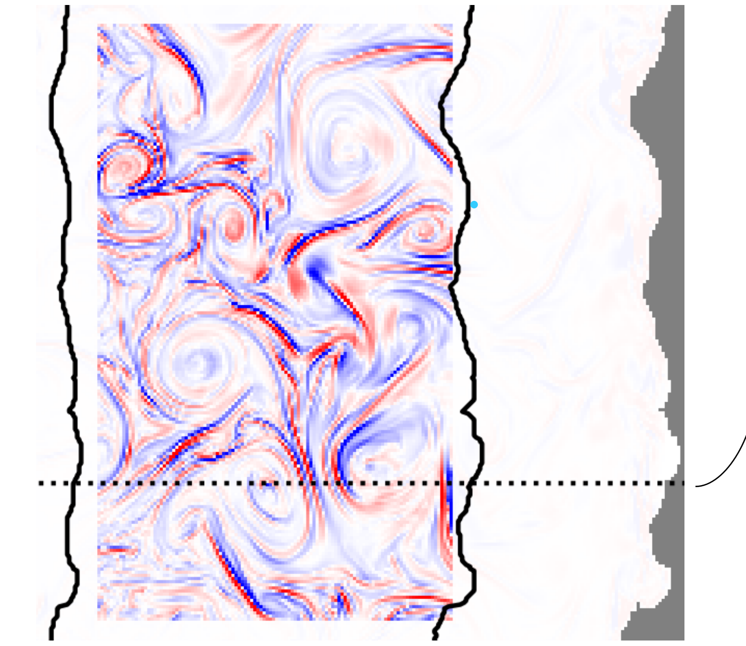

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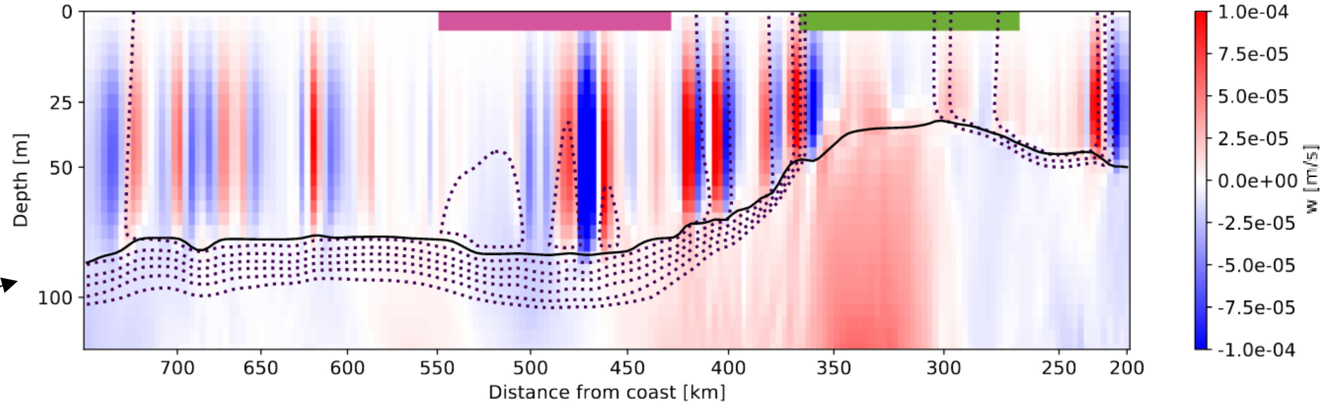

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2. connected components

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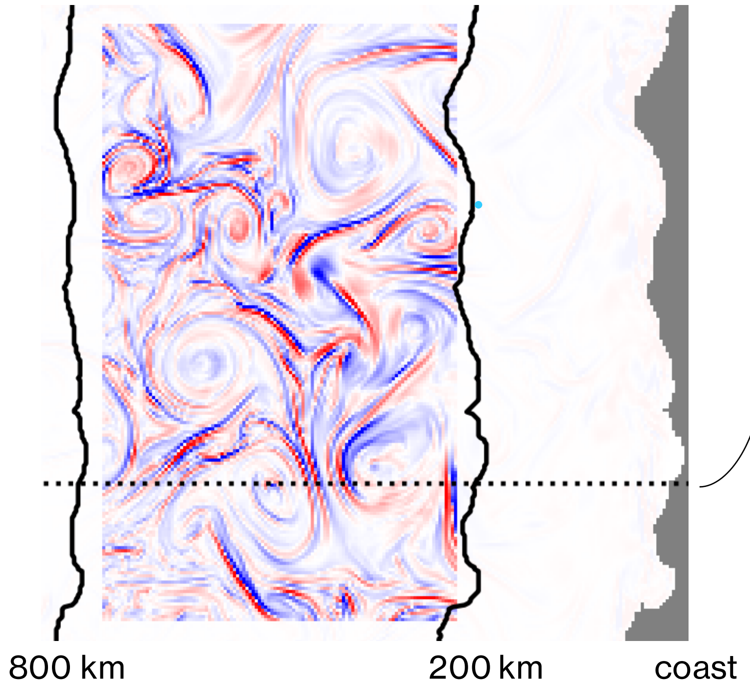

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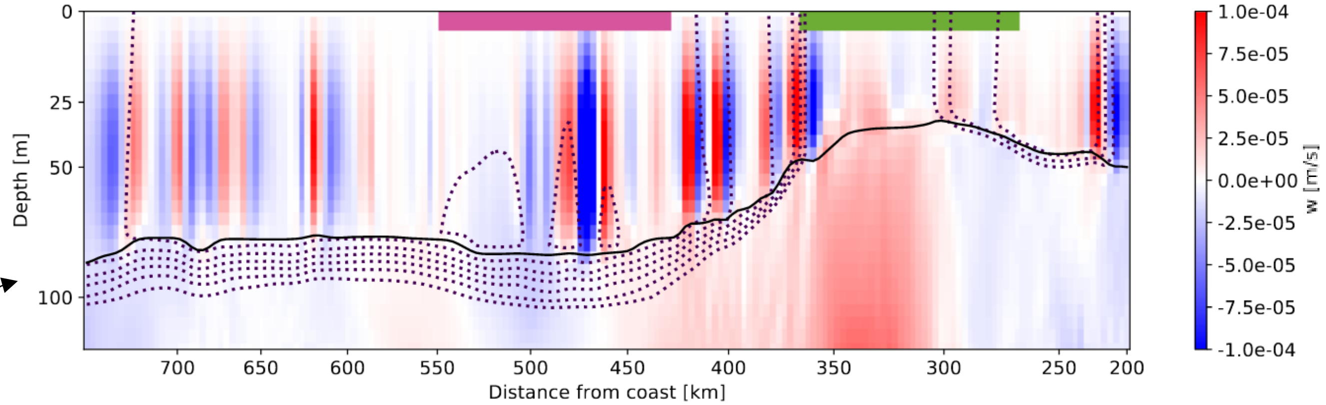

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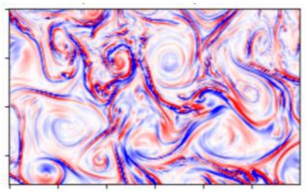
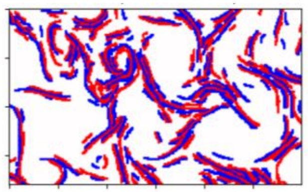
Continuous values of vertical velocity



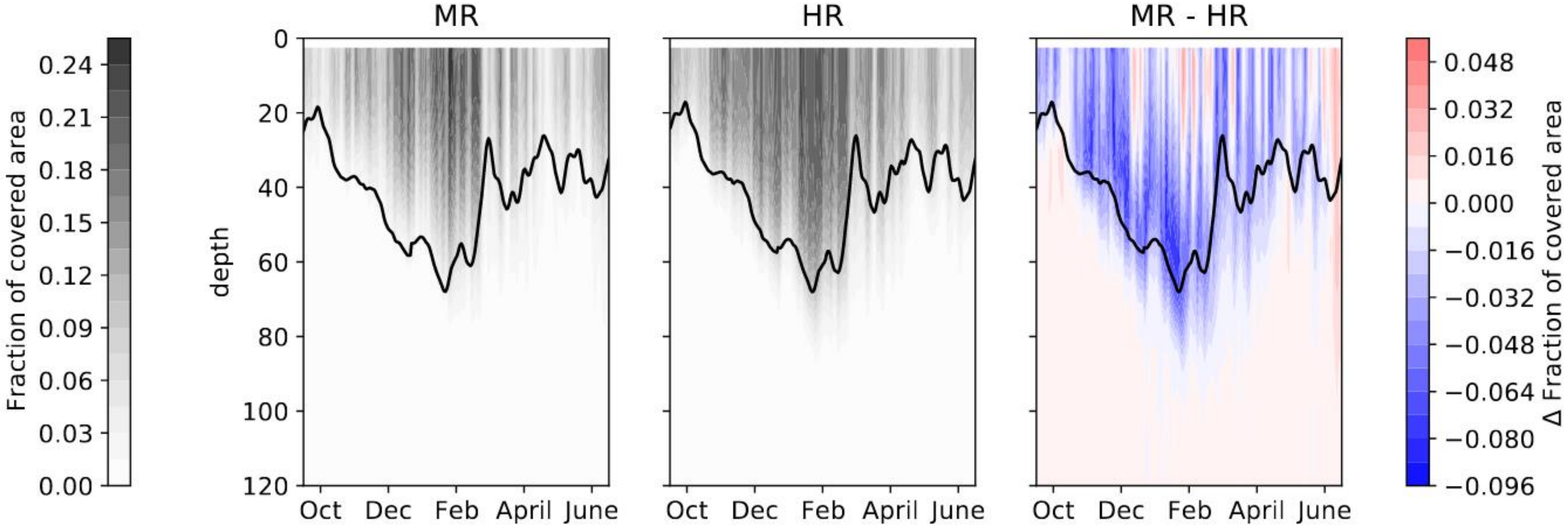
⇨



Boolean map of submeso-scale fronts

Submesoscale fronts shape vertical velocities in the mixed layer

Submesoscale Fronts: Detection Algorithm



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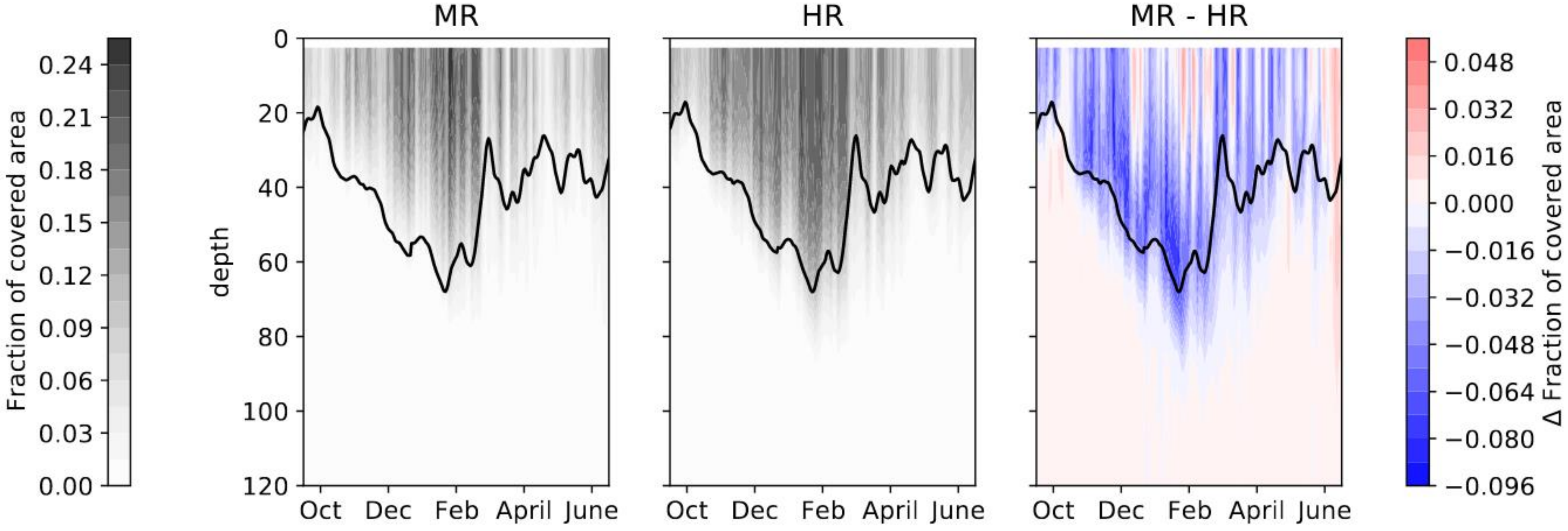

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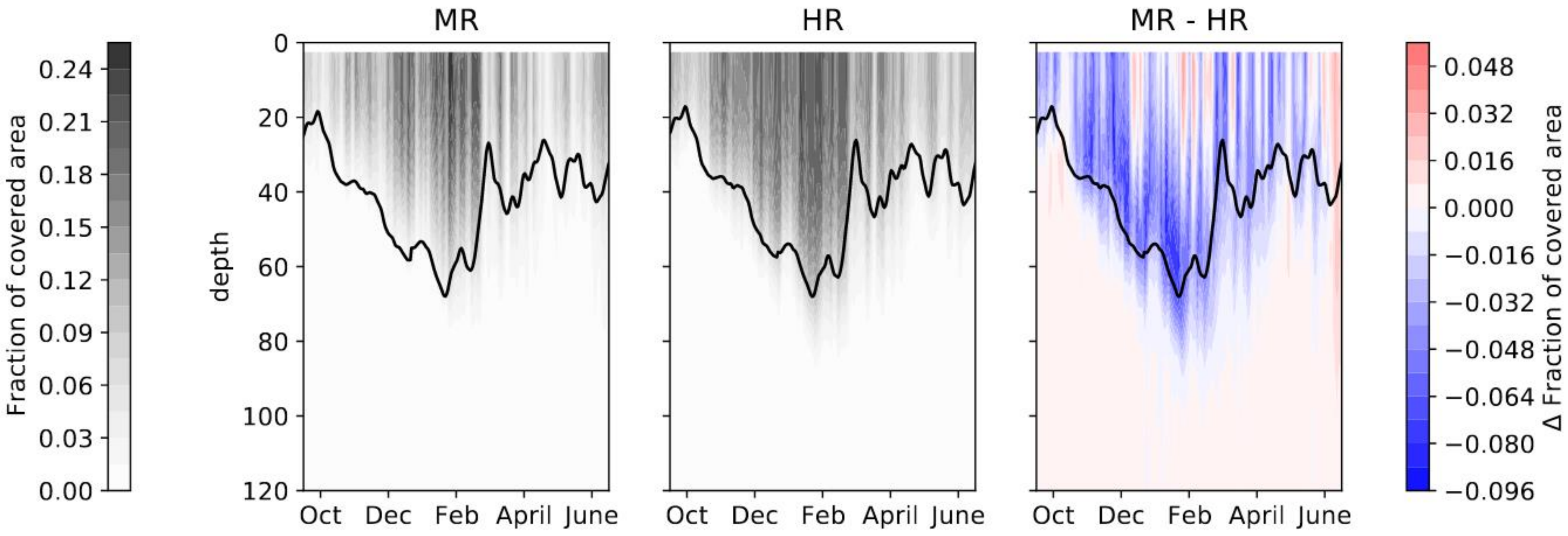

