Observations of Surface Currents in Panay Strait, Philippines

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Outline

Introduction

Environmental and instrumental setting

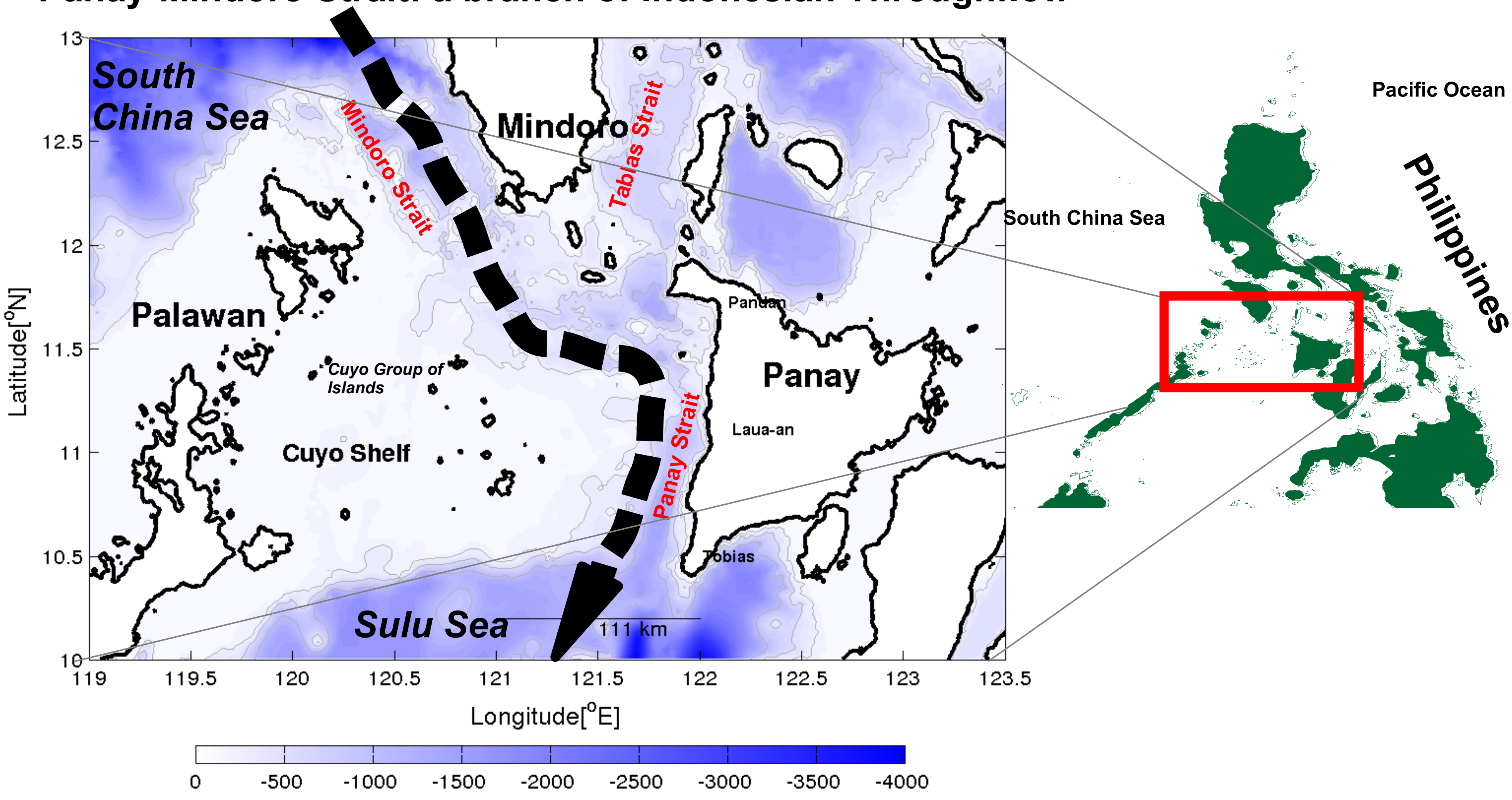
Low frequency flow in Panay Strait

- Surface and subsurface low
- Coastal jet and cyclonic eddy
- Onset and growth of cyclonic eddy
- Influence of eddy on biology
- Conclusions

Introduction

Philippine Straits Dynamics Experiment(PhilEx-ONR)

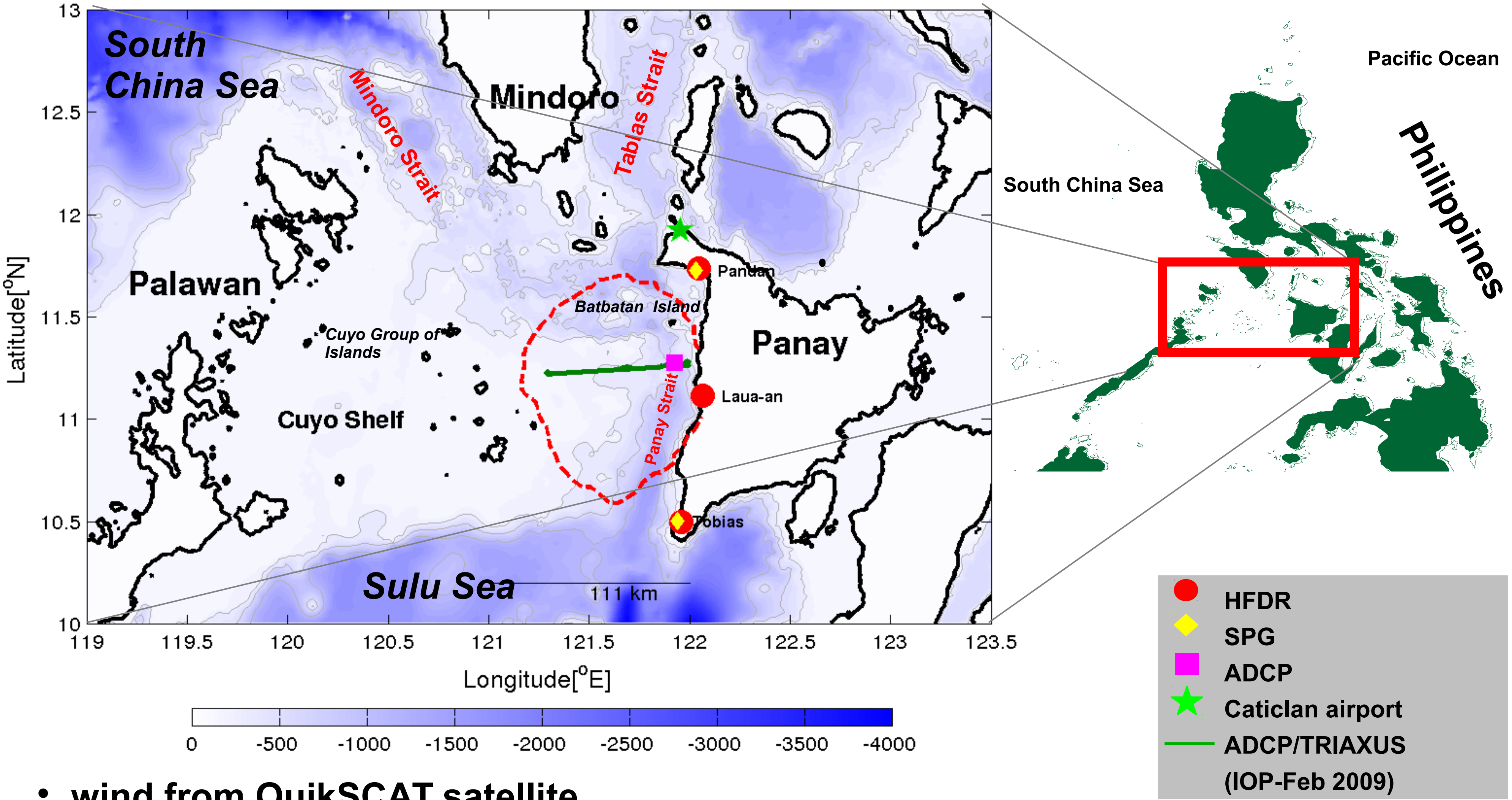
Panay-Mindoro Strait: a branch of Indonesian Throughflow



Environmental and instrumental setting

Philippine Straits Dynamics Experiment(PhilEx-ONR)

Mindoro-Panay Strait: a branch of Indonesian Throughflow



- **wind from QuikSCAT satellite**
- **modeled wind from COAMPS and satellite images of wind**


UP DILIMAN
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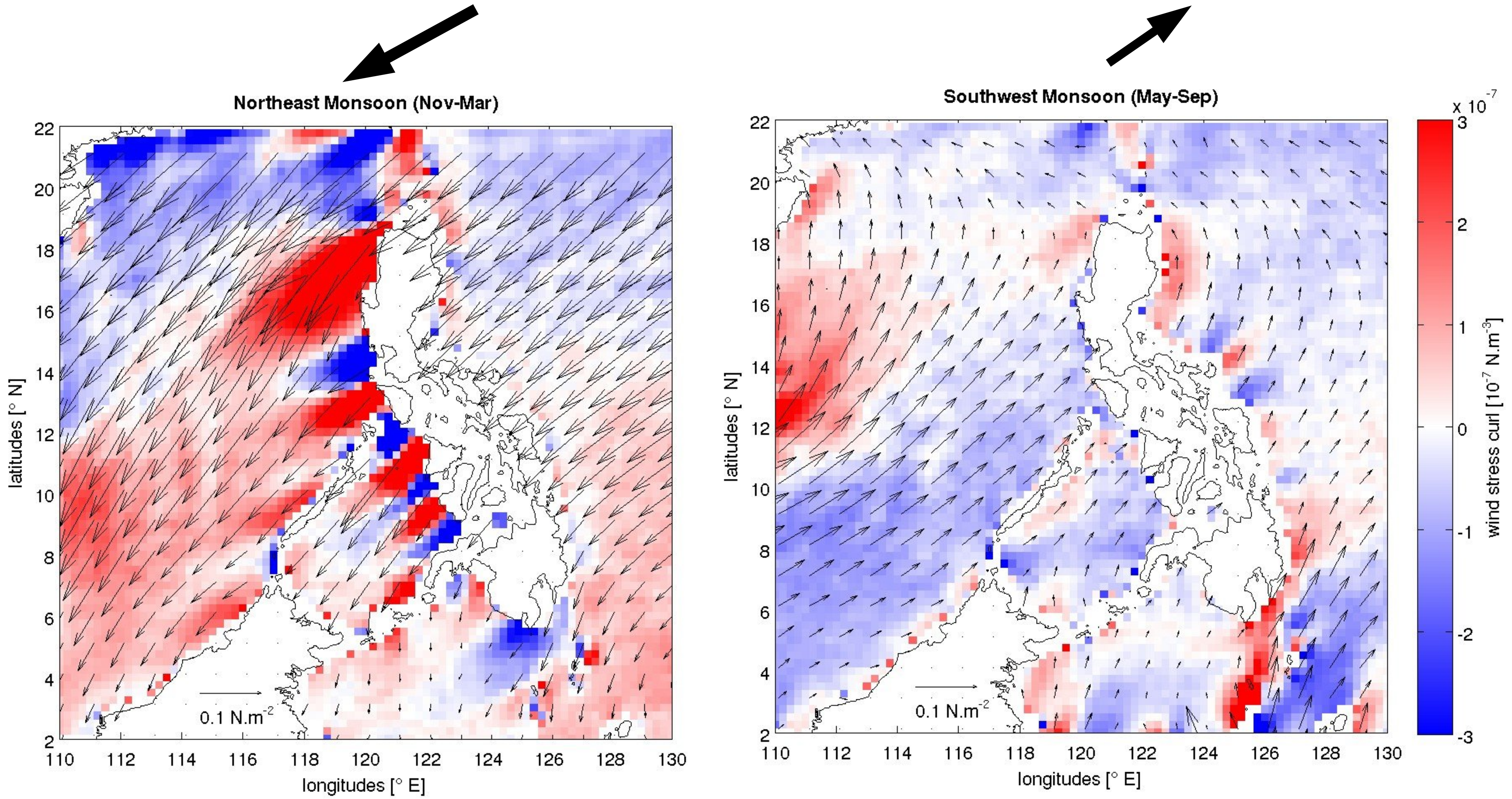
RADIO OCEANOGRAPHY PROJECT
DO NOT ENTER
BAWAL MAGSULOD ROGYA
SALAMAT GID...