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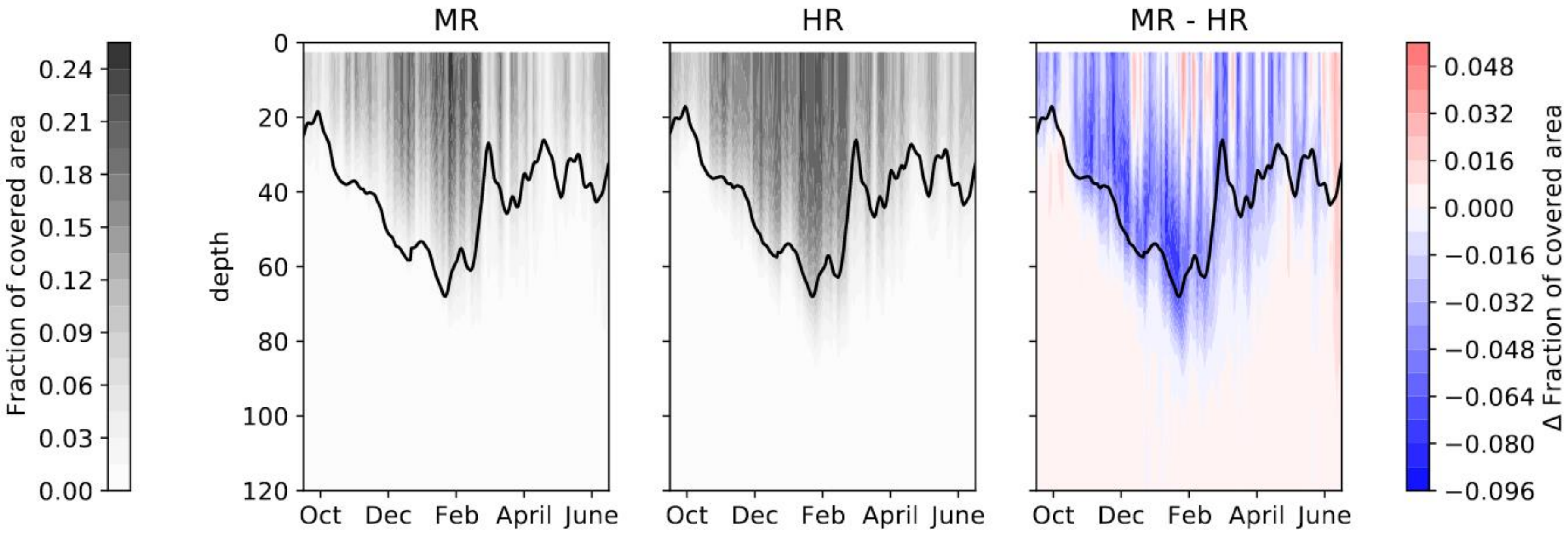

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Does its job in both, MR and HR ✓

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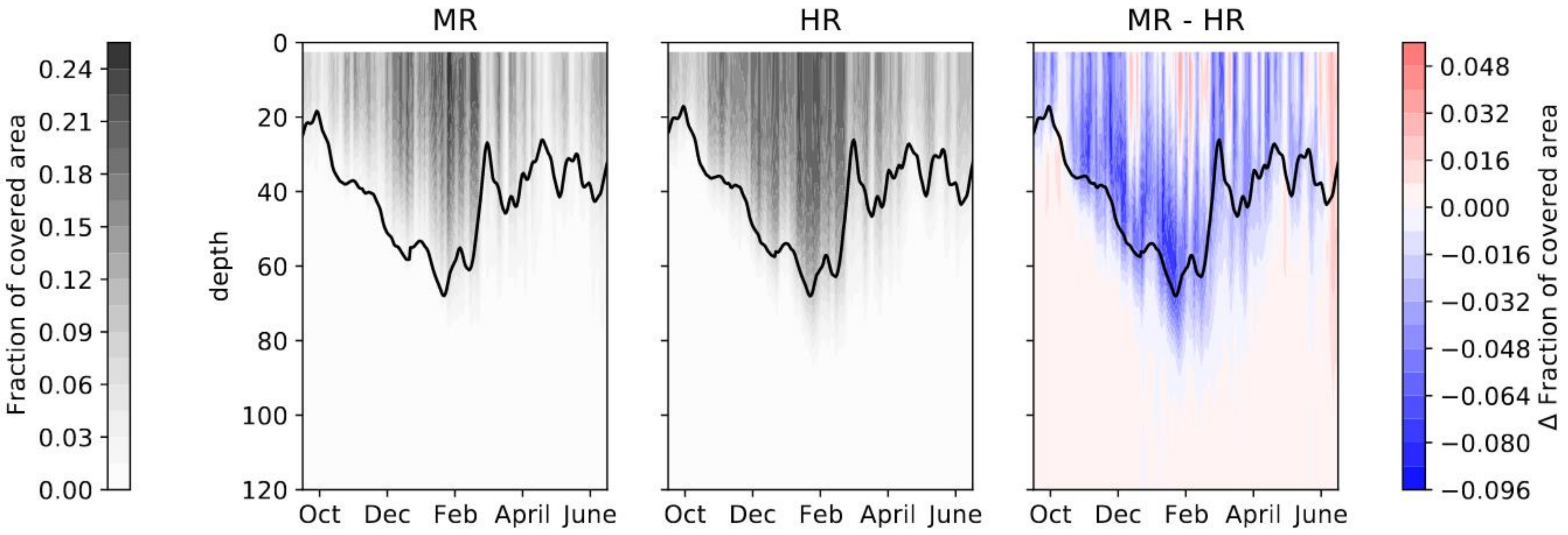

fronts cover larger fraction of domain in HR than in MR

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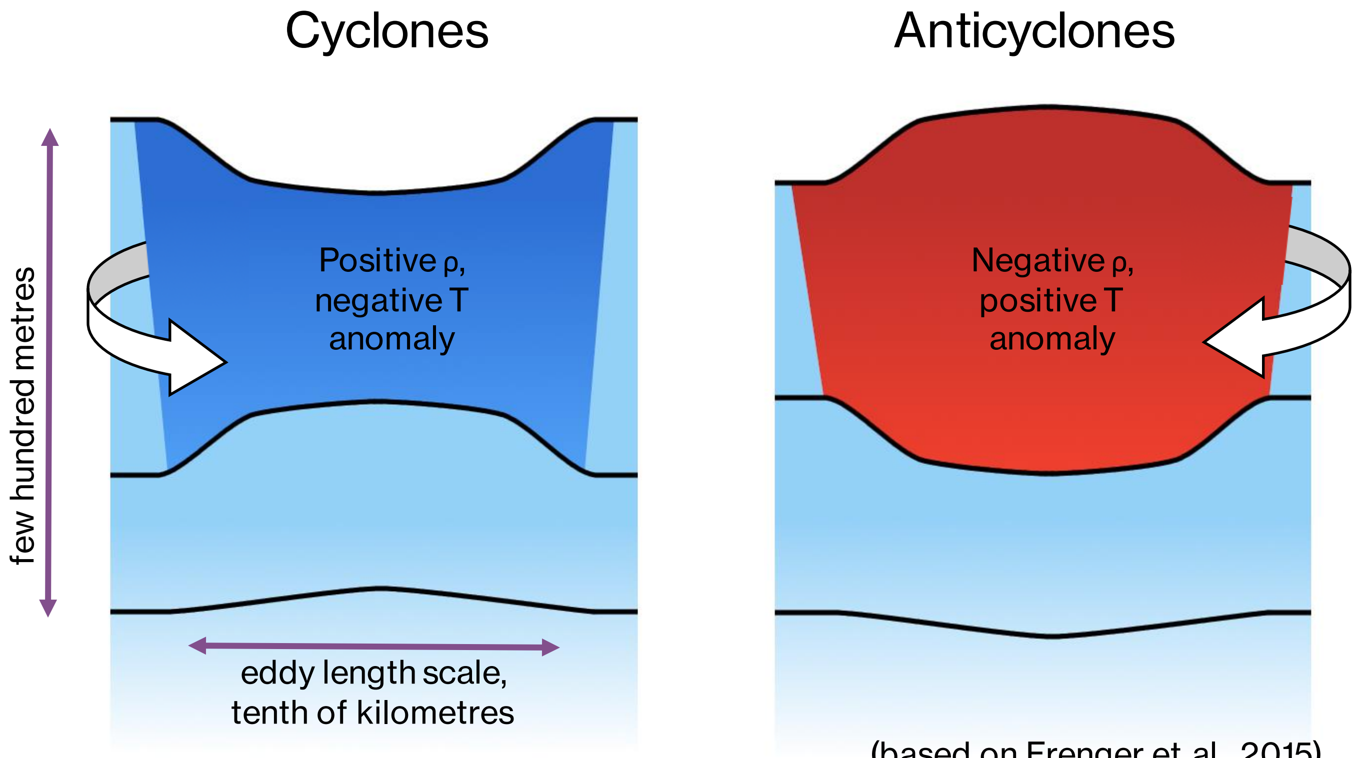
Impact on Mesoscale Eddies

Mesoscale Eddies

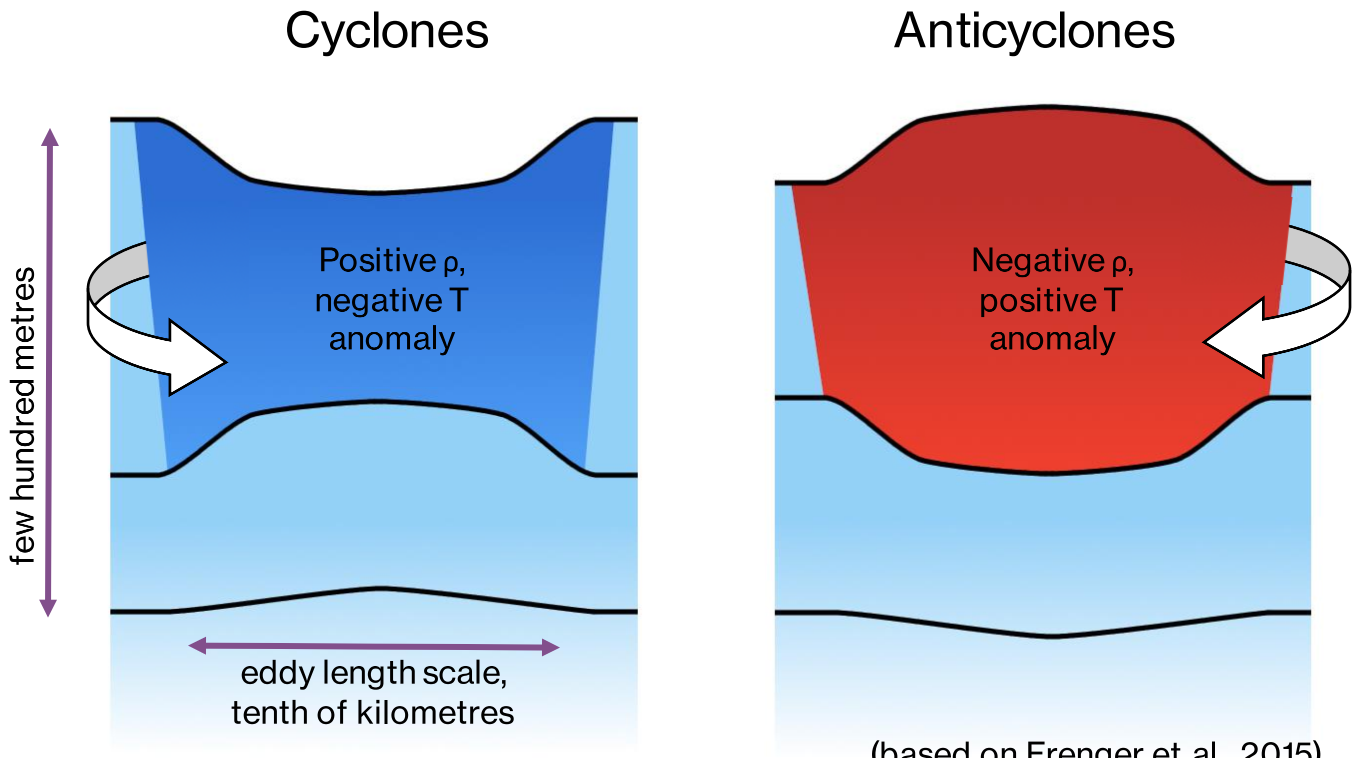


(based on Frenger et al., 2015)

- radius 20 km - 200 km, several months lifetime

(McWilliams, 2008; Kurian et al., 2011; Freilich & Mahadevan, 2019)