Wind stress and curl

QuikSCAT

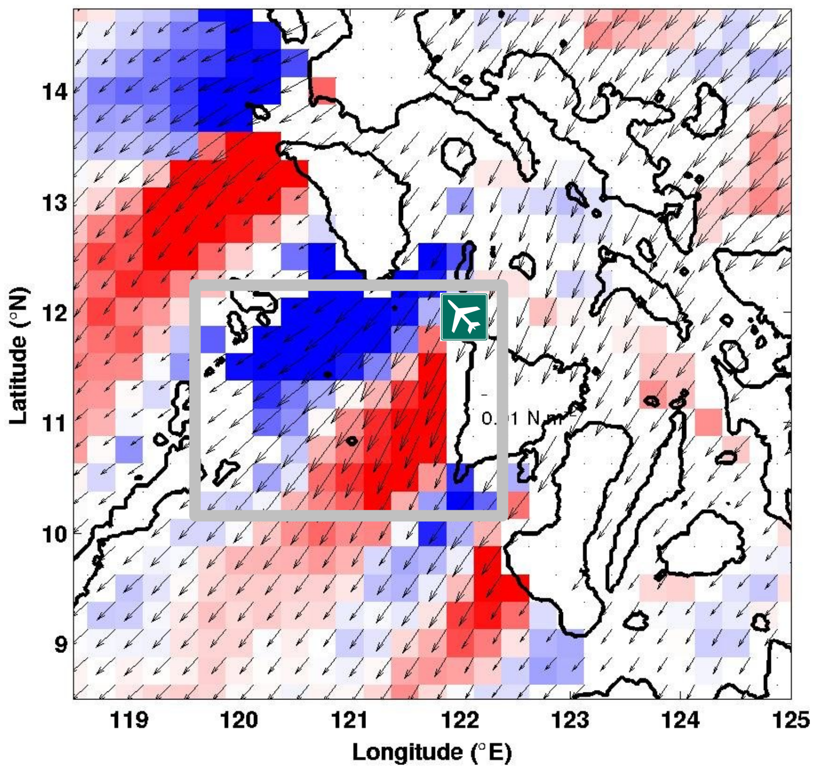


Situated within the strong influence of the Asian monsoon wind

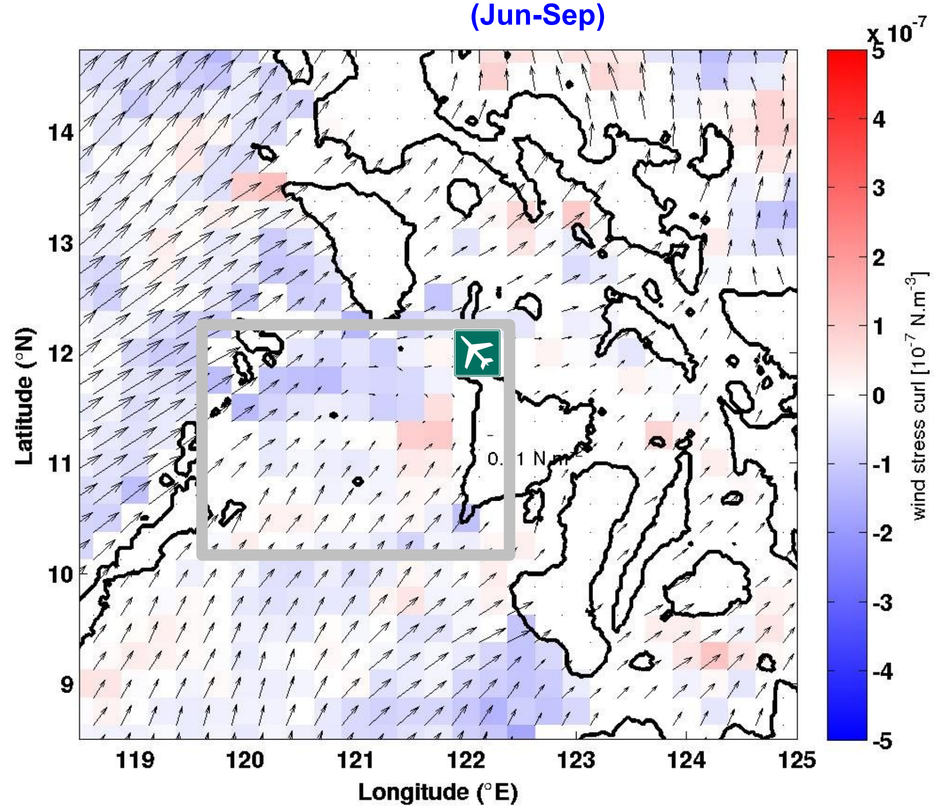
Wind stress and curl

QuikSCAT

NE Monsoon
(Nov-Mar)



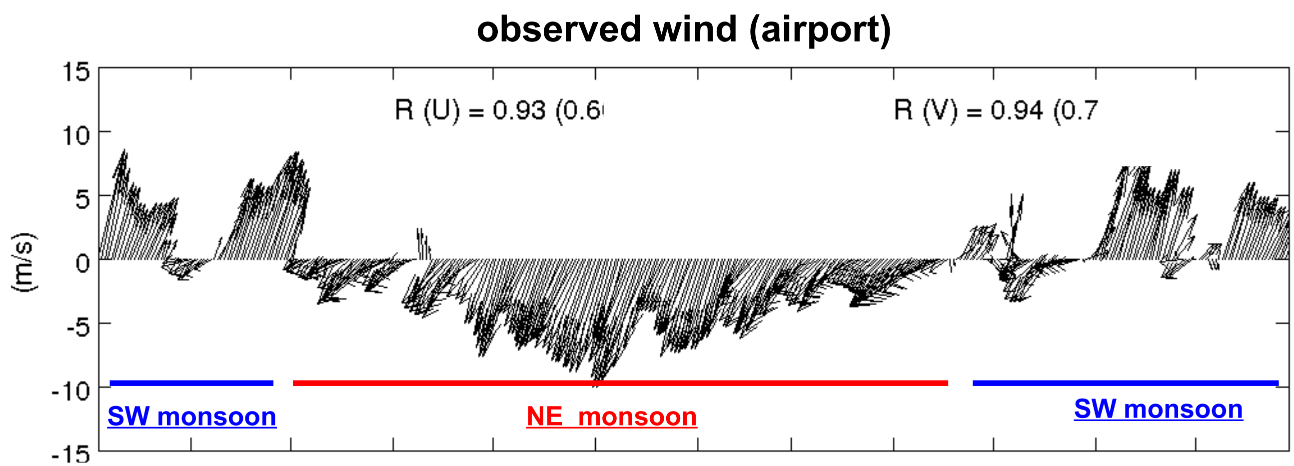
SW Monsoon
(Jun-Sep)

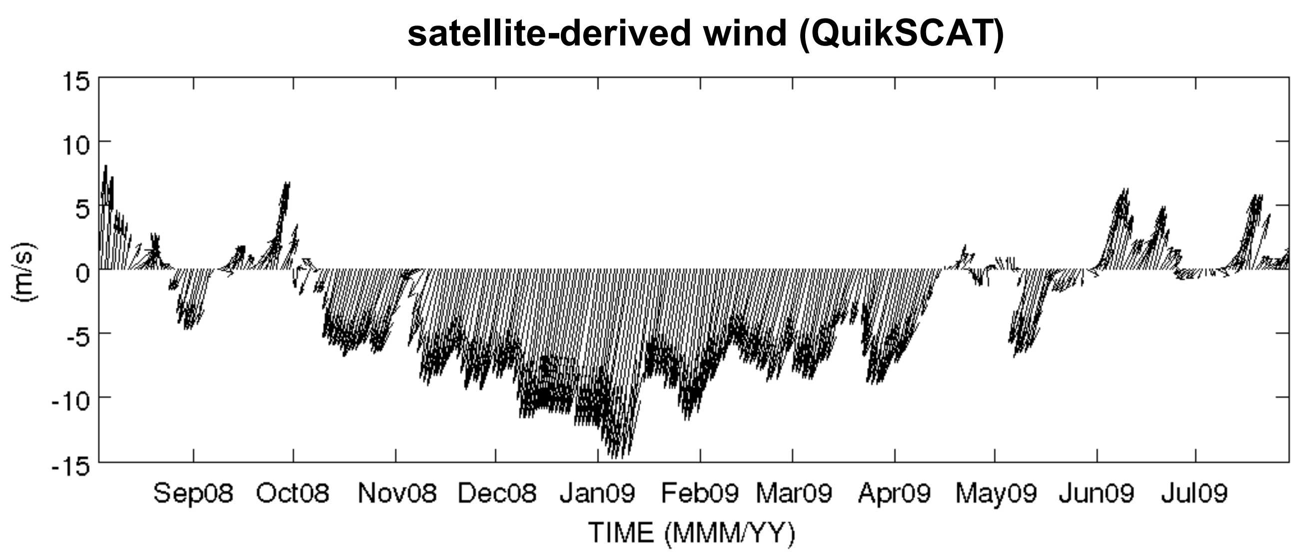


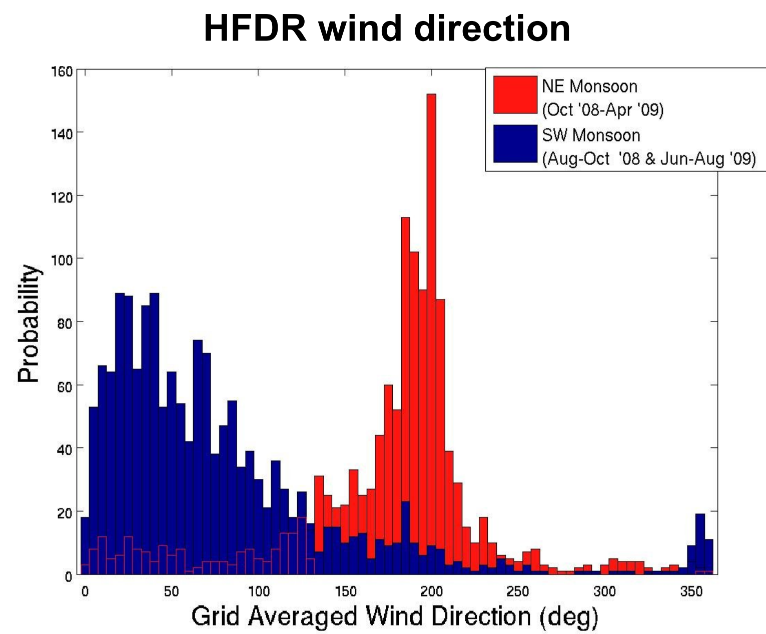
Pronounced seasonal cycle

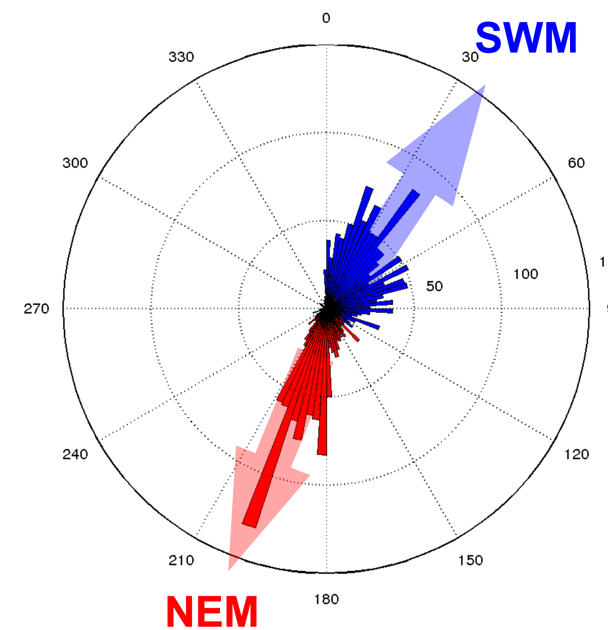
- NE monsoon, positive wind stress curl in the lee of Panay Island
- absent during SW monsoon