Mesoscale Eddies



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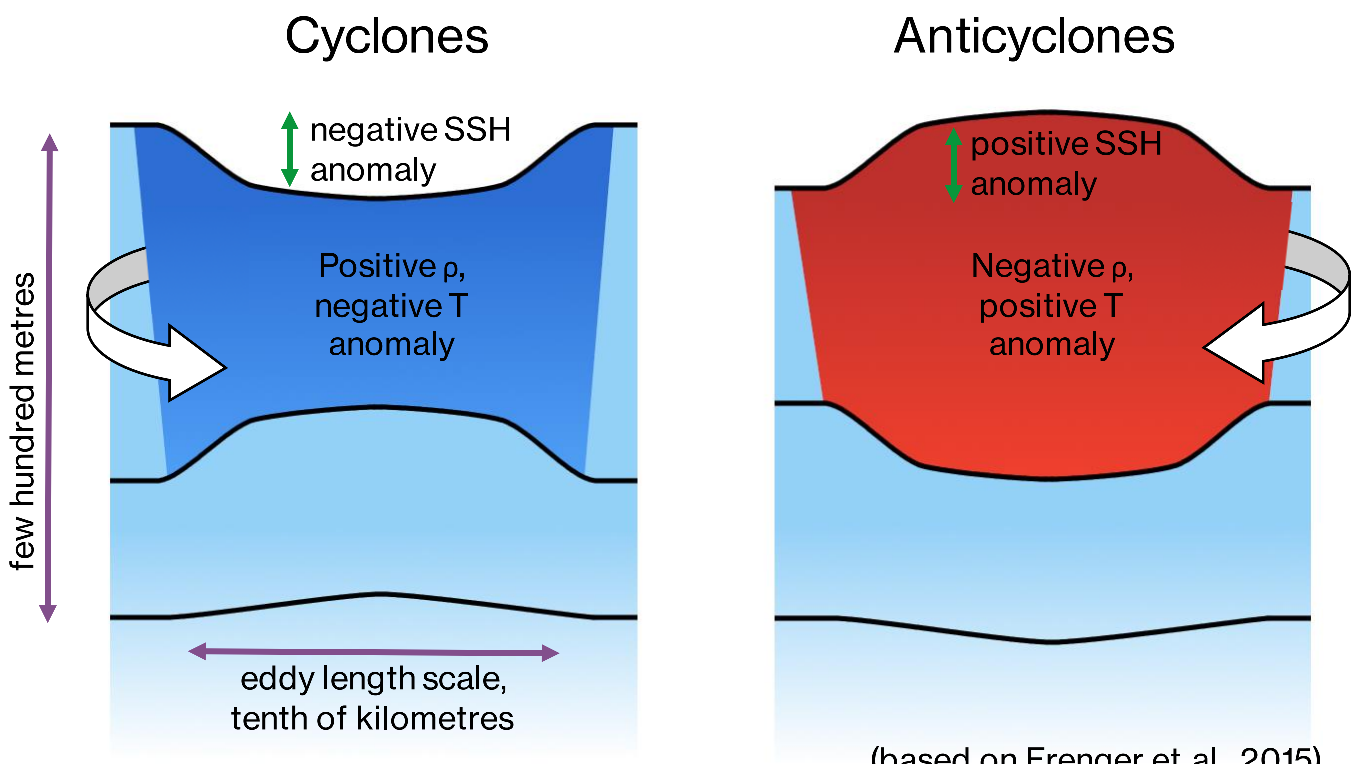

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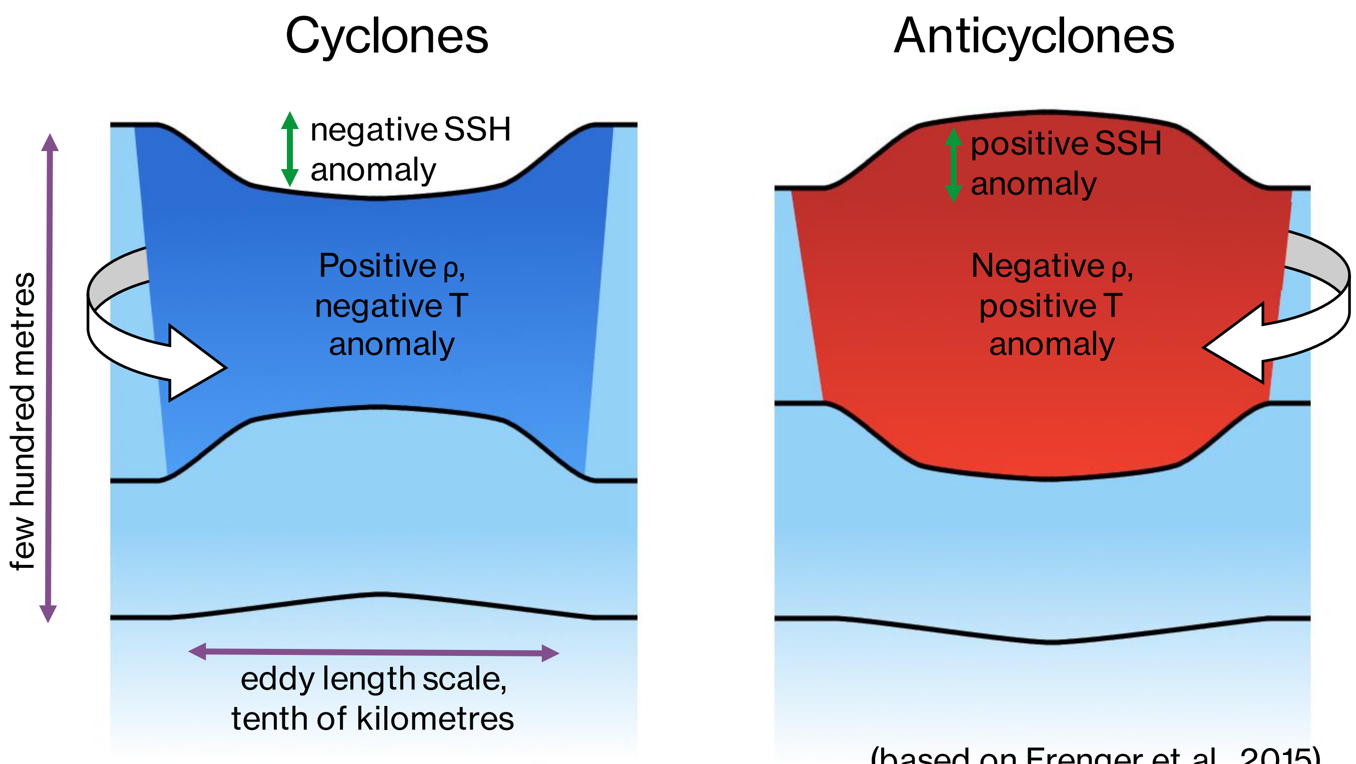

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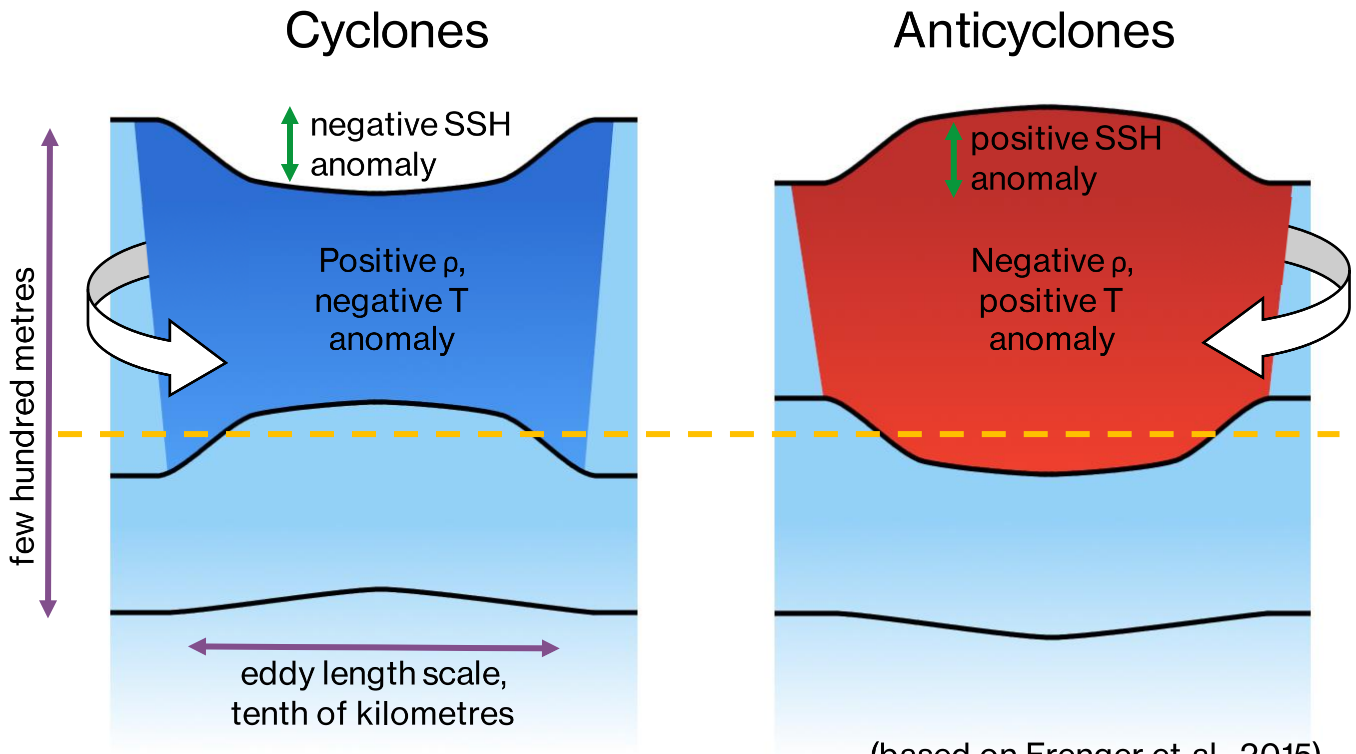

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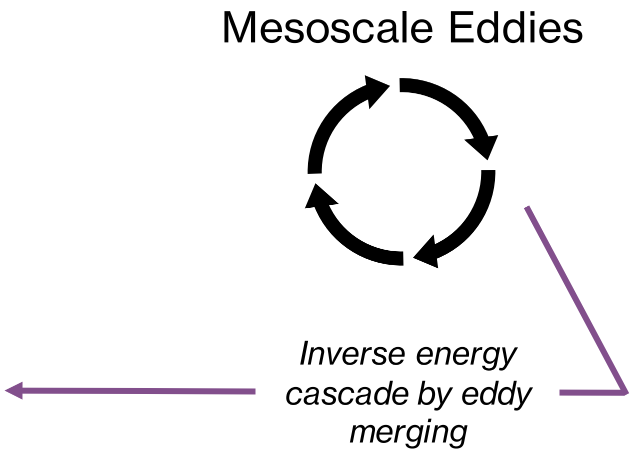
- interactions with wind stress or other eddies can induce strong vertical velocities
- displacement of isopycnals allows for fluxes into/out of euphotic zone and alters mixed layer depth

(McWilliams, 2008; Kurian et al., 2011; Freilich & Mahadevan, 2019)

Mesoscale Eddies: Energy Cascade



(McWilliams, 2016; Schubert et al., 2020)

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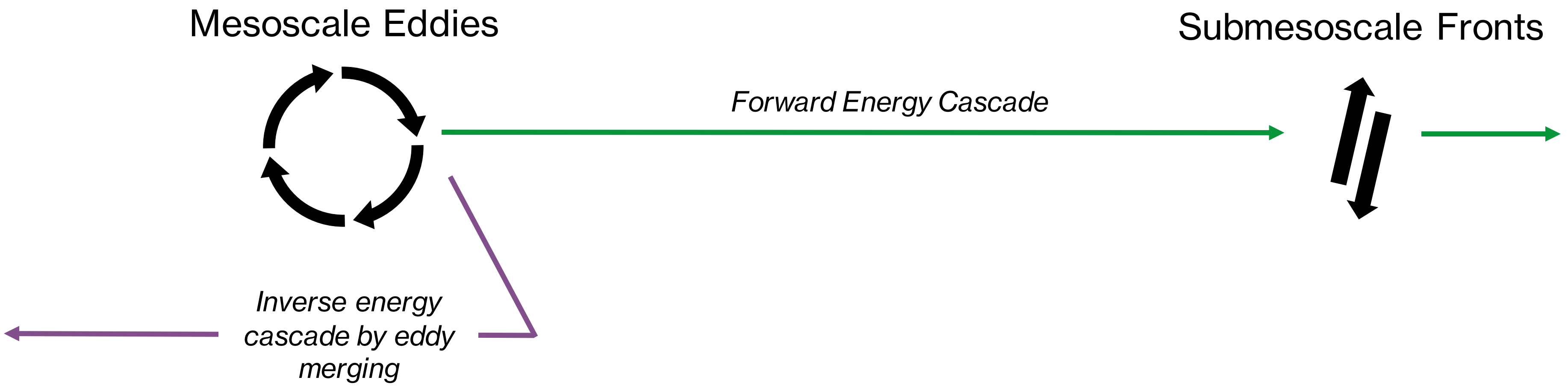

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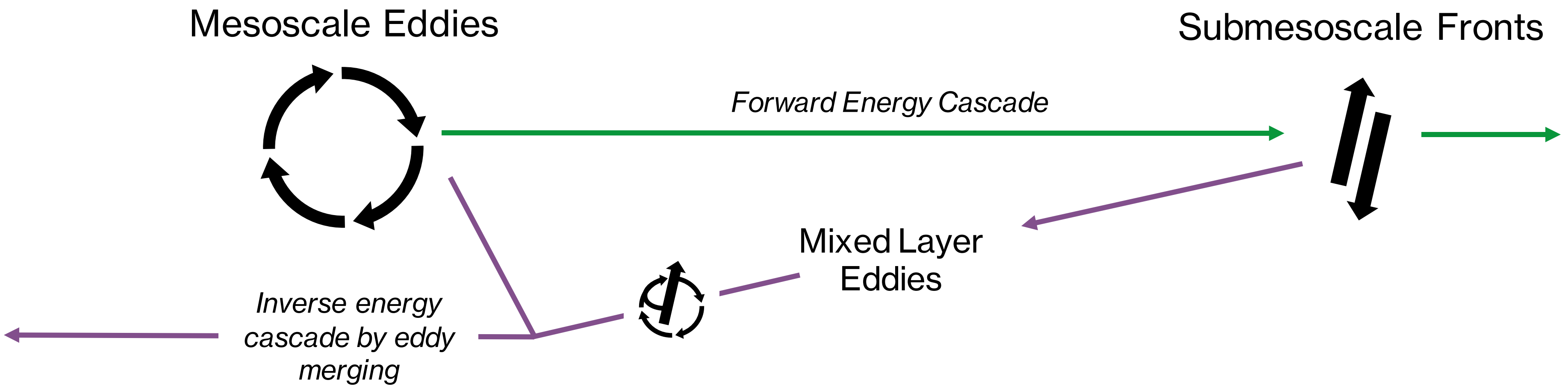

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Energy Cascade: Submesoscale Contribution

Schubert et al., 2020

- inverse energy cascade is fueled by eddies with radius down to 17 km

Our work

- eddies < 20 km much better resolved in HR model

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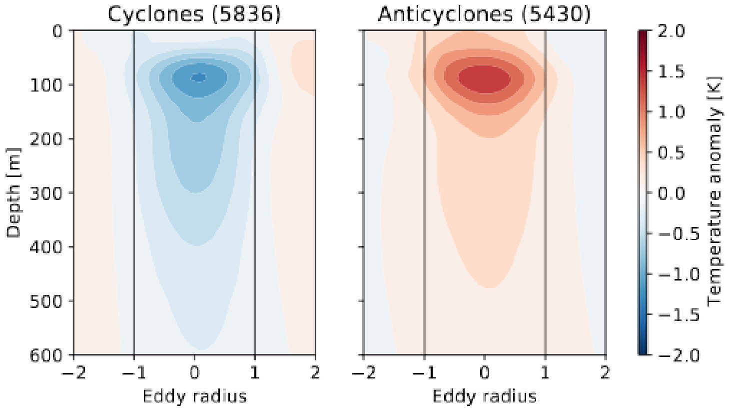
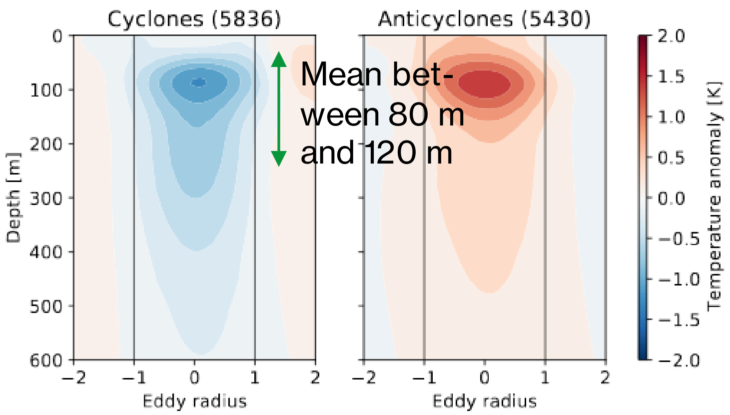
Submesoscale fronts energize mesoscale eddies

Mesoscale Eddies:
Impact on Density Anomaly



Mesoscale Eddies: Impact on Density Anomaly



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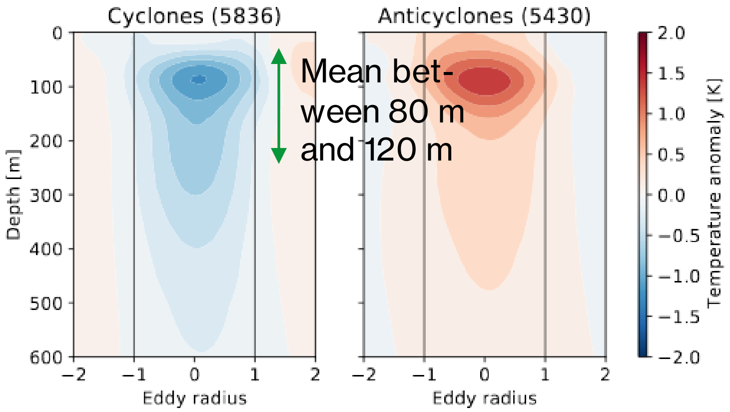

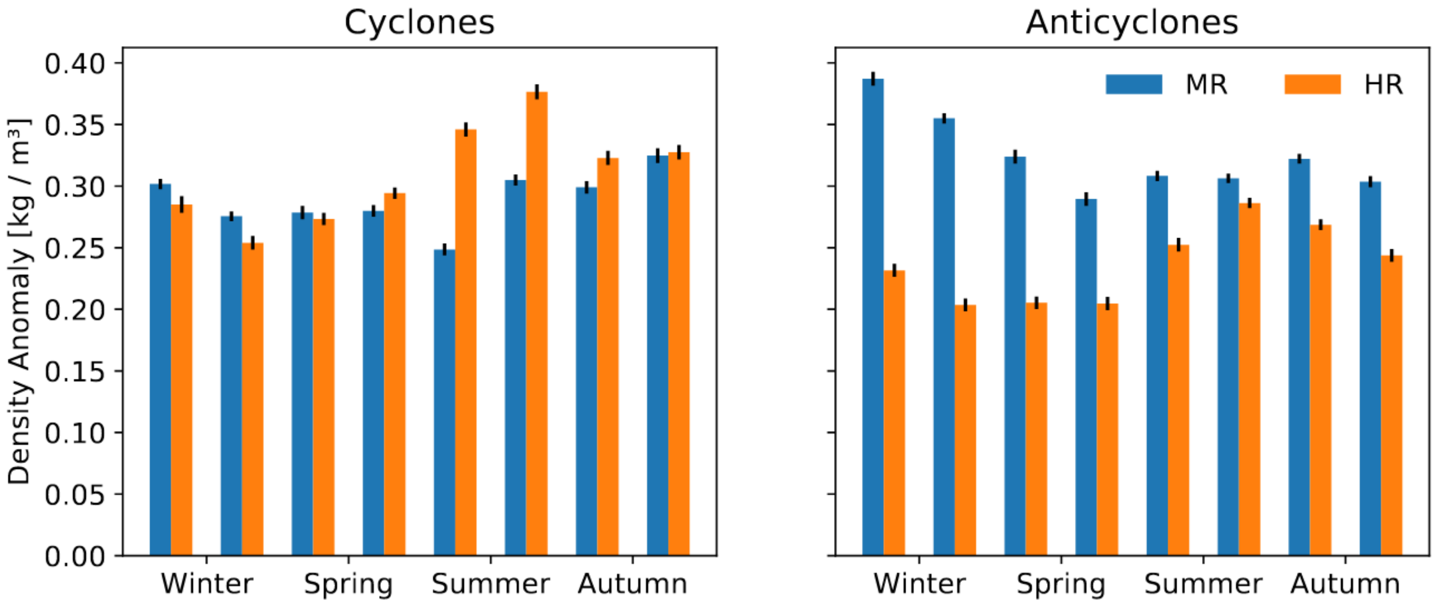

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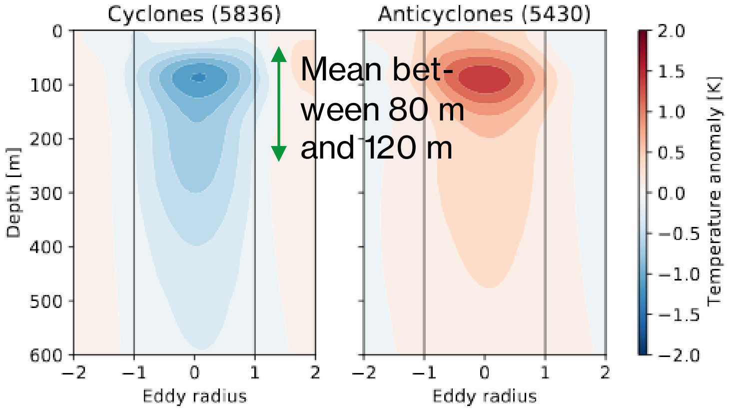

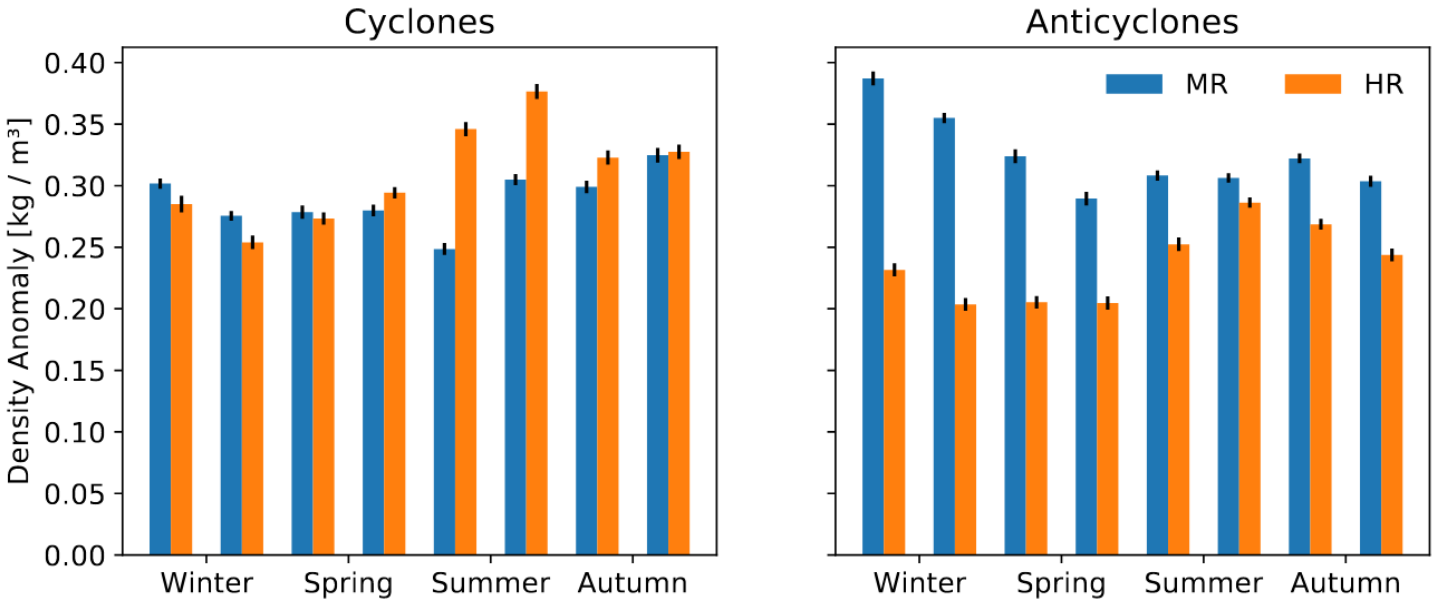

- cyclones are only little affected

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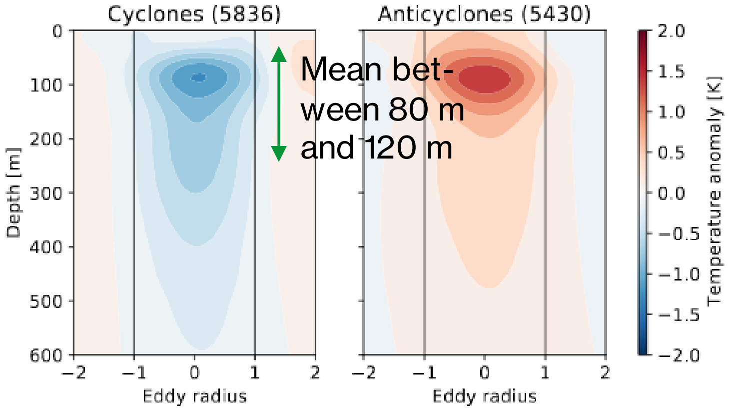
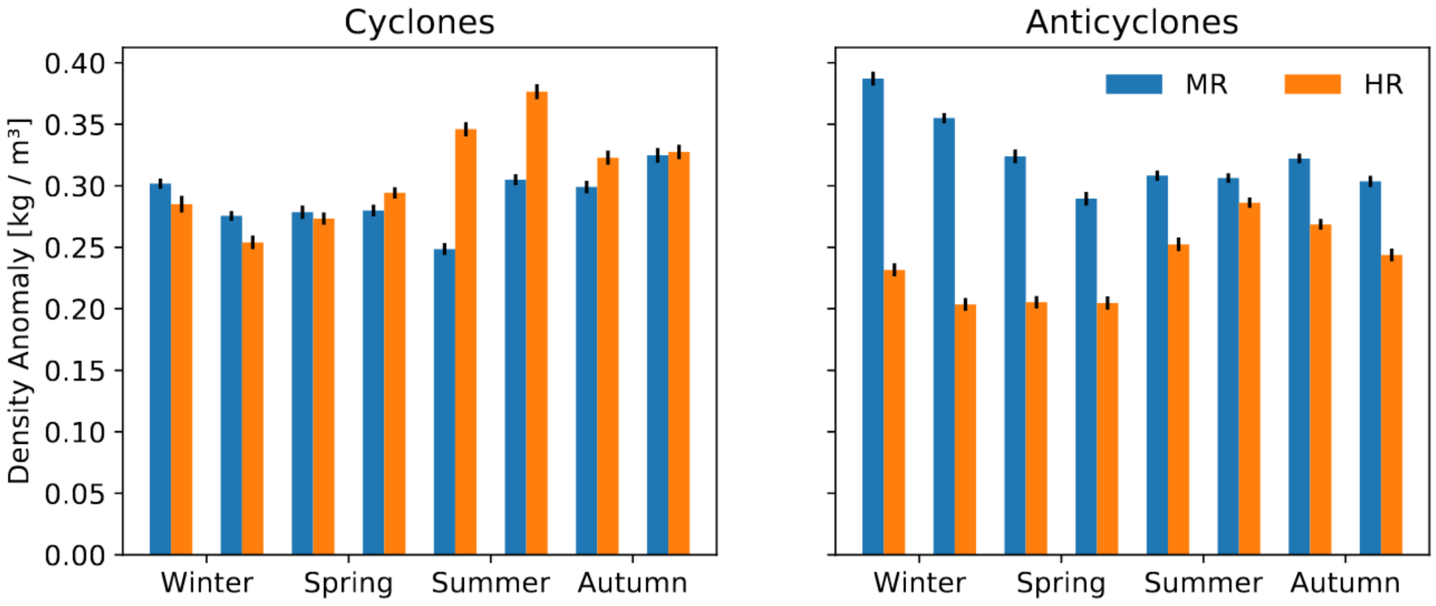
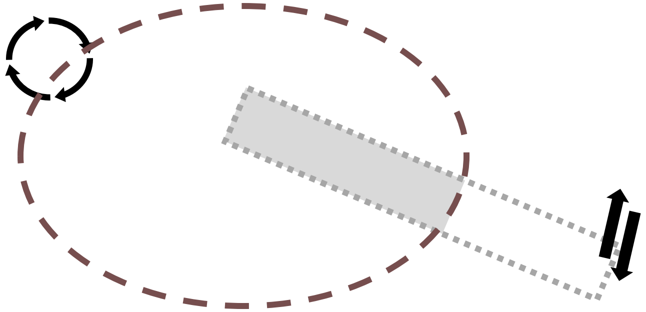
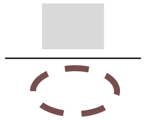




- cyclones are only little affected
- anticyclones are strongly damped during winter and spring by ~40 %