Local wind







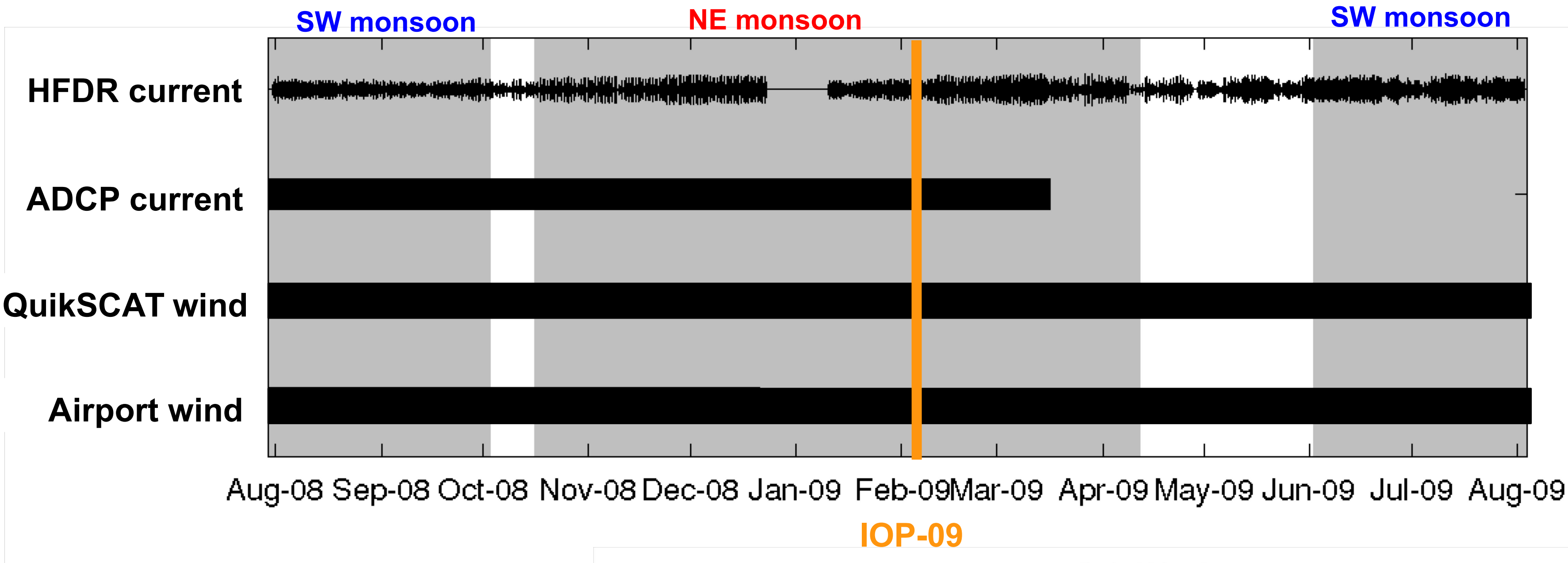


- **Observed and satellite-derived winds well-correlated**
- **Persistent northeasterly wind Oct - April**
- **Variable southwesterly wind May - Sep**
- **Well-defined transition periods, October and April**

Low frequency flow in Panay Strait

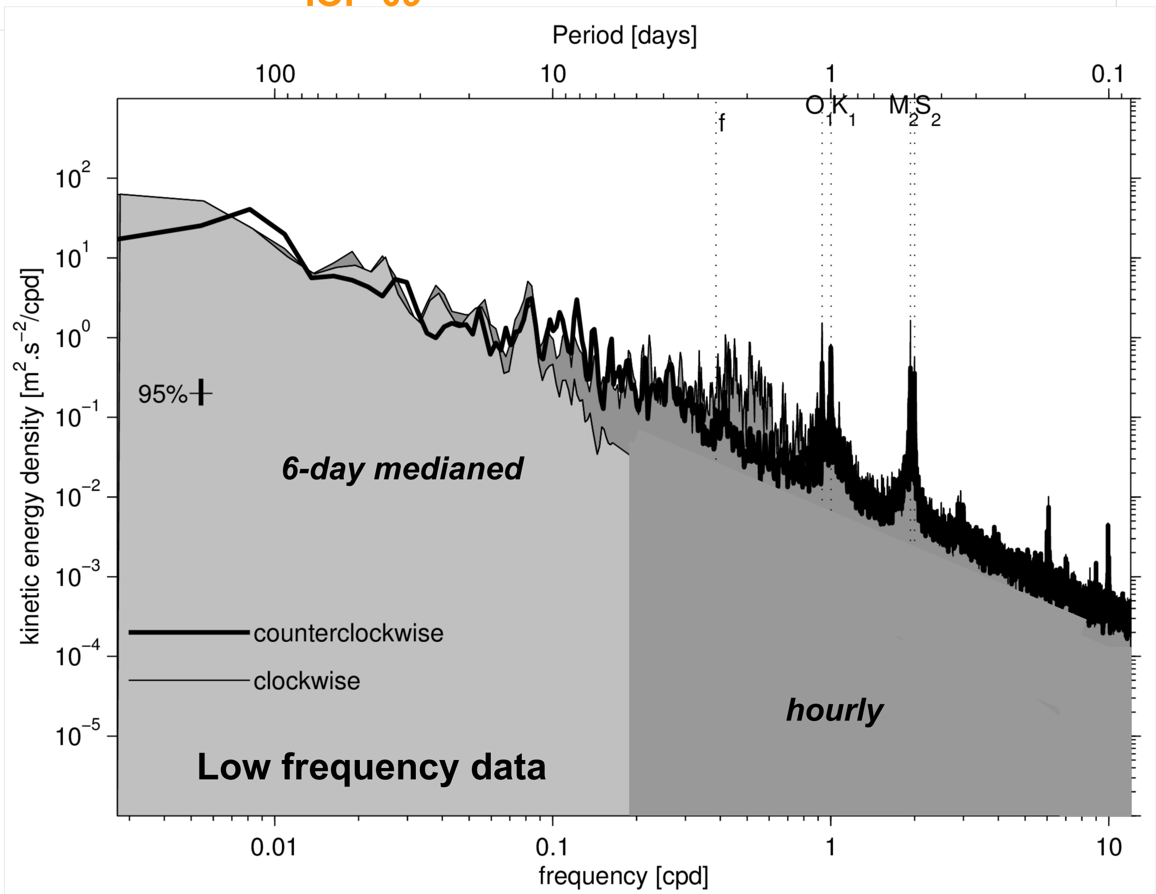
- **characterize the dominant surface and subsurface flows**
- **assess the wind contribution on the onset and growth of cyclonic eddy**
- **describe the influence of eddy on biology**

Data

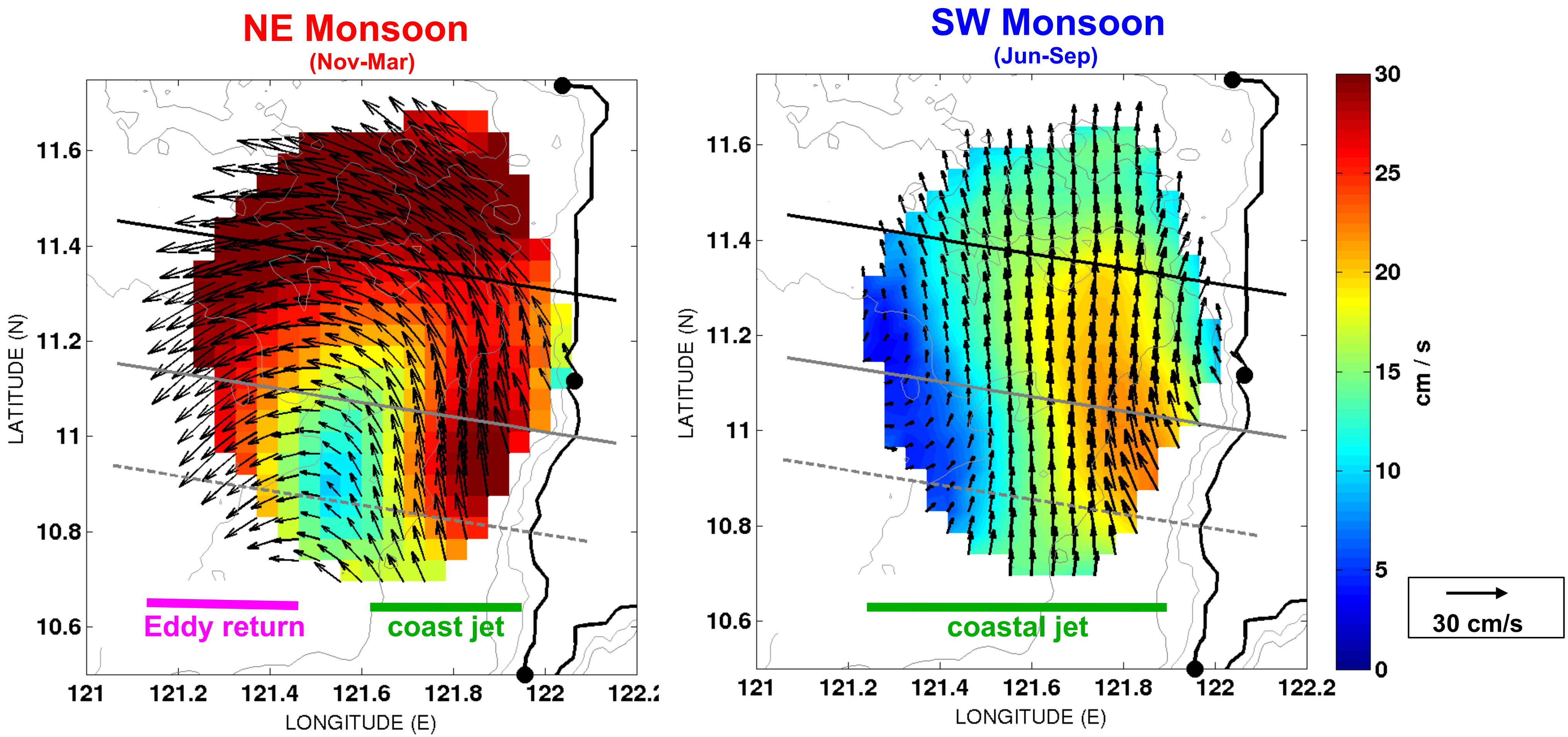


Low-frequency time series obtained by

- **removing the tides (*t-tide*)**
- **6-day running median**

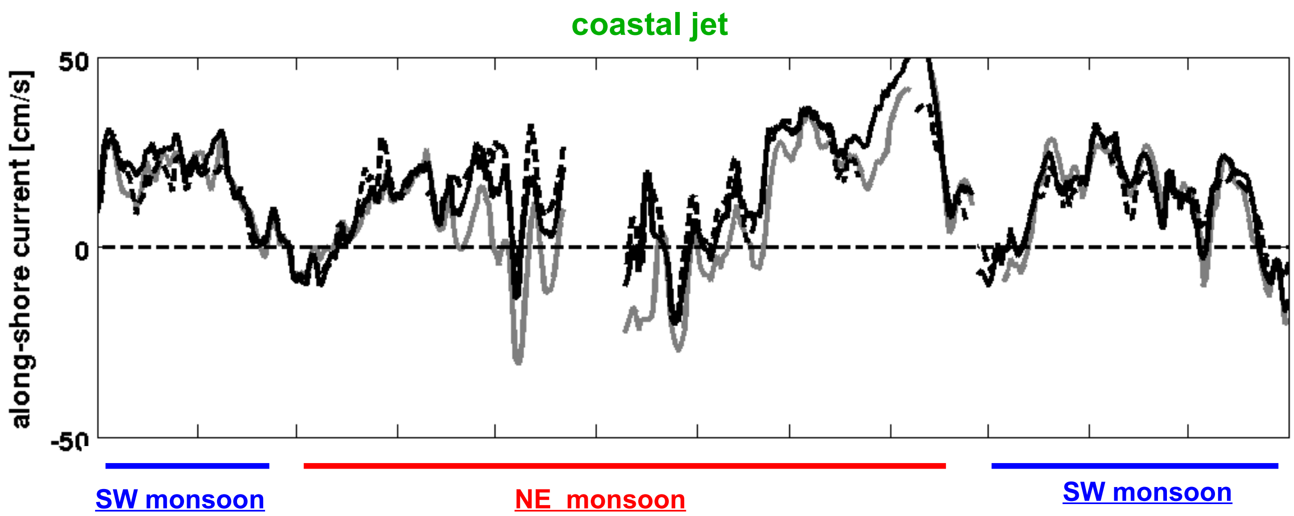


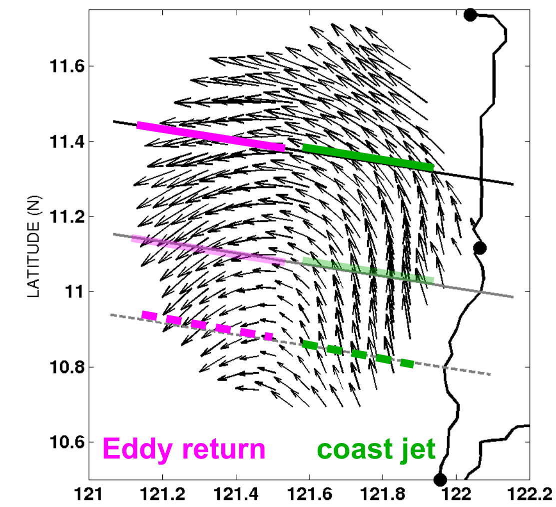
Surface flow (HFDR)