Mesoscale Eddies: Intersection with Fronts

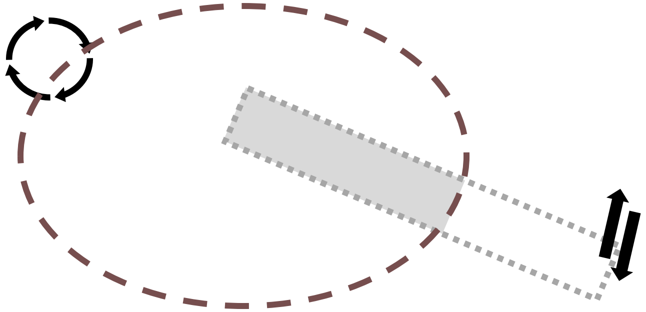


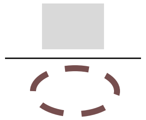


Coverage of mesoscale eddies by submesoscale fronts at 25 m depth from January to March

(Thomas et al., 2013; Brannigan et al., 2017; Su et al., 2018; Klein et al., 2019)

Mesoscale Eddies: Intersection with Fronts





Coverage of mesoscale eddies by submesoscale fronts at 25 m depth from January to March

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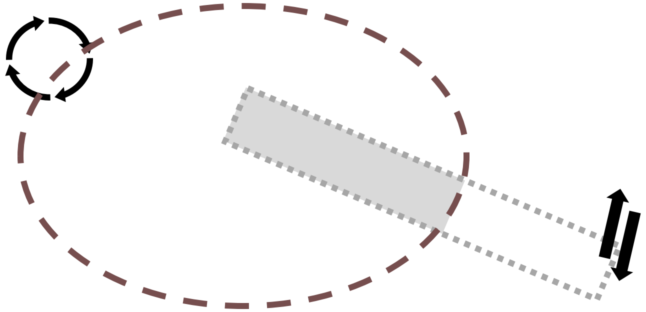

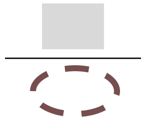

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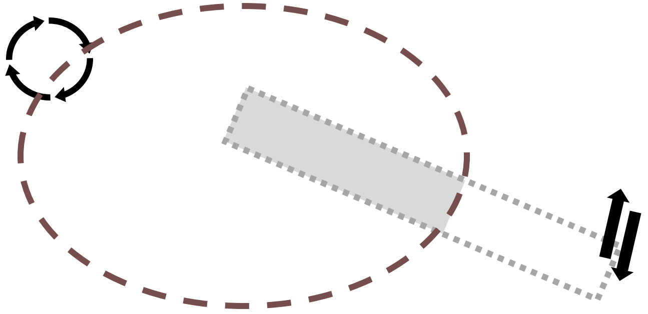

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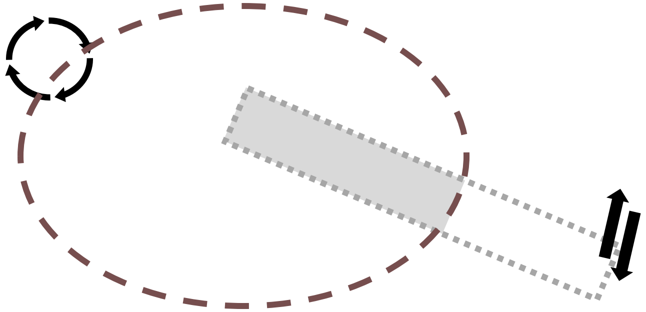

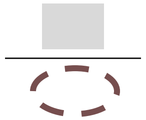

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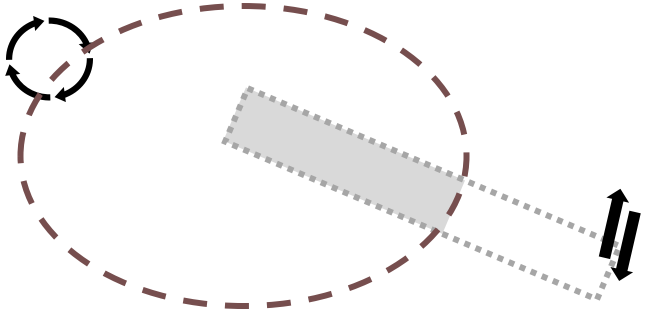

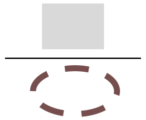

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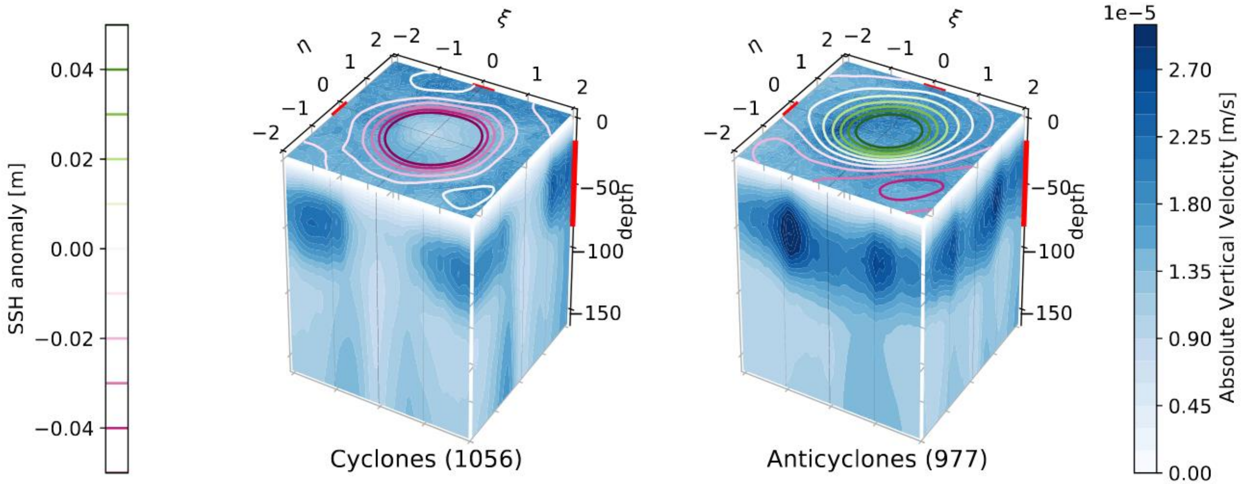

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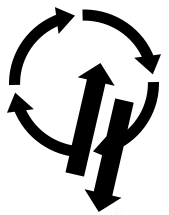

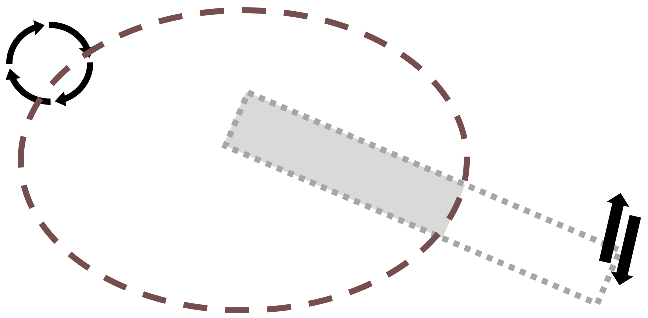

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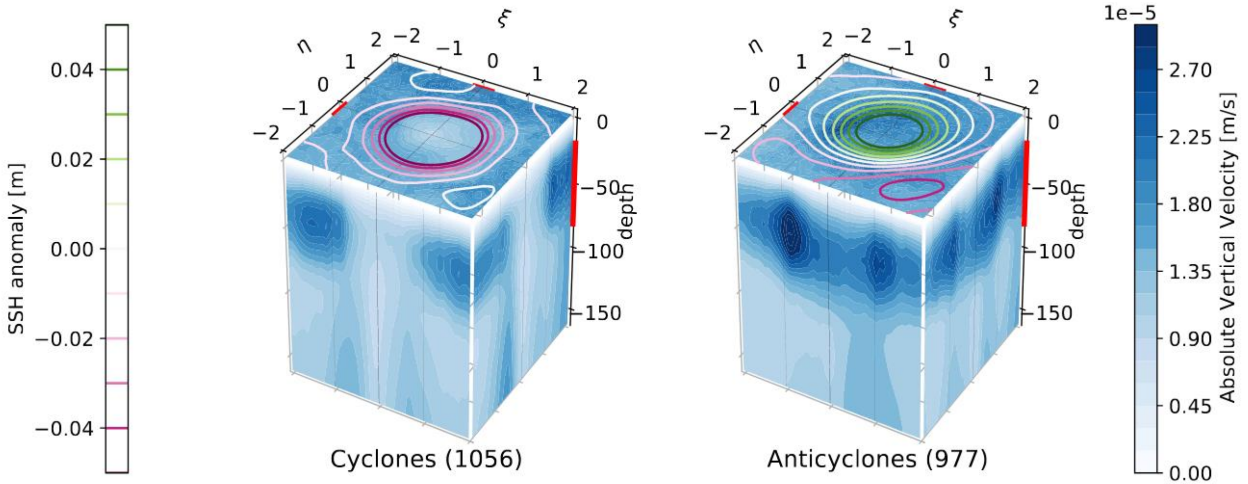

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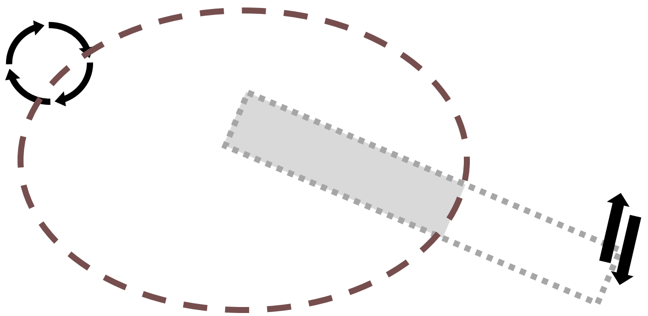

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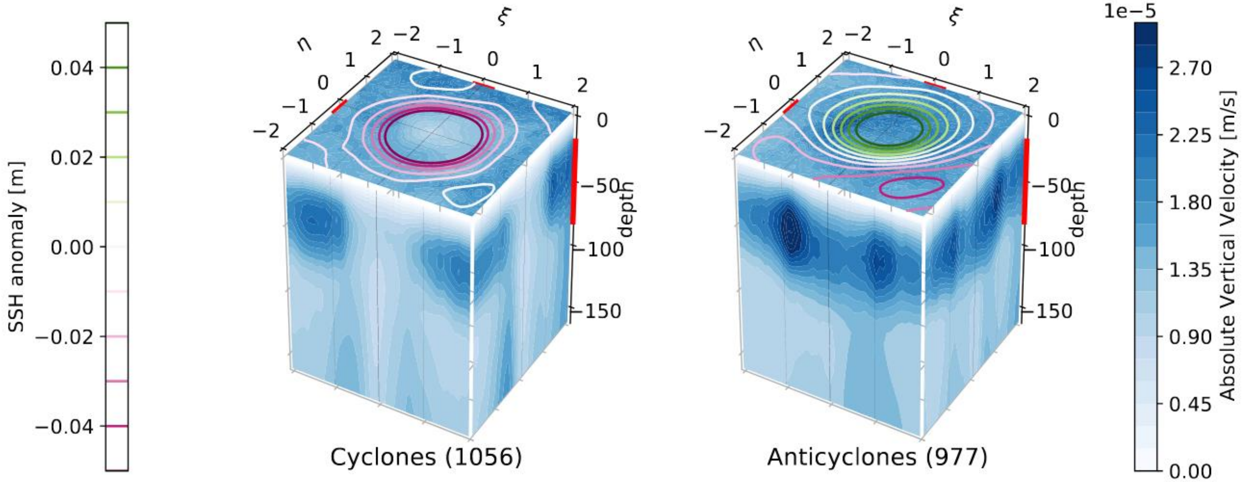

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Biological Productivity

Submesoscale Impacts on Biological Productivity

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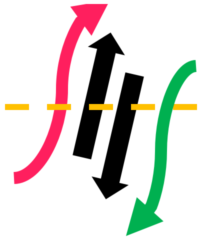

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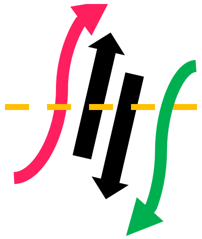

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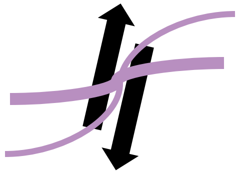

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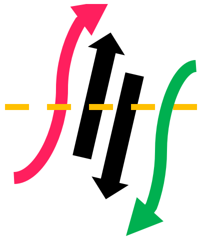

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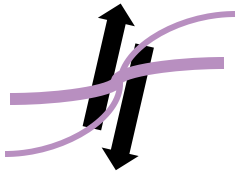

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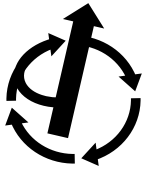

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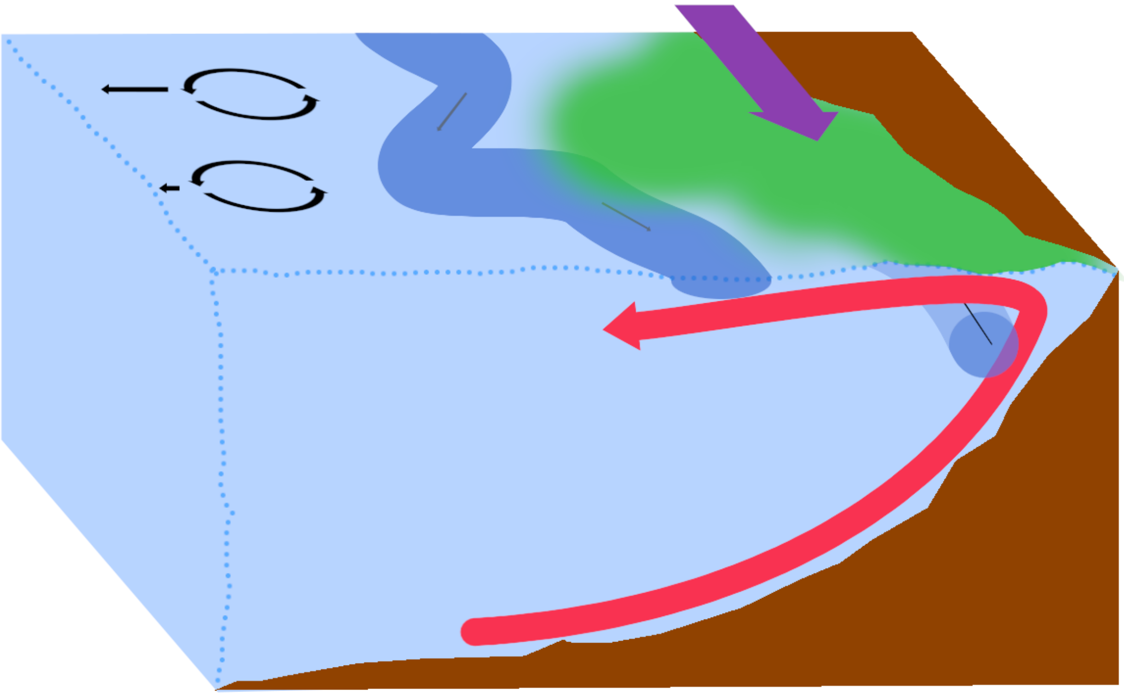