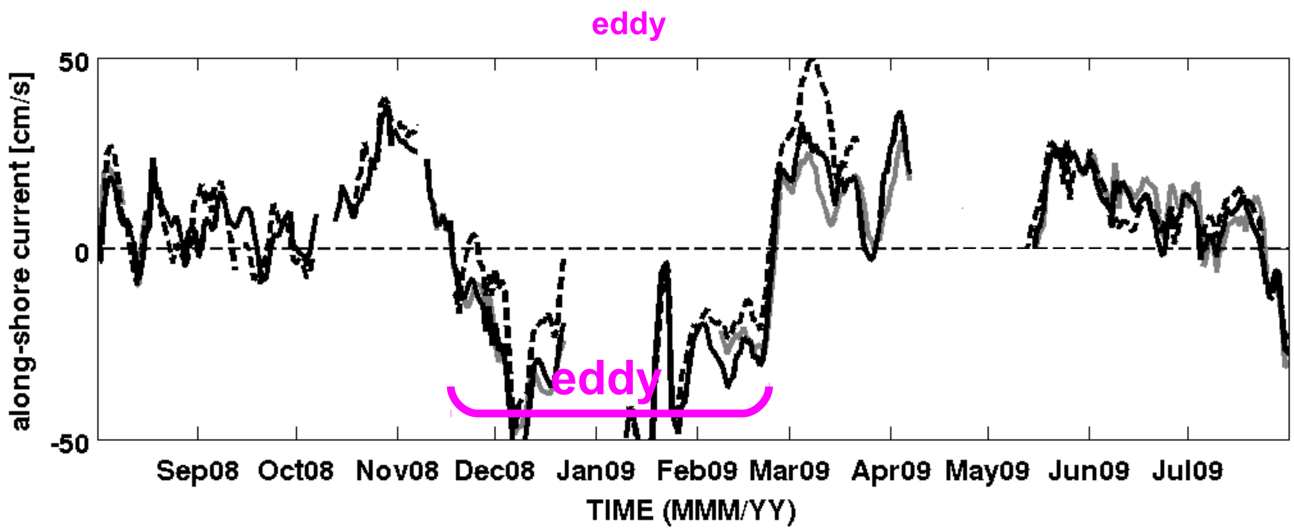


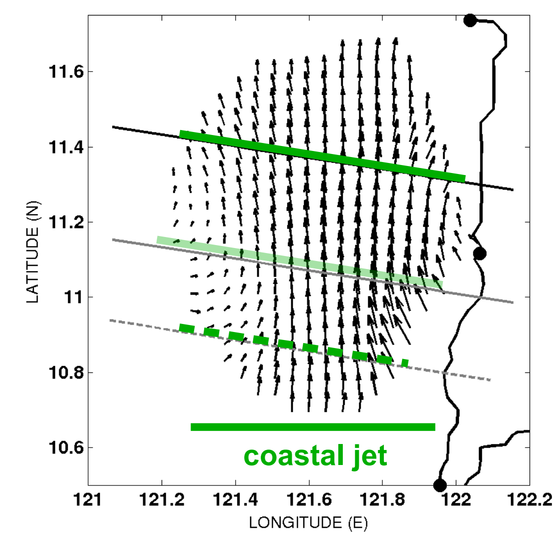
- coastal jet – northward alongshore flow from the coast to the center of the eddy
- eddy – southward return flow from the center of the eddy to the west

. Coastal jet and cyclonic eddy

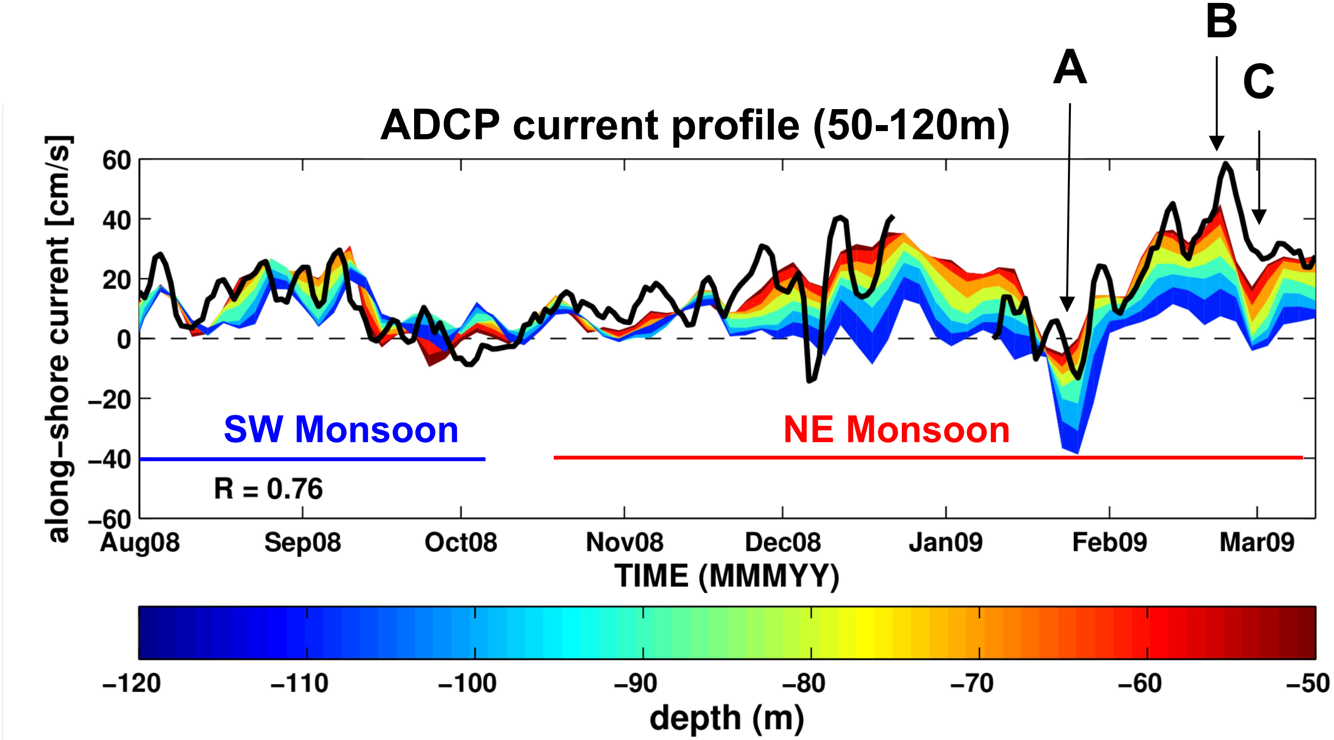


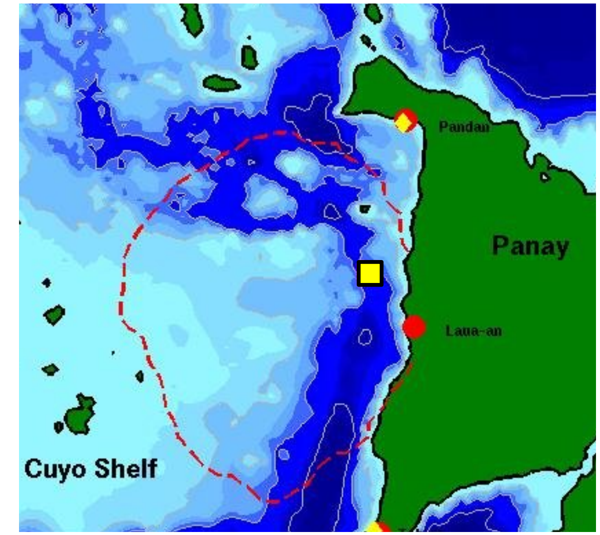




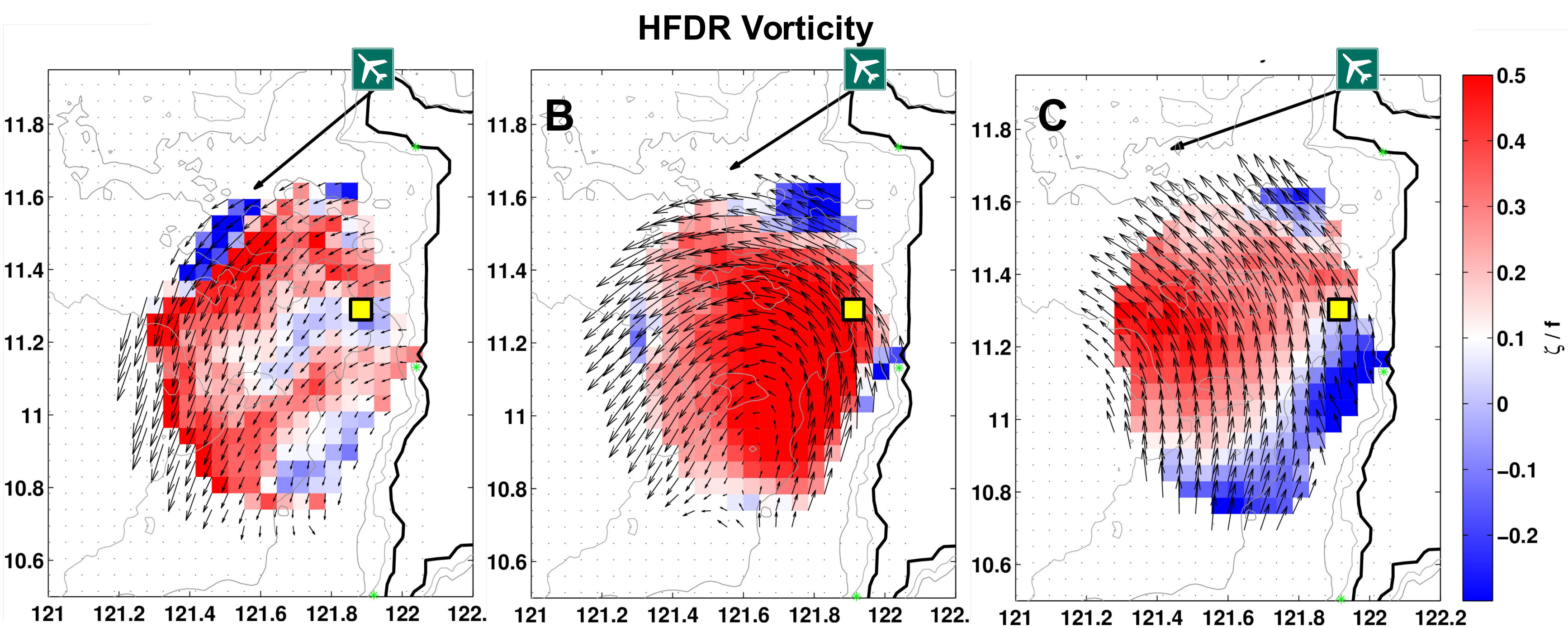


- coastal jet is permanent
- cyclonic eddy is distinctly seasonal, NE monsoon
- well-defined transition periods, October and April
- intermittent variation of coastal jet concurrent with the eddy formation



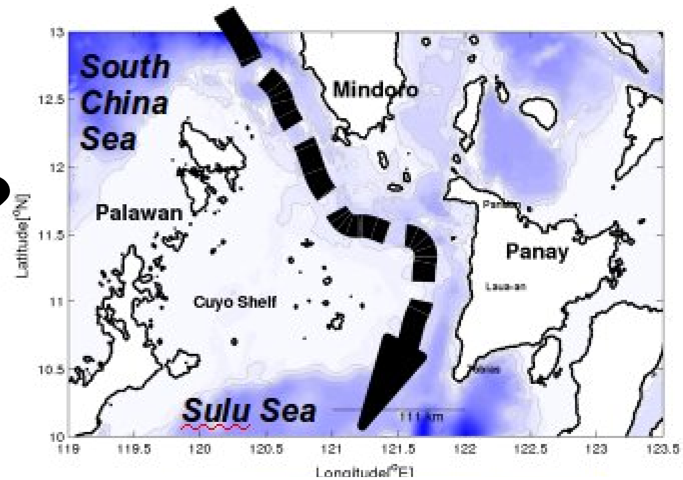


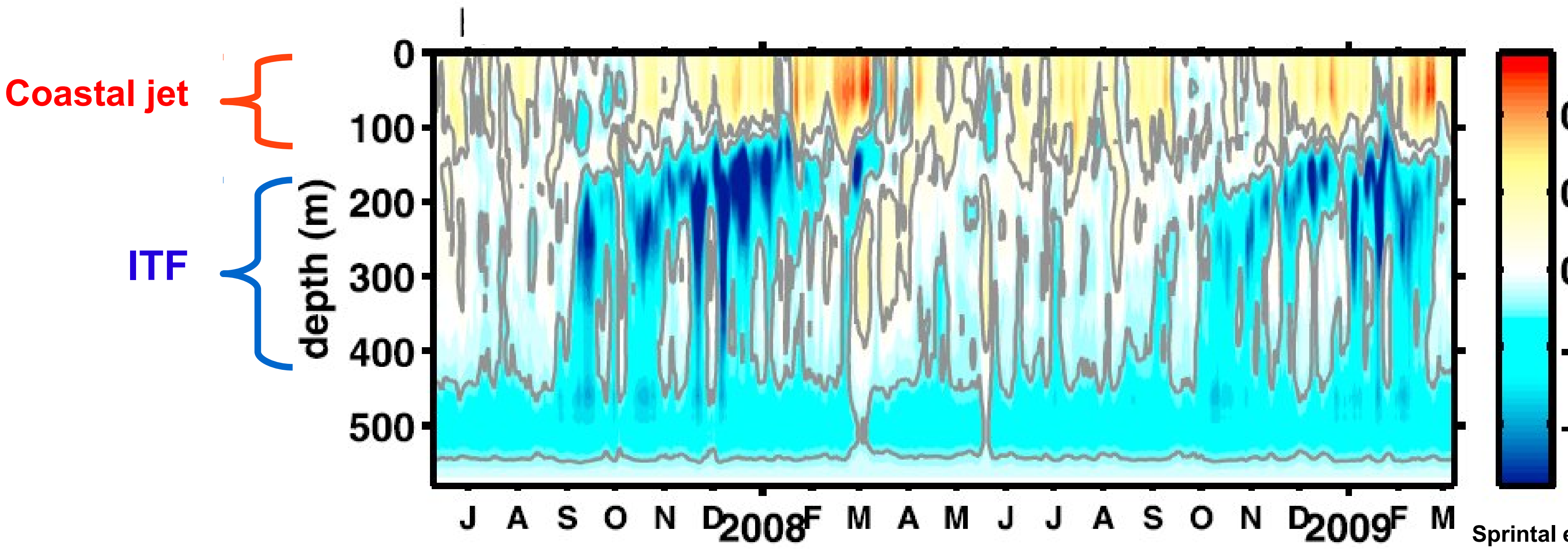
- coastal jet stronger and variable during NE monsoon
- reinforced and shift by the eddy



• Where is the Indonesian Throughflow?