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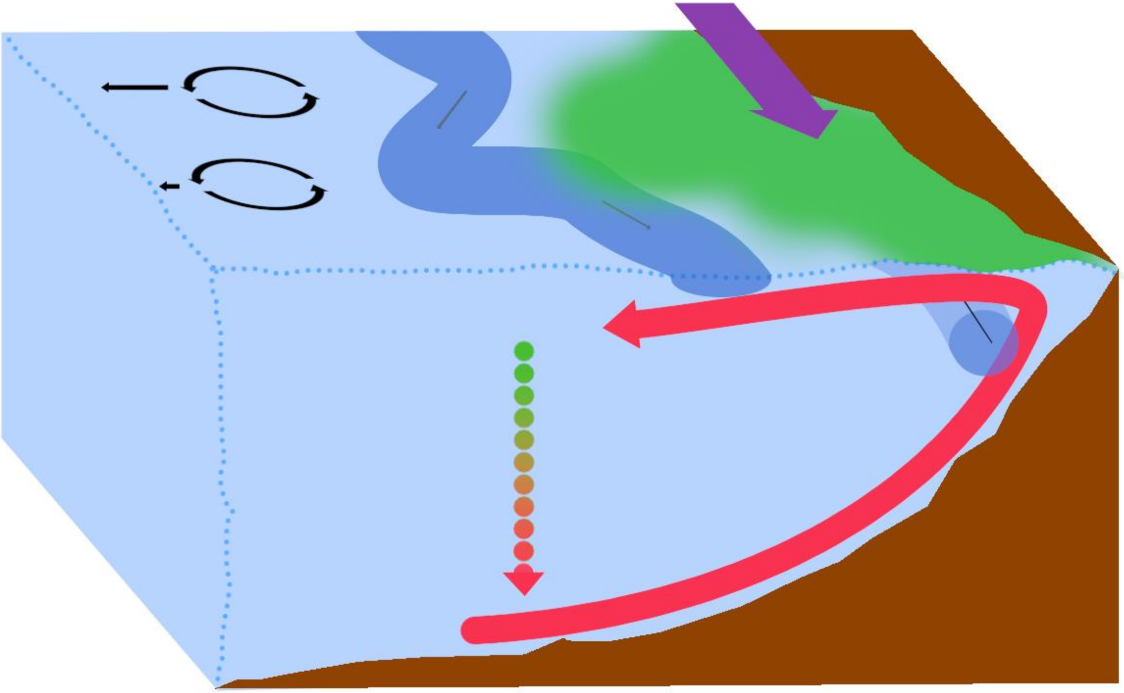

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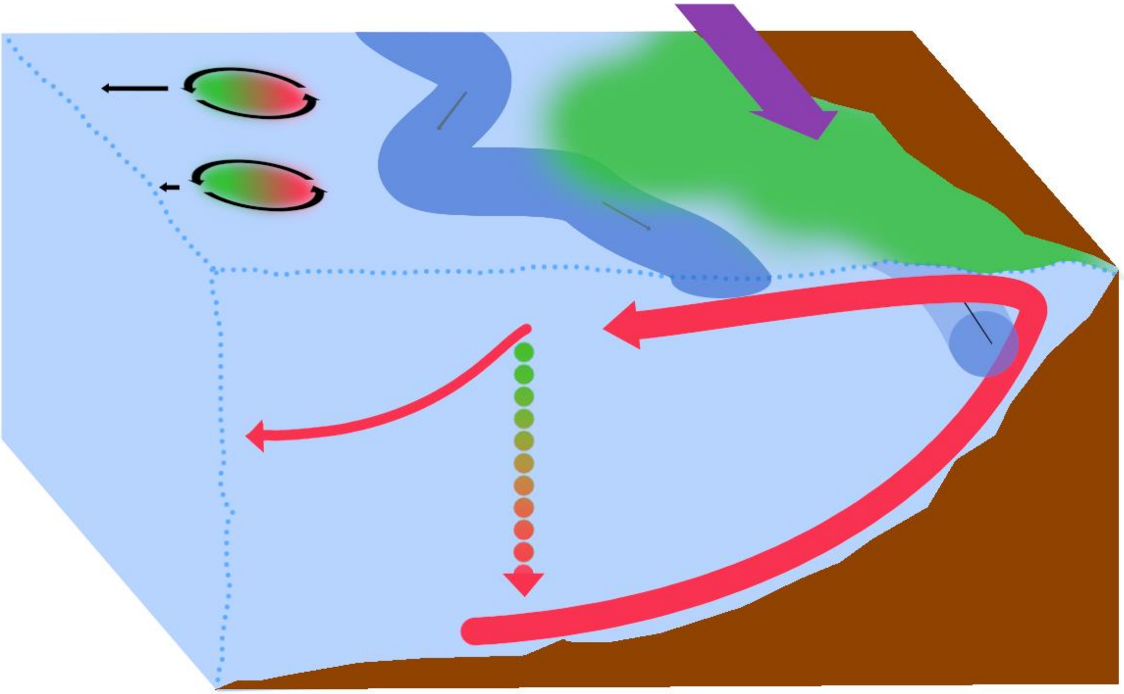

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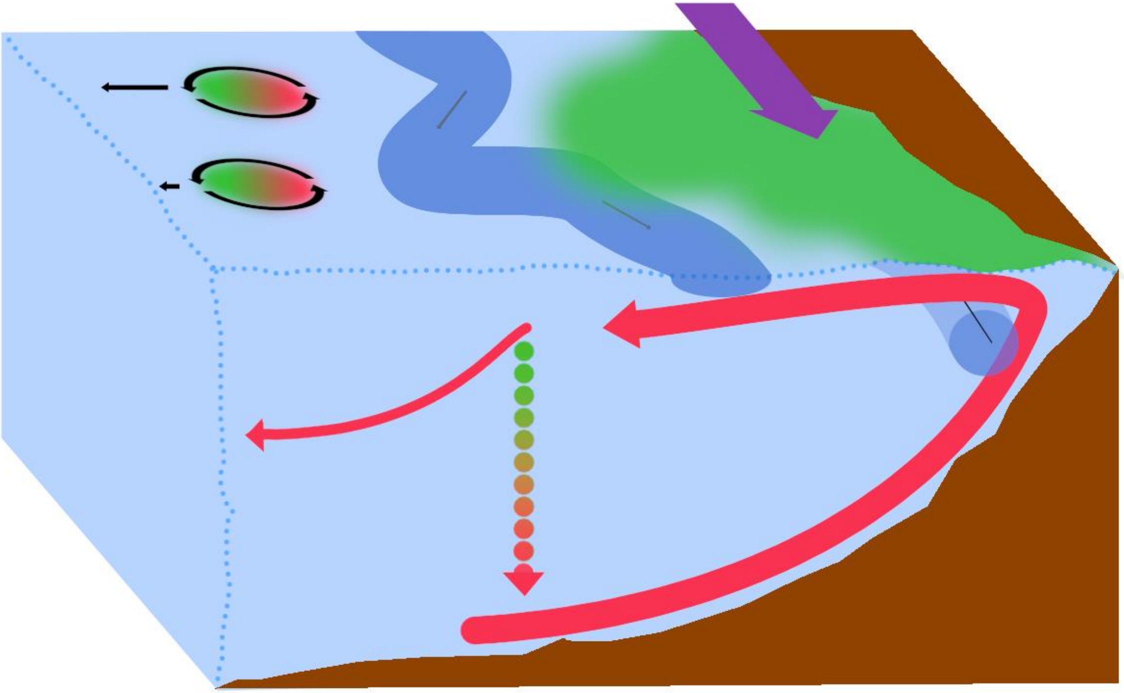

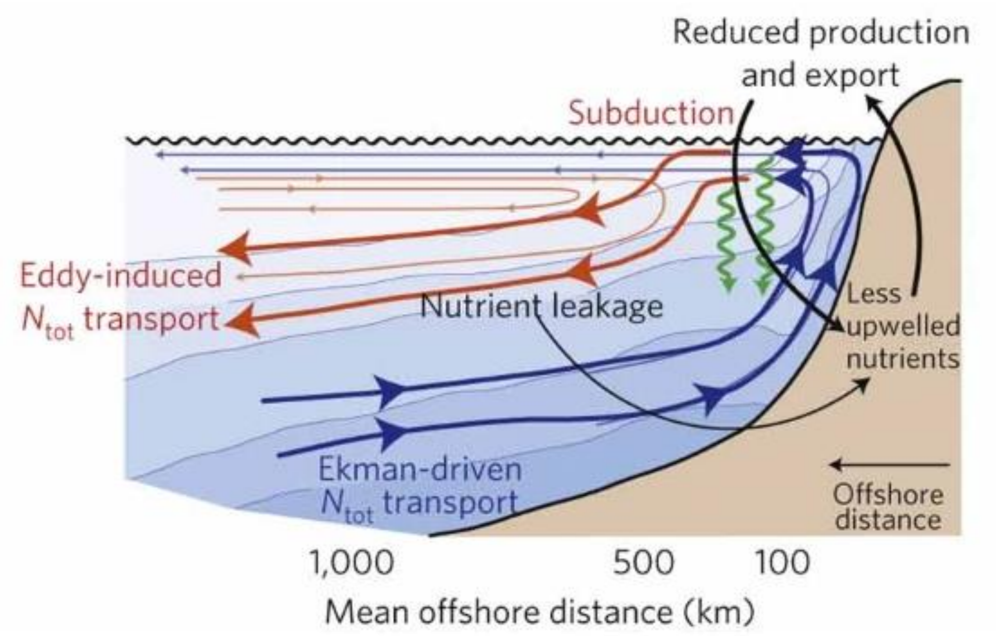

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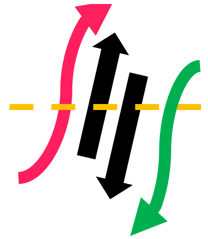

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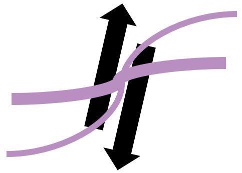

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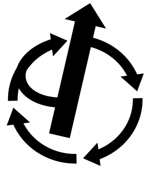

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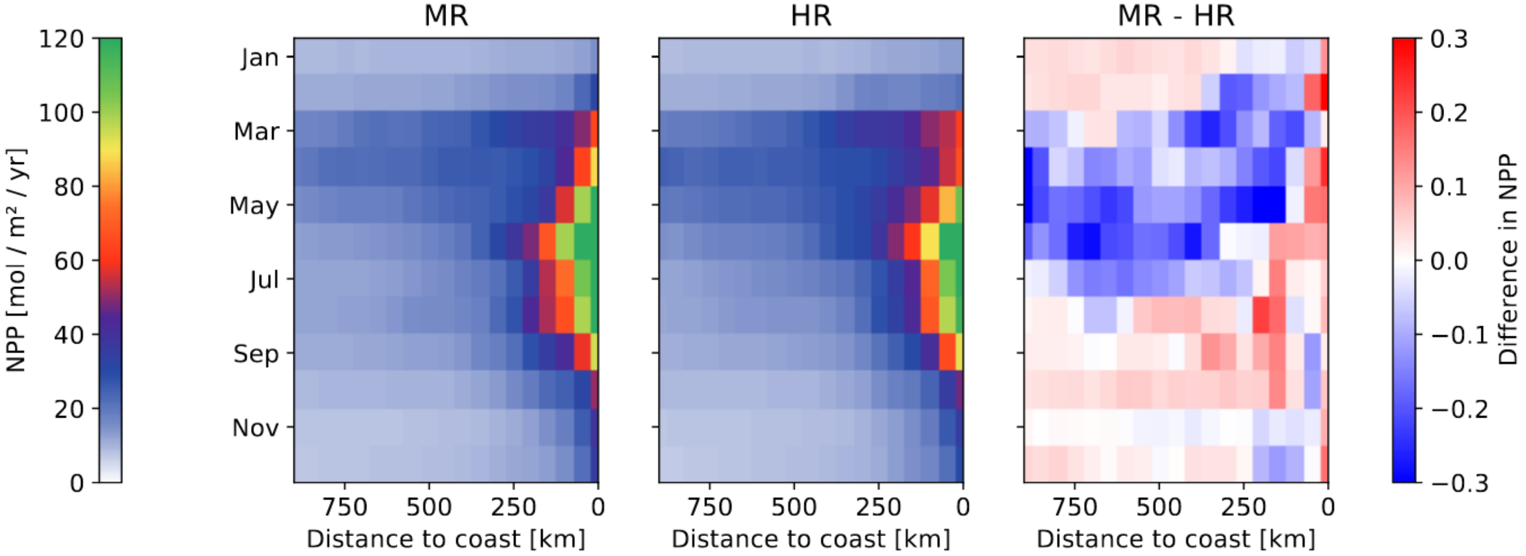