- move water from South China Sea southwest to Sulu Sea





Sprintal et al., 2012

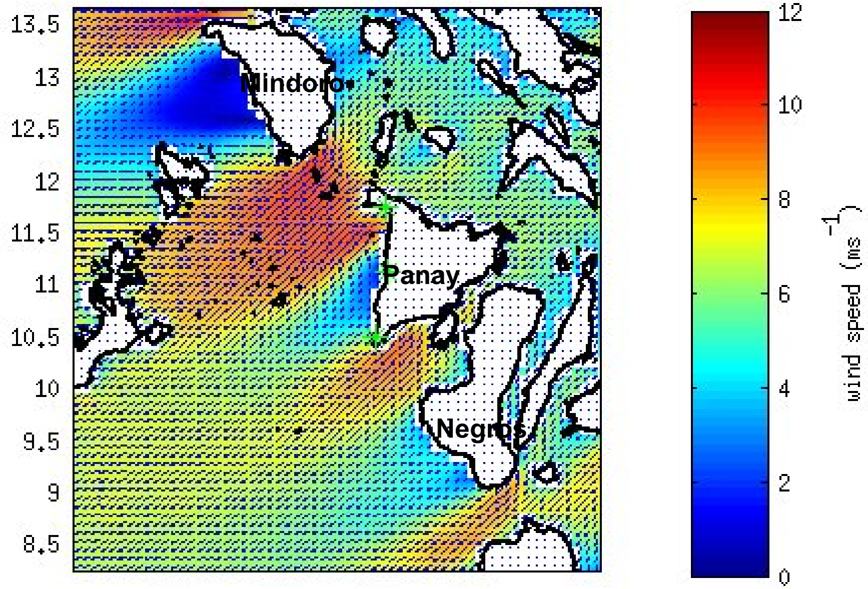
Vertical distribution of transport per unit depth (Sv m^{-1}) to Panay sill depth

- **southwestward Indonesian Throughflow (ITF) is subsurface, under locally forced northward coastal jet**

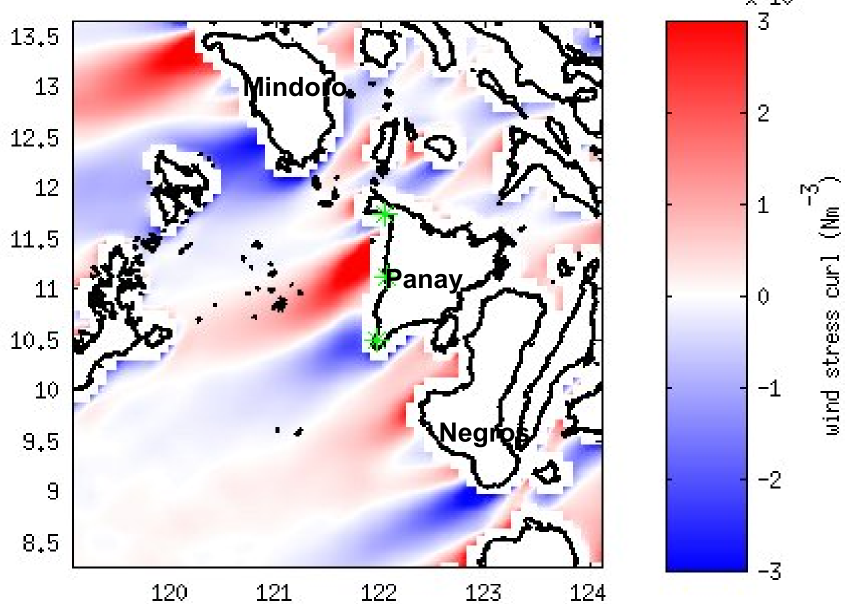
Onset and growth of cyclonic eddy

High resolution COAMPS wind (9km): mean Feb-Mar 2009

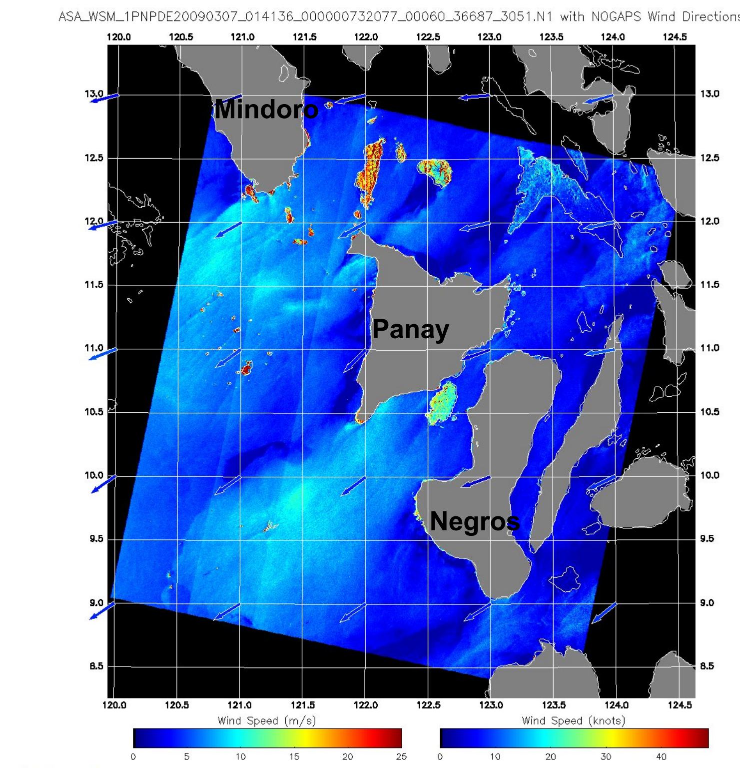
COAMPS Wind



COAMPS Wind Stress Curl



Envisat SAR Surface wind (Mar. 7, 2009)



- **wind jet in between islands and a calm lee**
- **positive curl in the lee of Panay**

• Ekman pumping velocity, w_E

$$w_E = w\left(-H_E\right) = \frac{curl\tau}{\rho f}$$

H_E - Ekman depth

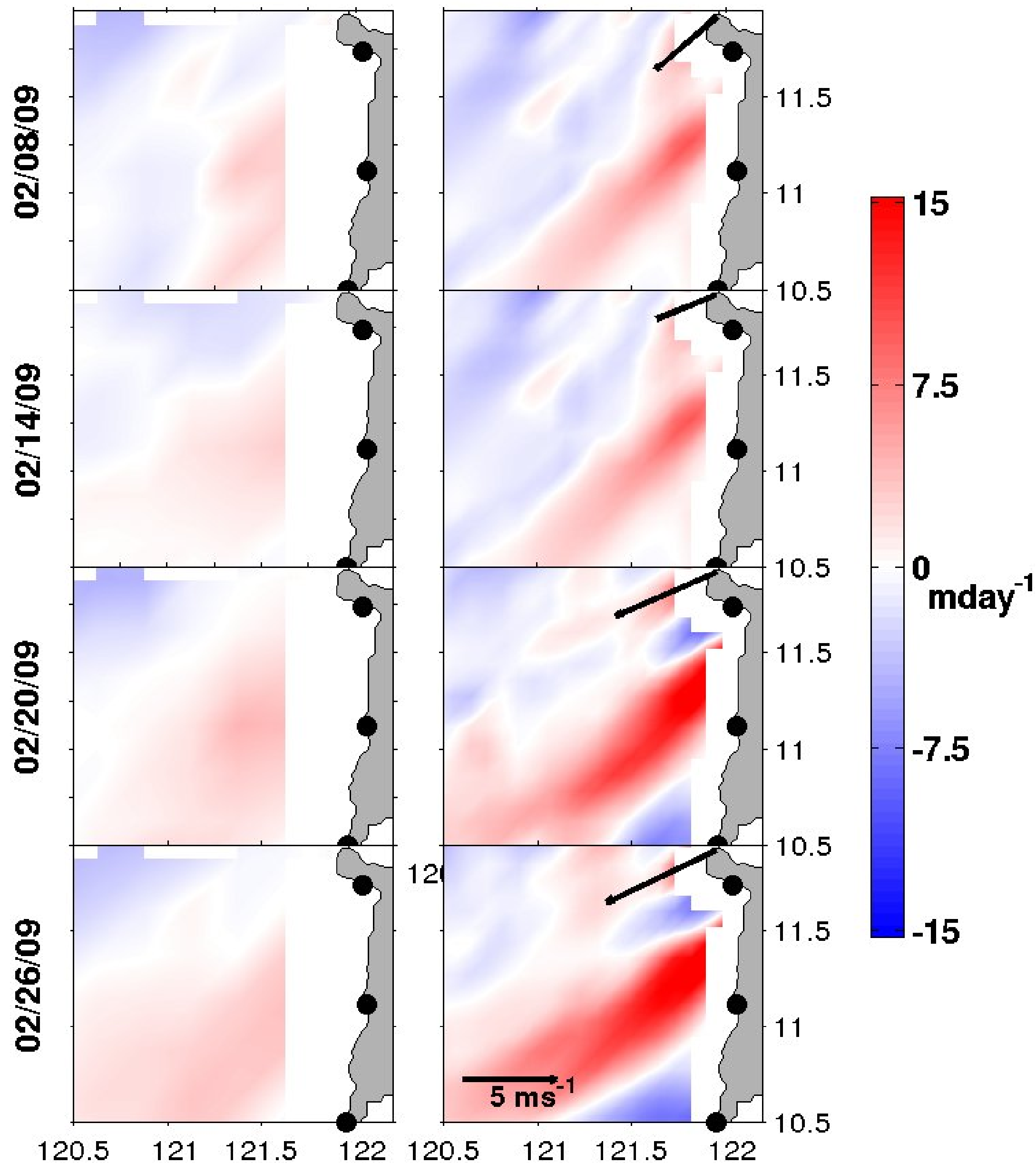
τ - Wind stress

ρ - Density

f - Coriolis parameter

- **positive Ekman pumping velocity indicates divergent Ekman transport**

QuikSCAT vs. COAMPS



COAMPS wind (9km x 9km)

QuikSCAT wind (25km x 25km) - too low resolution

• Surface current and divergence: Feb-Mar 2009

assuming:

- **divergence entirely wind-driven**
- **divergence confined to Ekman/mixed layer**

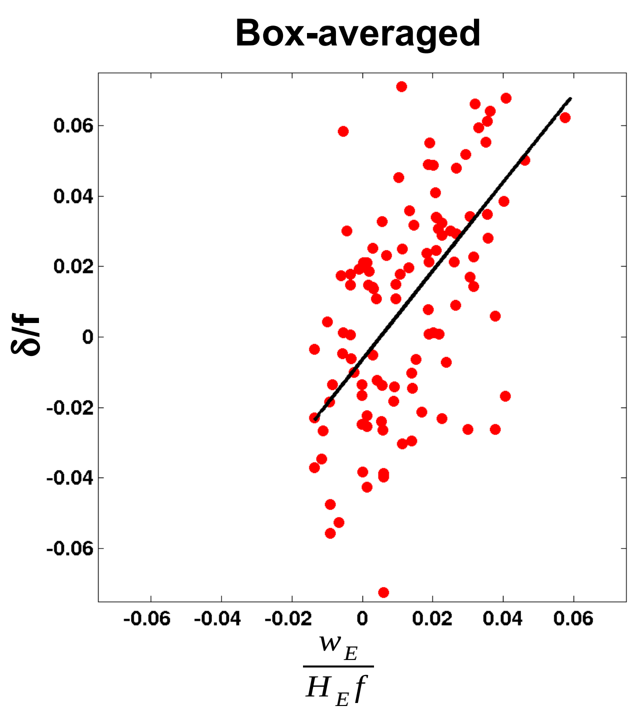
then

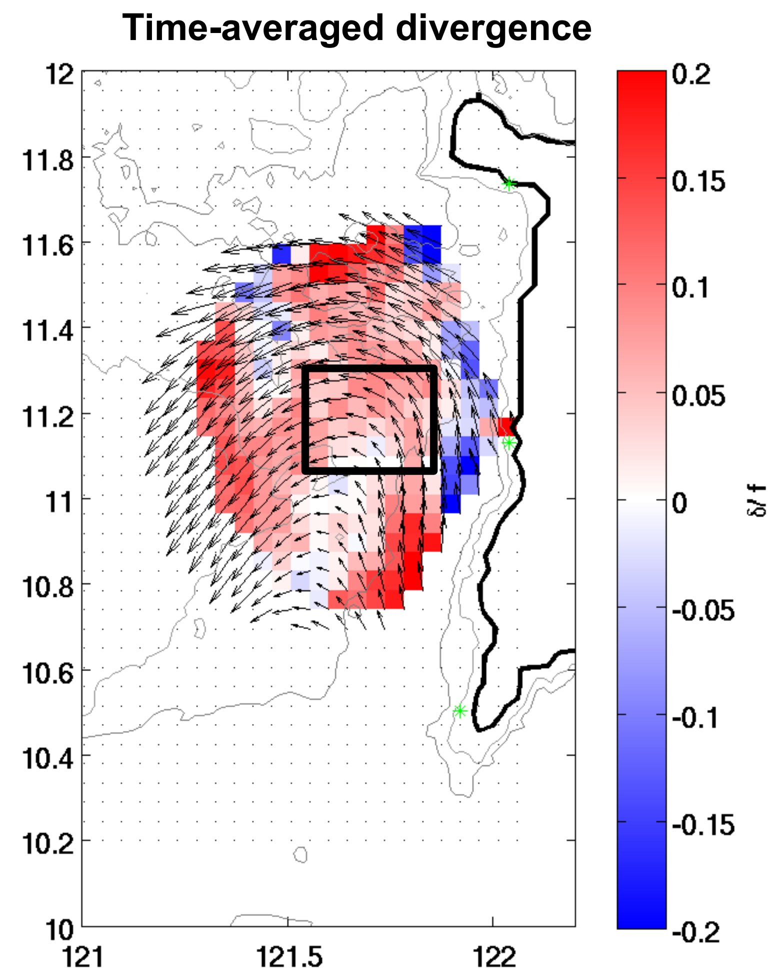
$$div\,\vec{u} = \delta = \frac{w_E}{H_E}$$

$div\,\vec{u}$ - divergence, (HFDR)

w_E - Ekman pumping velocity, (COAMPS)

H_E - Ekman depth, best fit = 32m

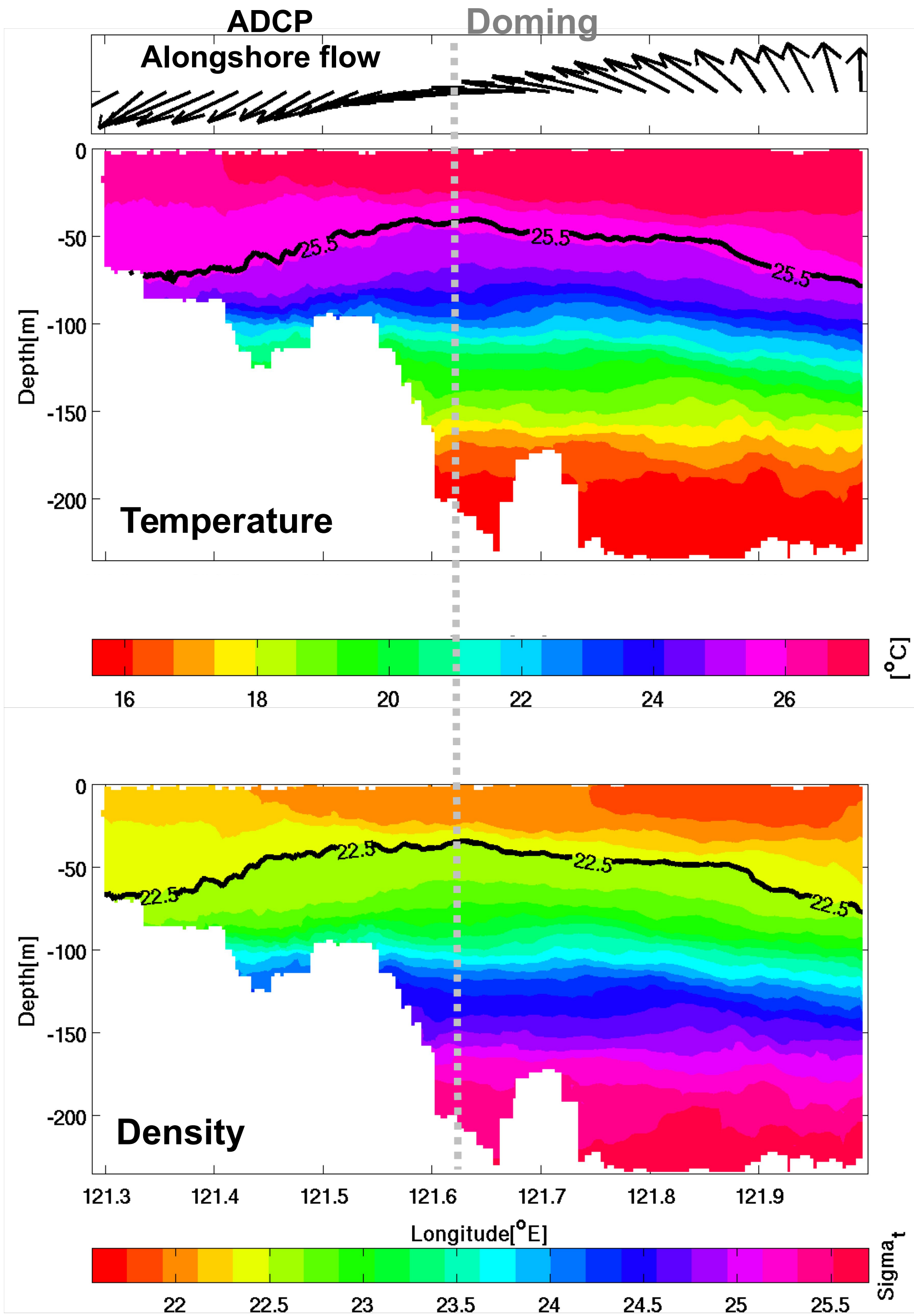


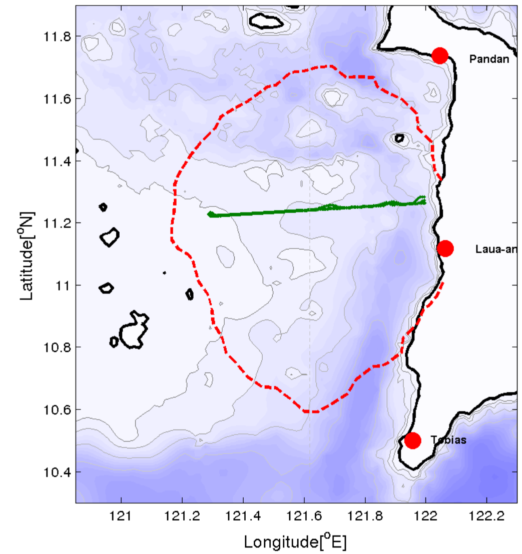


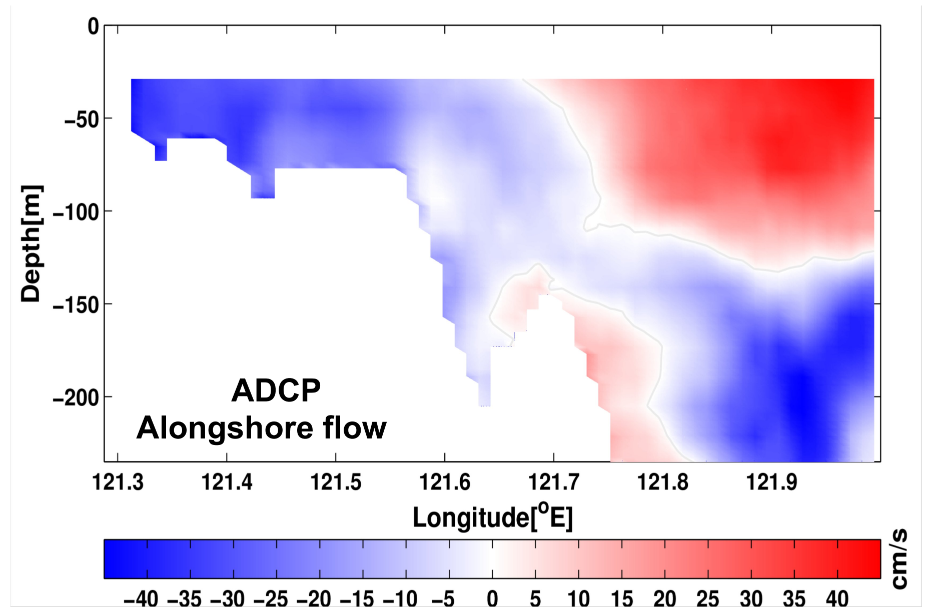
- **divergent Ekman transport induce upwelling**

• Signature of cyclonic eddy

(Feb 8, 06:07:21 – Feb 9, 07:10:44, 2009)