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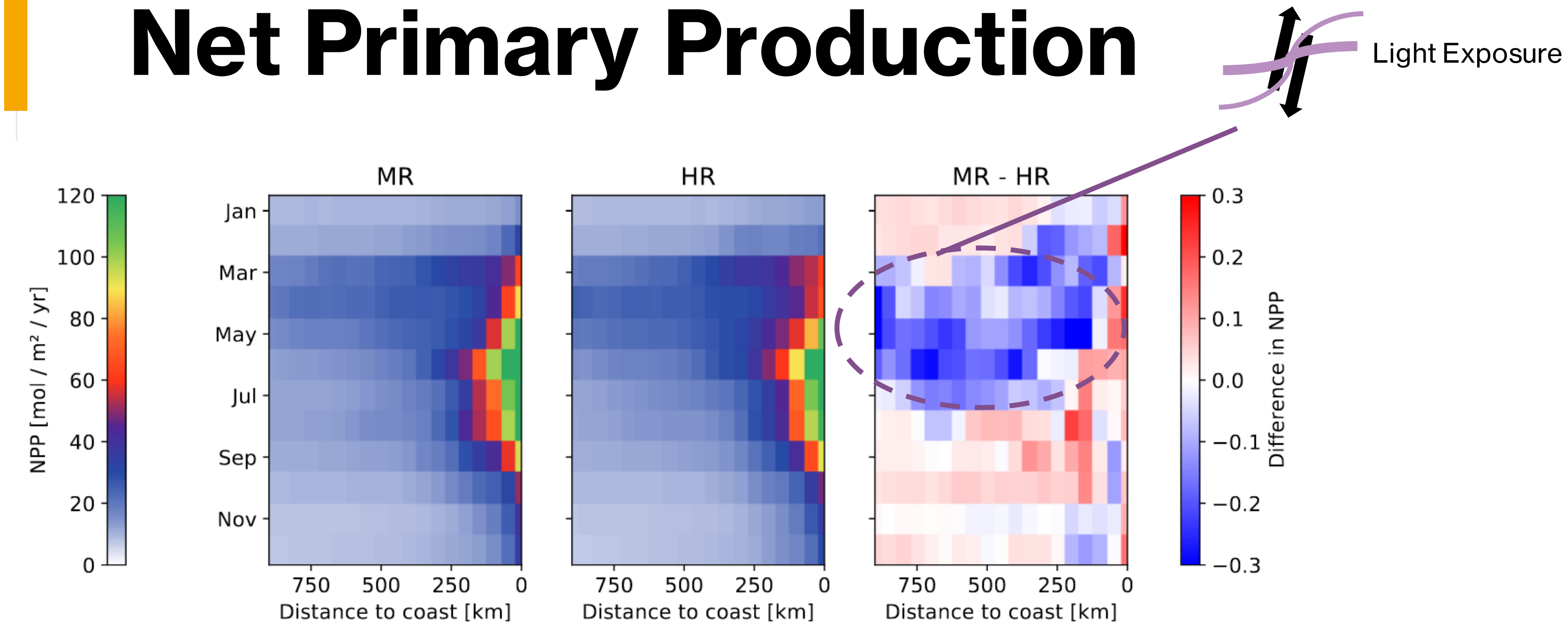

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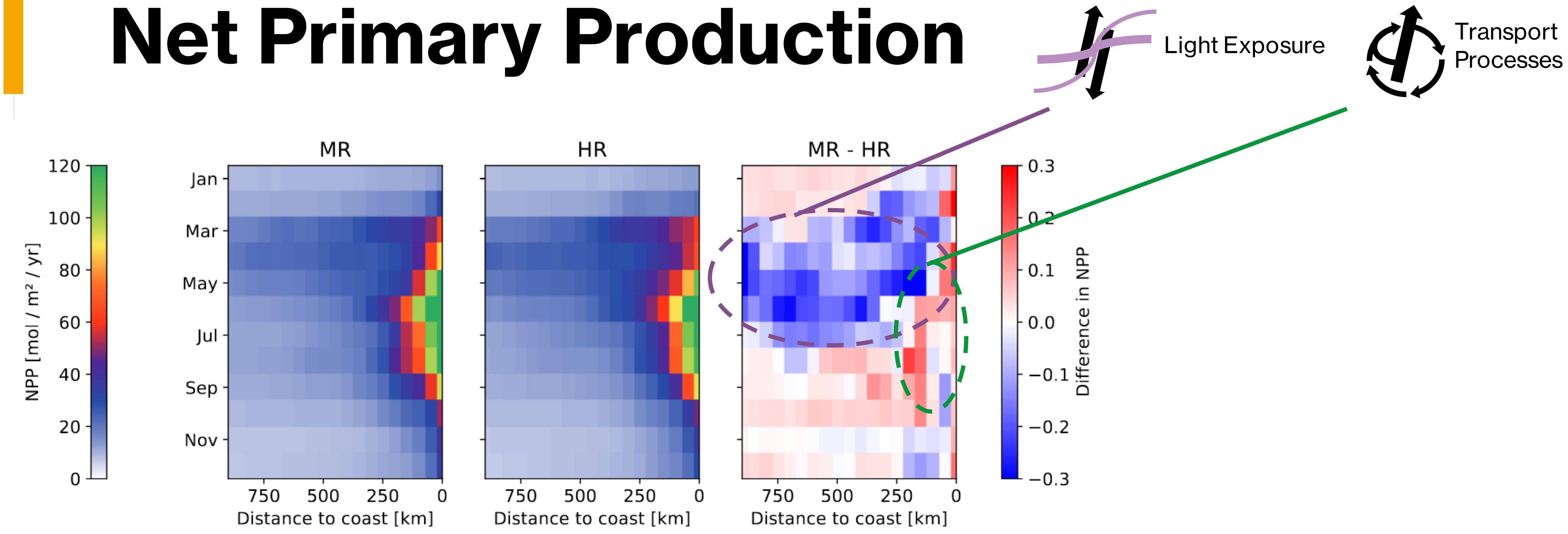

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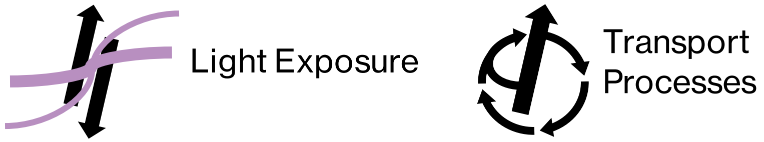

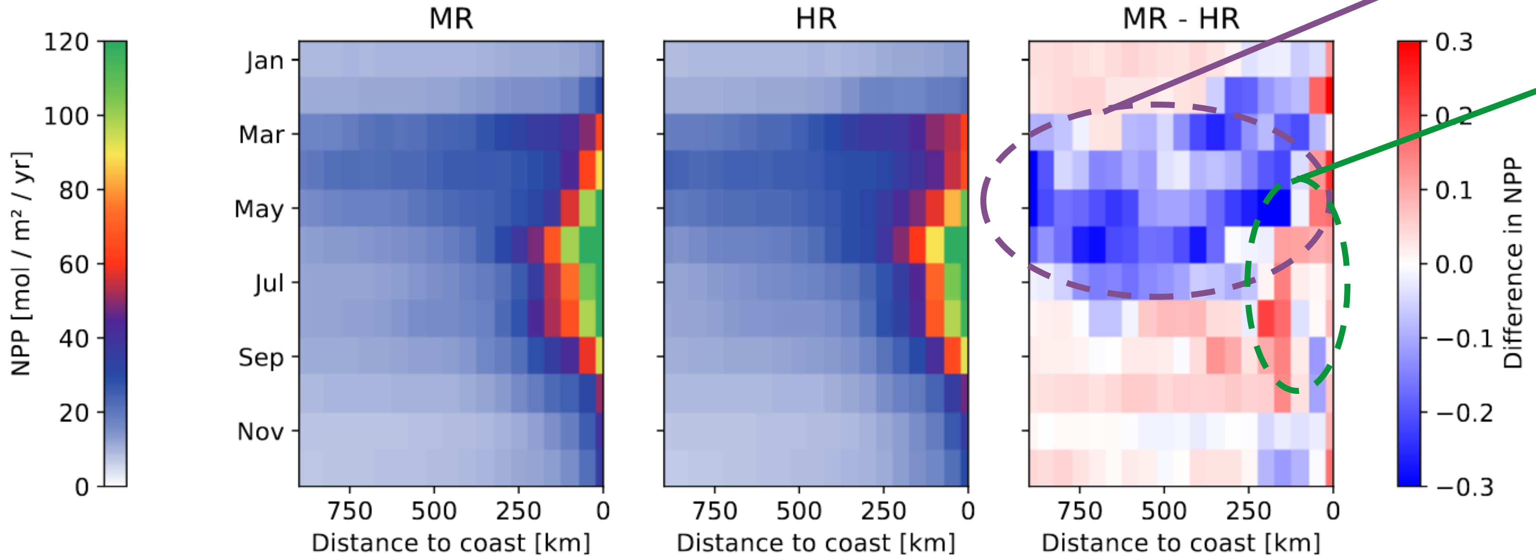

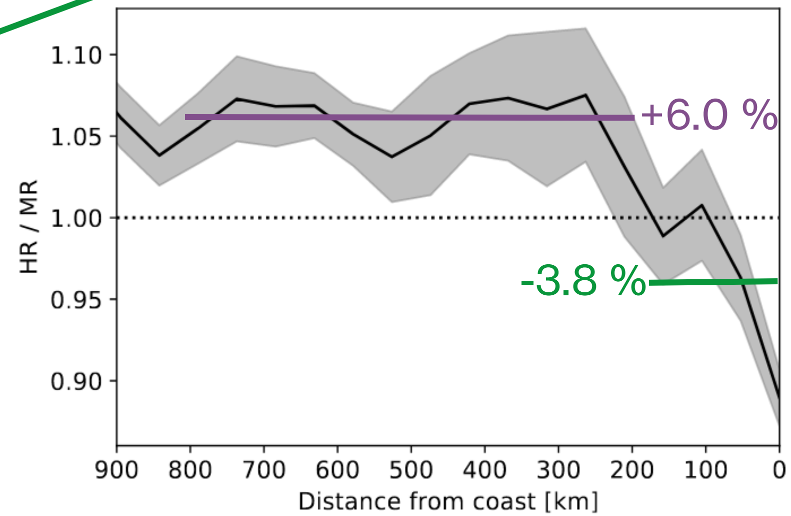

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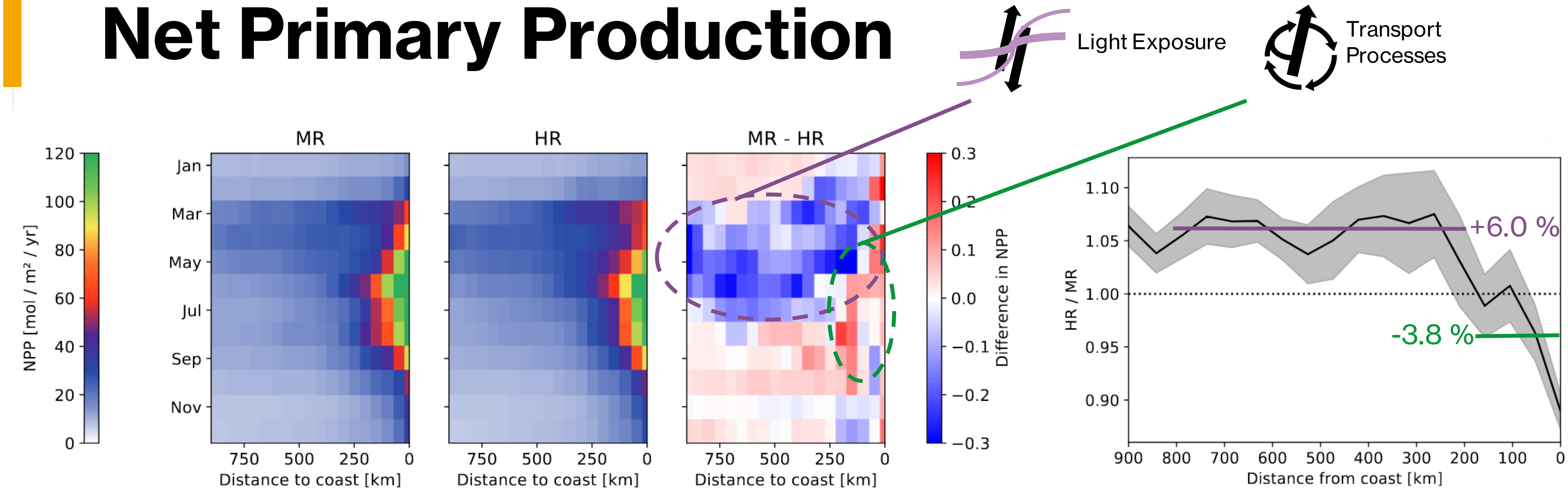

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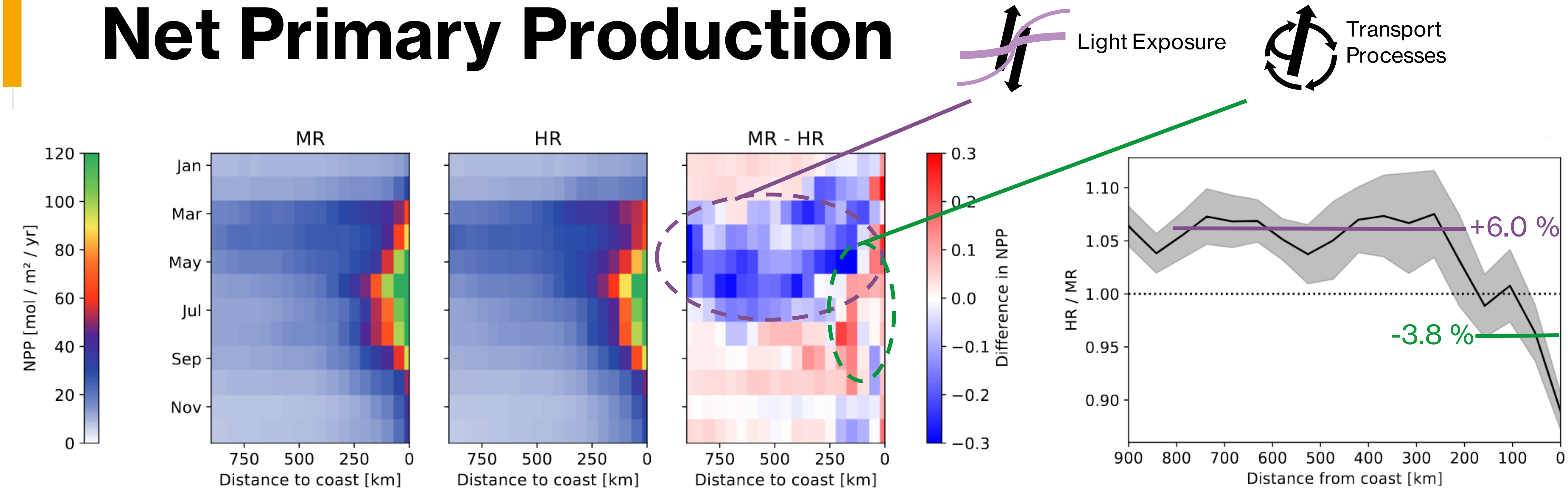