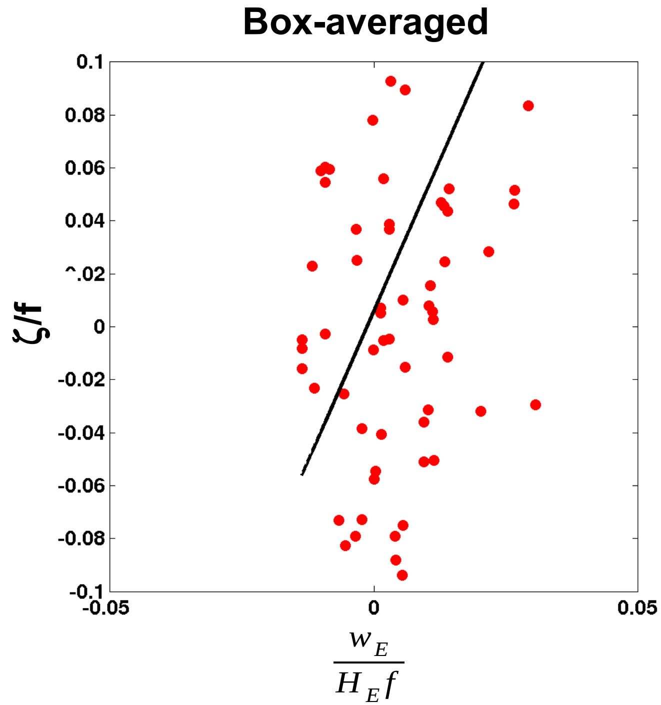


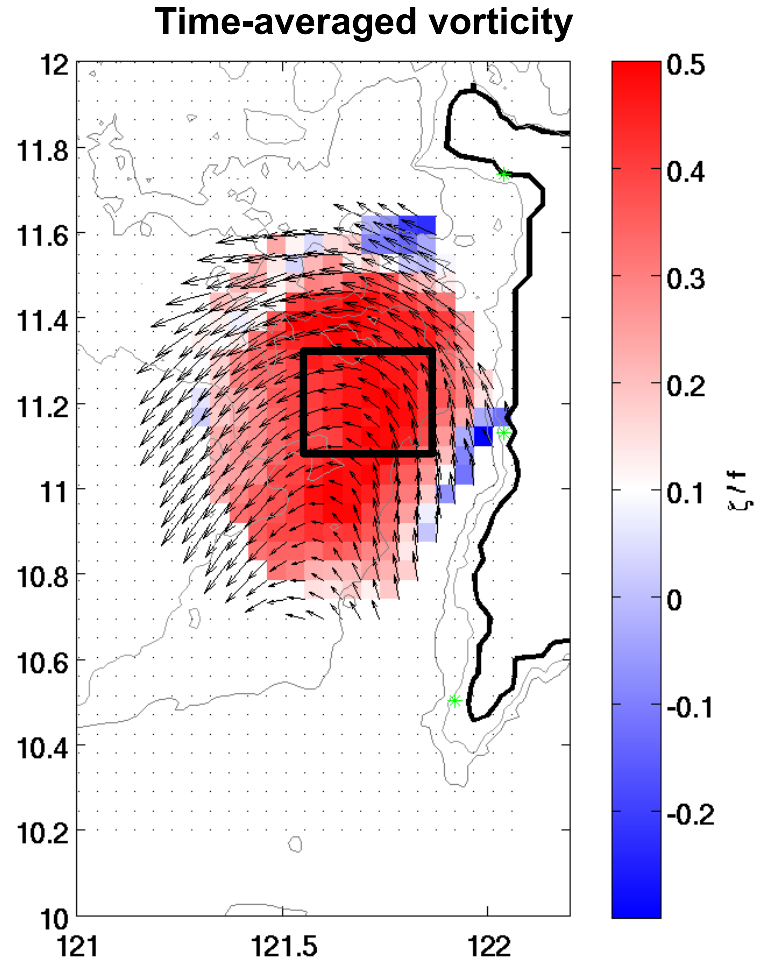


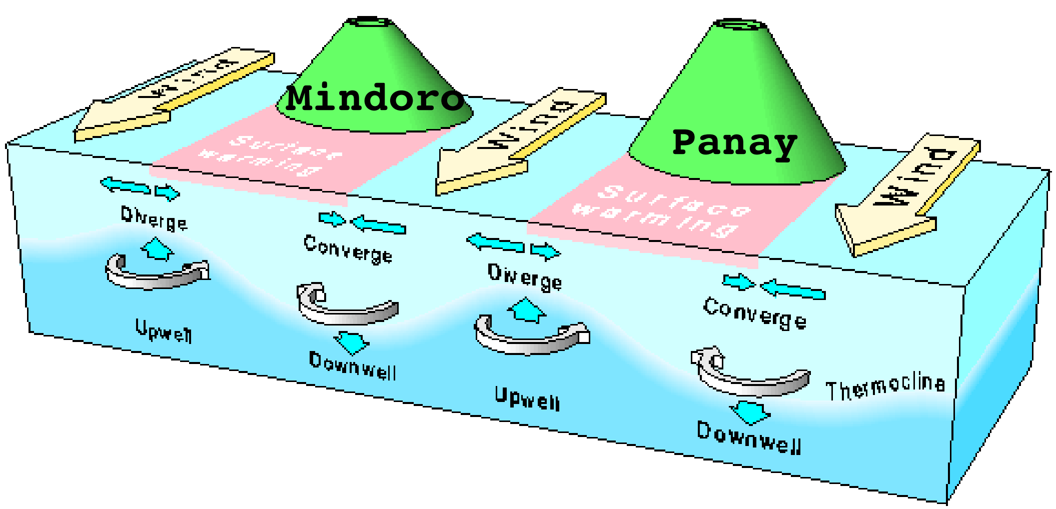


- divergence and upwelling result in doming
- sets up pressure gradient
- geostrophic eddy spins-up

• Surface current and vorticity: Feb-Mar 2009

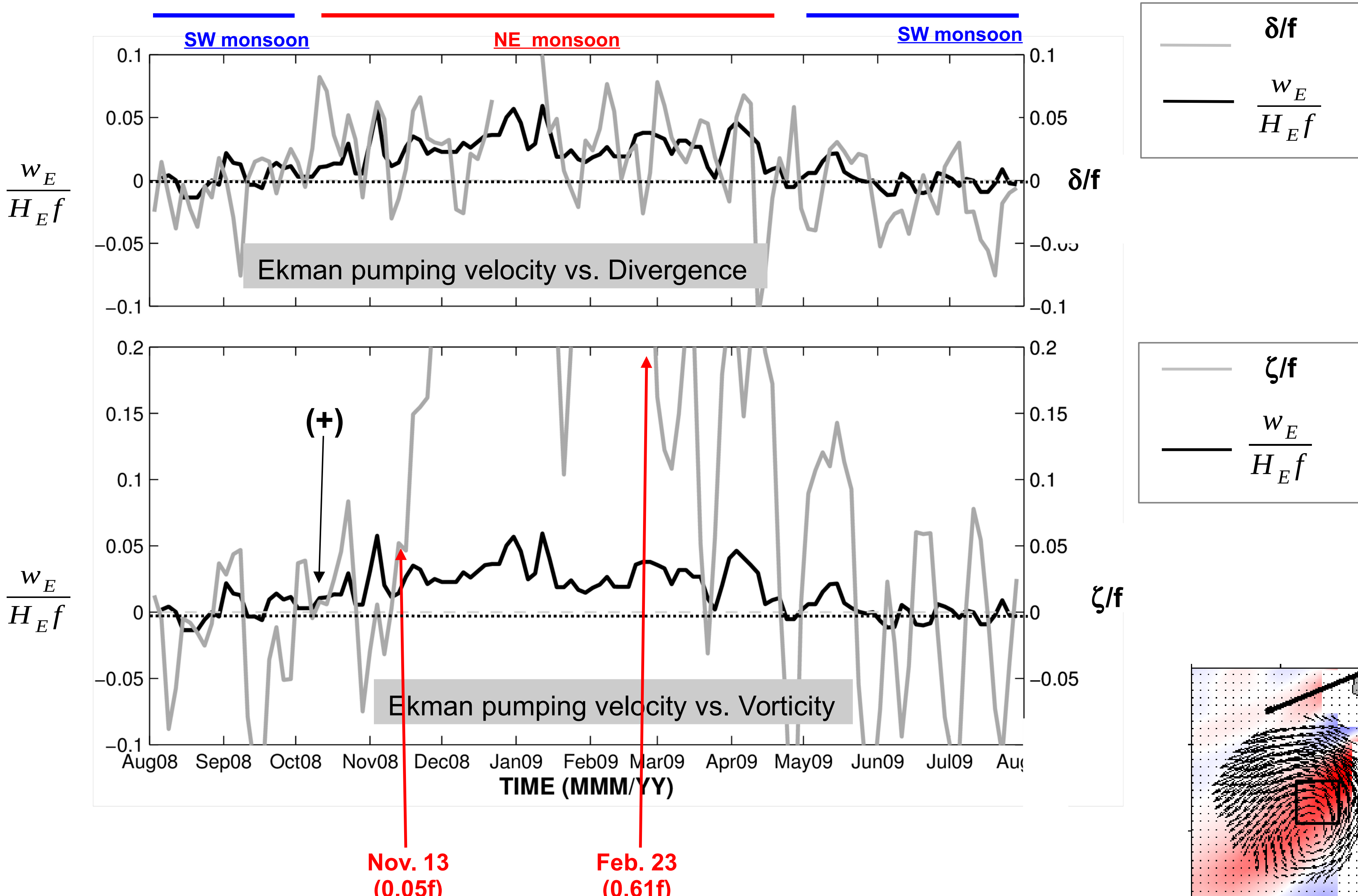




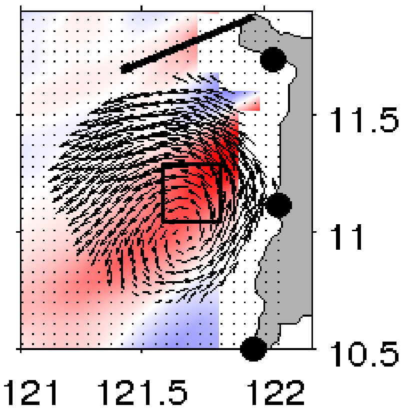


• **Wind stress curl induces divergence that generates positive vorticity**

• **Time series**

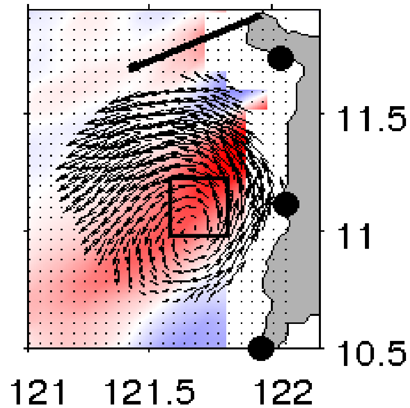


SW monsoon
NE monsoon
SW monsoon
$\frac{w_E}{H_E f}$
δ/f
Ekman pumping velocity vs. Divergence
0.1
0.05
0
−0.05
−0.1
(+)
ζ/f
Ekman pumping velocity vs. Vorticity
0.2
0.15
0.1
0.05
0
−0.05
−0.1
Aug08
Sep08
Oct08
Nov08
Dec08
Jan09
Feb09
Mar09
Apr09
May09
Jun09
Jul09
TIME (MMM/YY)
Nov. 13
(0.05f)
Feb. 23
(0.61f)

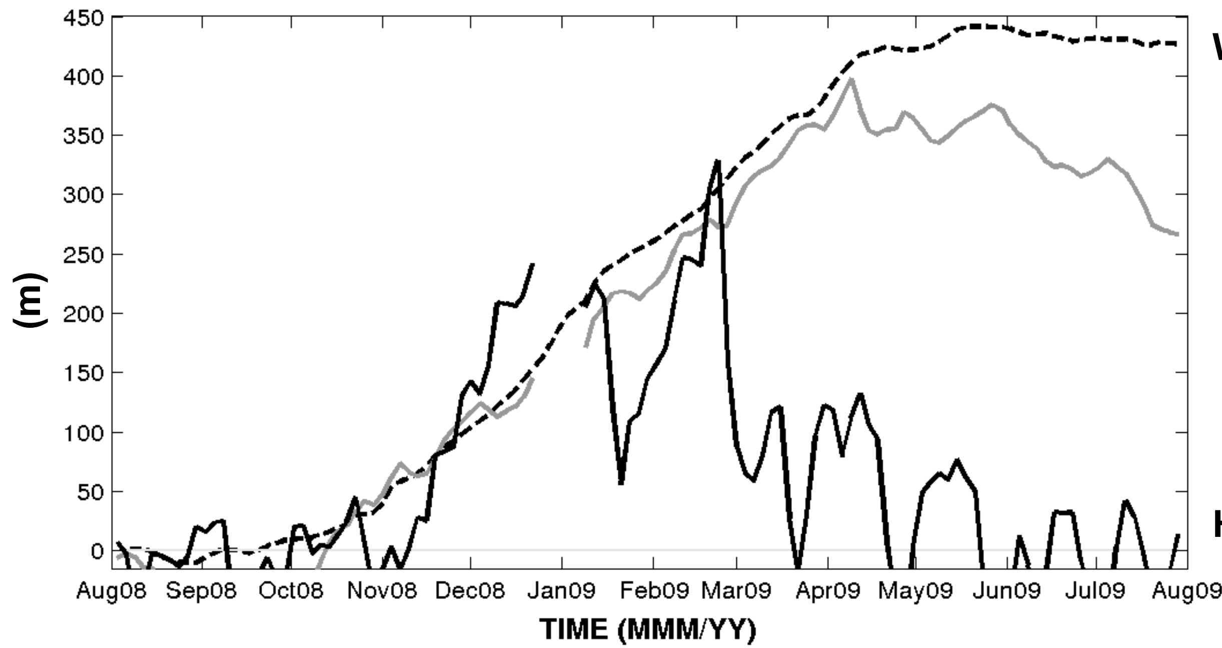


11.5
11
10.5
121
121.5
122

- **Time integral**



Cumulative effect of wind stress curl generates divergence, permanently lifting the thermocline and increases vorticity