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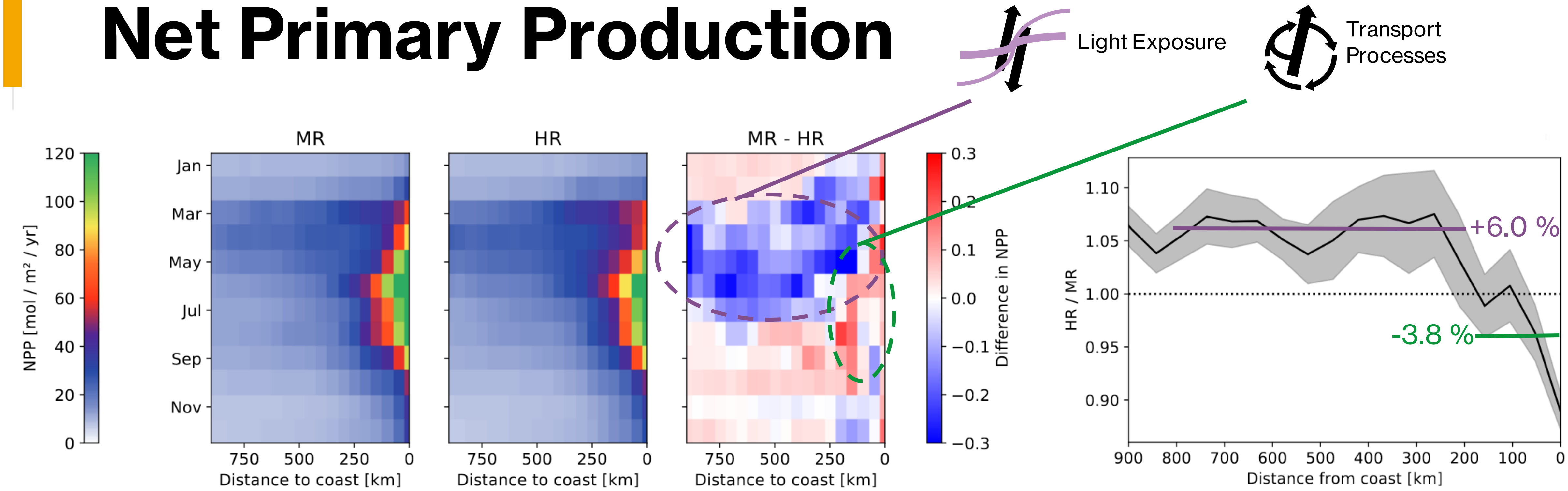

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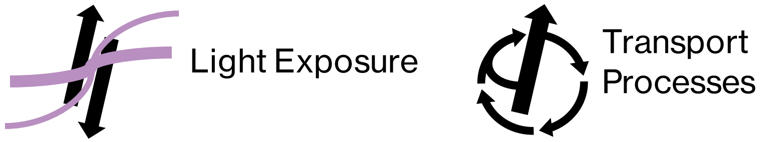

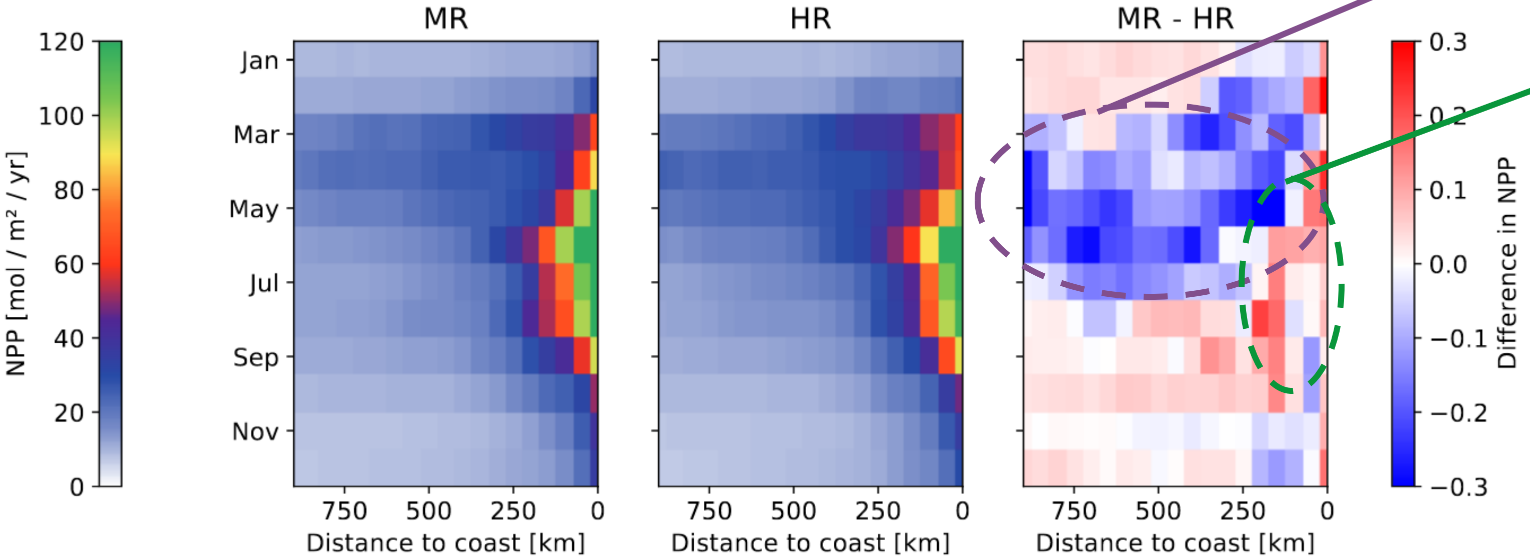

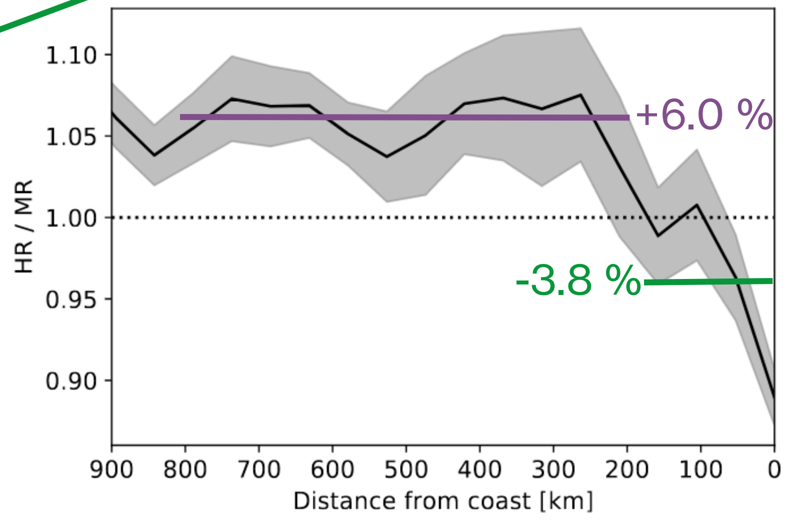

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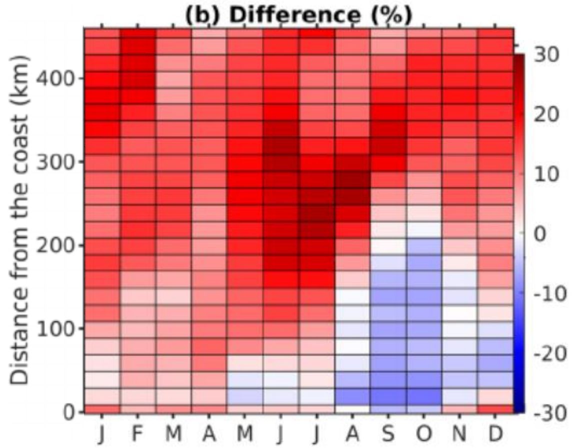

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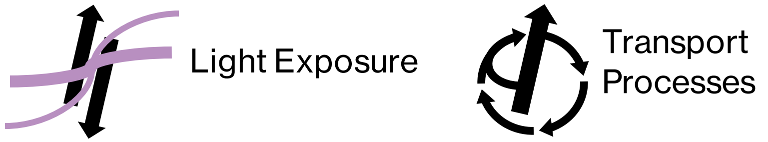

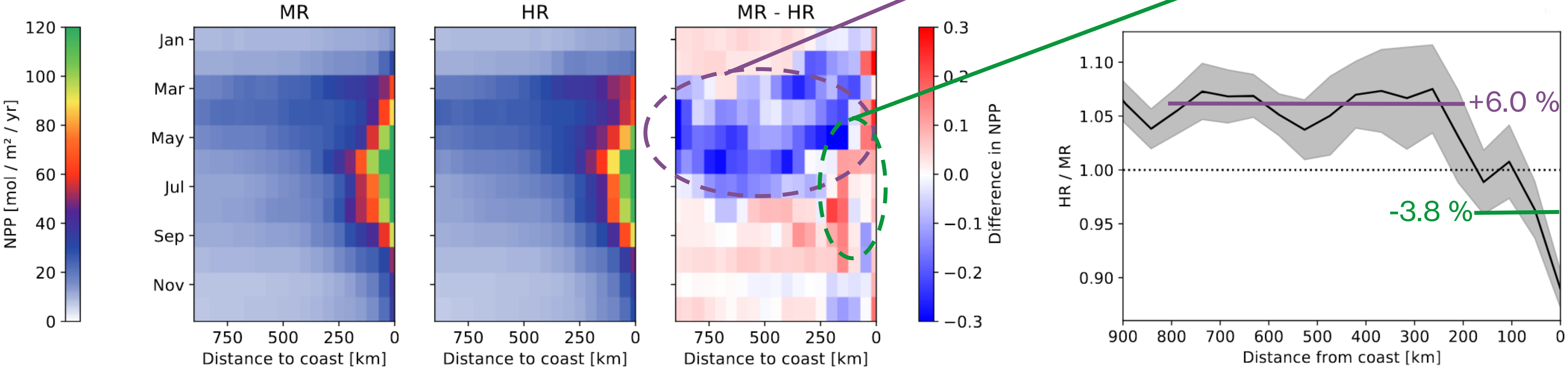

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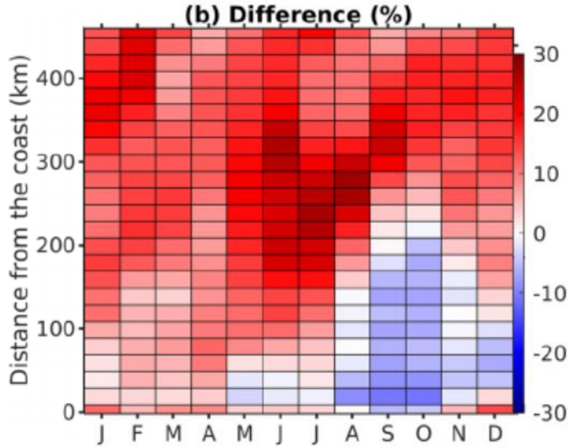

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Thesis and source code:
https://github.com/max-simon/master-thesis

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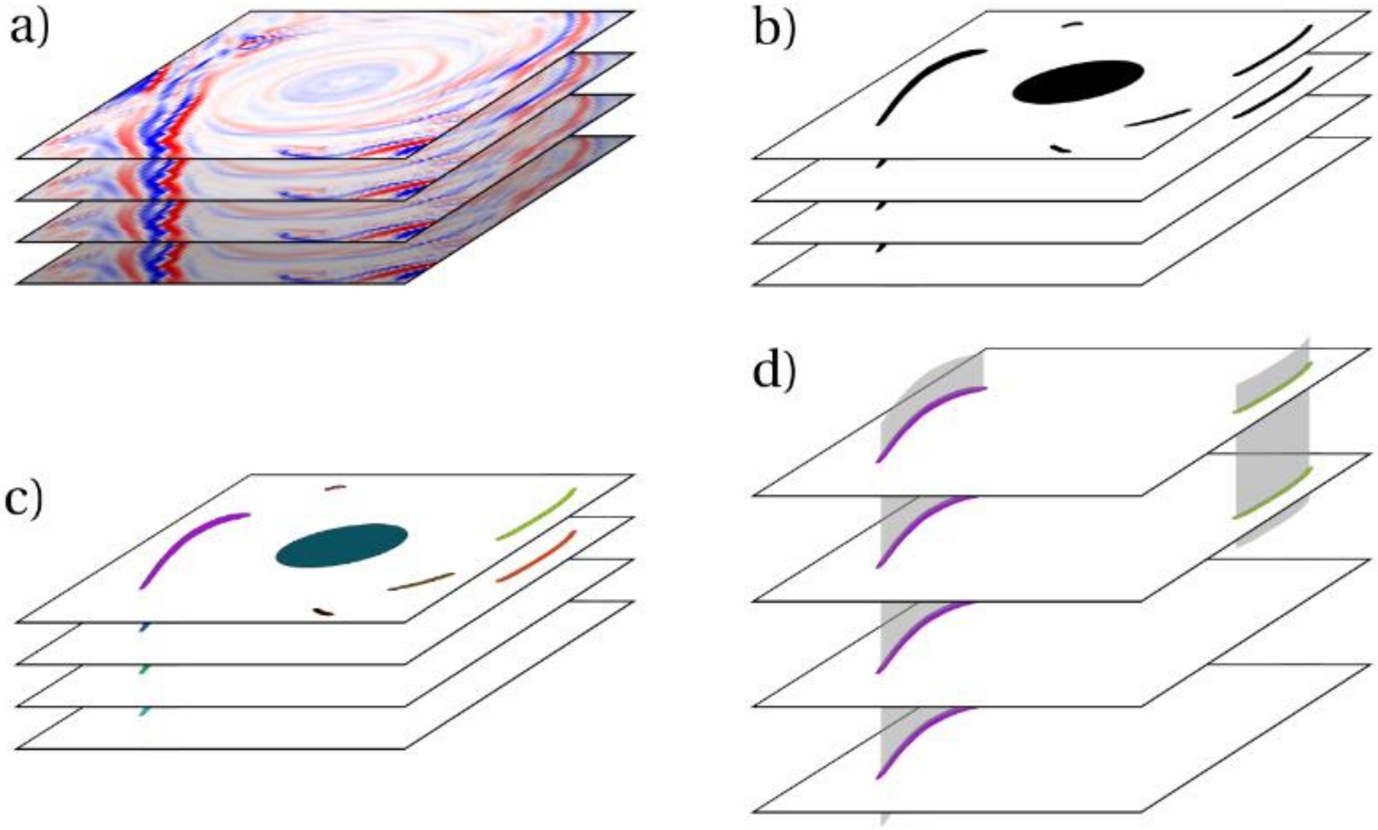
Submesoscale Fronts: Detection Algorithm



1. Calculate an adaptive threshold for every depth level (Gaussian filter, average). Threshold vertical velocities.
2. Perform 2D connected component on every depth level, filter out noise and too circular structures.
3. Perform 3D connected component, filter out too shallow fronts.