W_E - wind stress curl

δ **- divergence**

H_g - vorticity

$\int_0^T W_E$ **(COAMPS)** **W_E – Ekman pumping velocity**

$H_E \int_0^T \delta$ **(HFDR)** **H_E – Ekman depth, best fit = 32 m**

H_g **(HFDR)** **H_g – thermocline height**

$$H_G = \frac{\zeta f L_G^2}{g'}$$

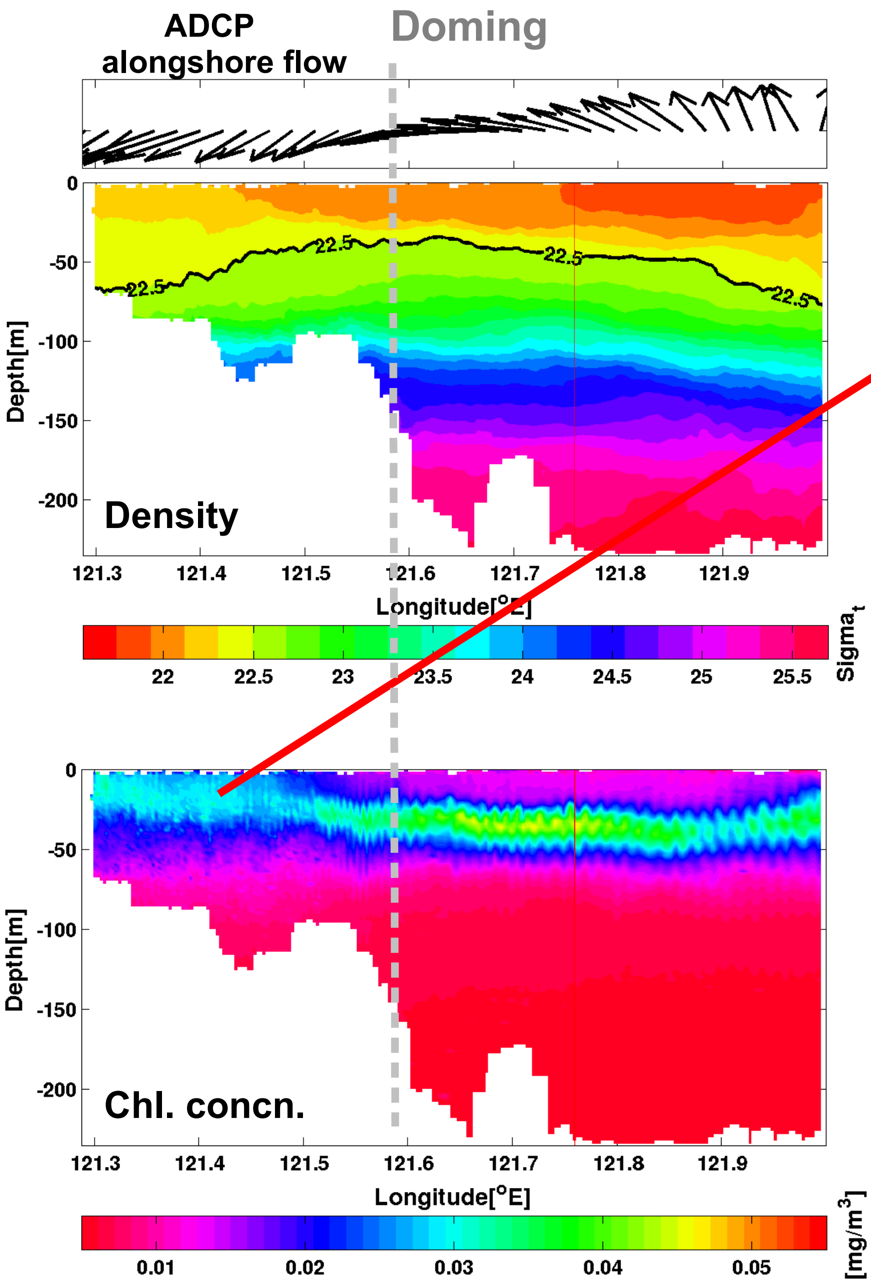
ζ - vorticity

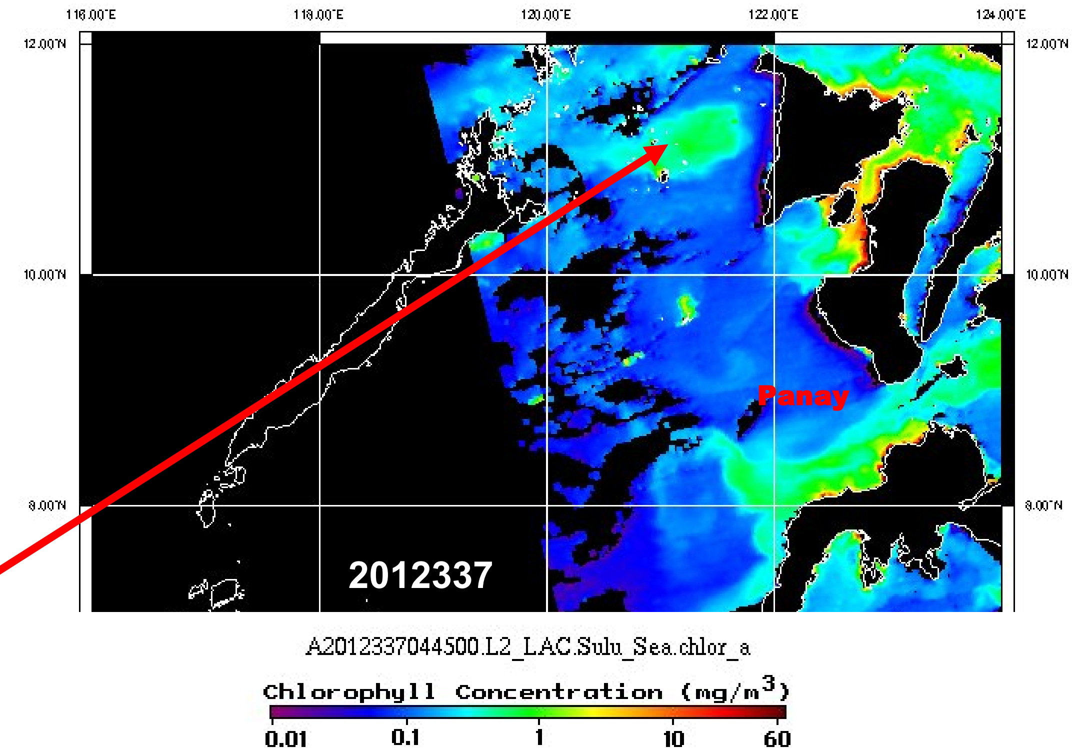
f - Coriolis parameter

L_G - radius the eddy, best fit=100km

g' - reduced gravity

Influence on Biology





two competing forcing, doming and enhanced vertical mixing

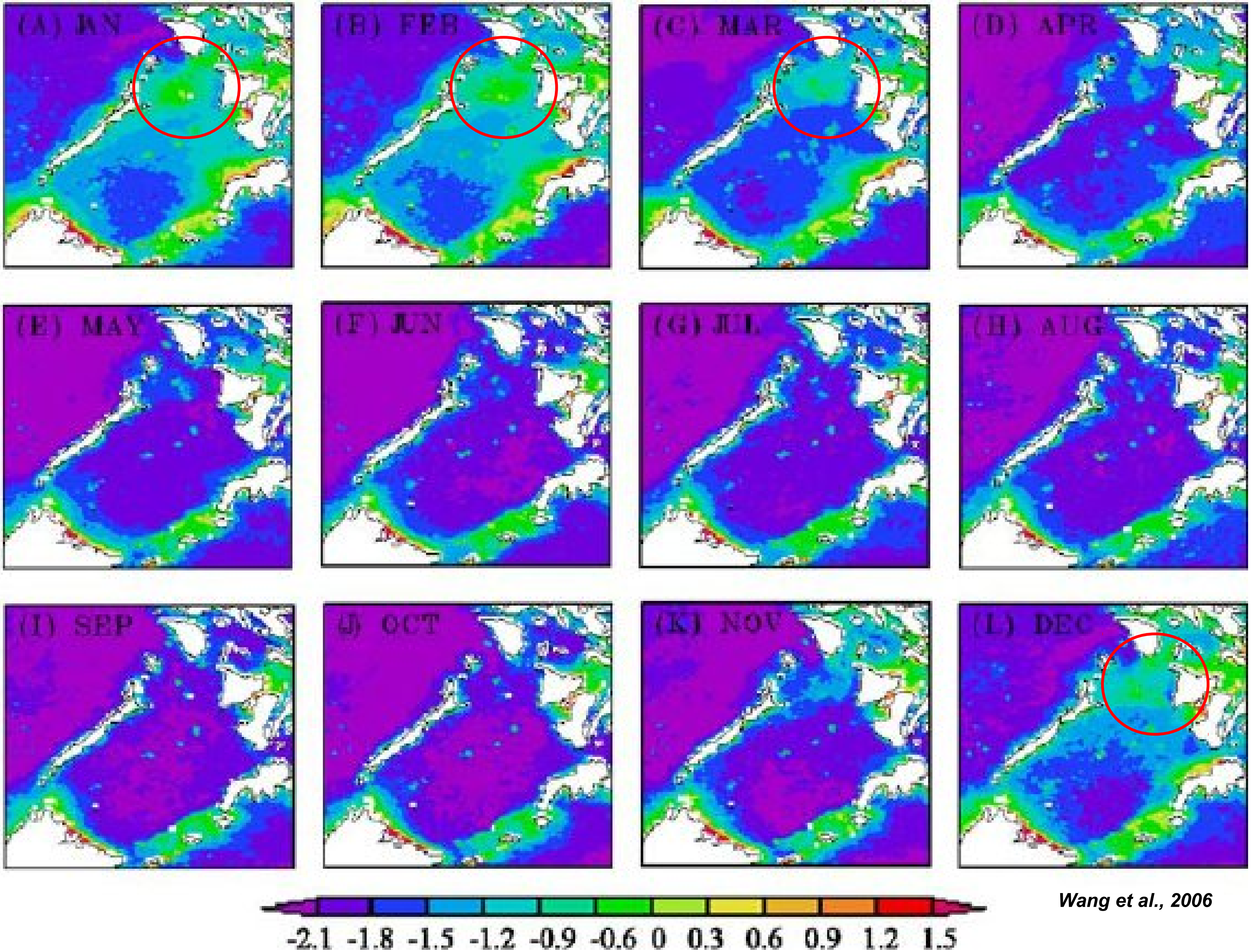
doming

- low chl in the mixed layer – consumption
- high chl at subsurface

shallow shelf

- high chl on the upper 40m
- organisms sink and decay in shallow shelf
- enhanced vertical mixing reached the bottom
- less stratification in the water column
- brings nutrient back to the surface

7-year monthly mean distributions of chlorophyll concentration (mg/m^3) in Sulu Sea



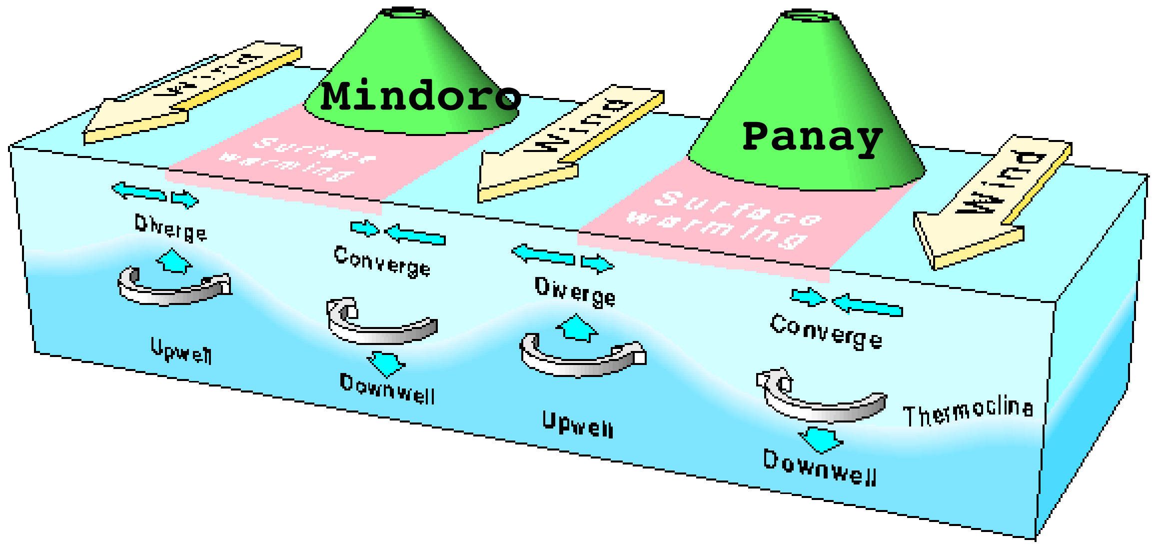
Wang et al., 2006

- **an obvious increase in chlorophyll concentrations in December–March over Cuyo shelf**

Conclusions

- **Conceptual diagram showing Ekman pumping in the lee of islands**

  1. wind intensifies between islands
  2. wind stress variations form positive wind stress curl in the lee of Panay
  3. induces divergent surface currents
  4. which in turn uplift thermocline
  5. pressure gradient spins-up eddy in geostrophic balance



- **robust mechanism of cumulative wind stress curl to eddy kinetic energy**

Acknowledgement

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USN
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SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY
UNIVERSITY OF HAWAI'I AT MĀNOA

MSI

Radio Oceanography Laboratory

Thank you!

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- Committee members: Mark Merrifield, Glenn Carter
  Francois Ascani and Camilo Mora
- Cesar Villanoy and Laura David, M.Sc. adviser and co-adviser

The Radio Oceanography Team

The Marine Science Institute Team

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- Local government units of the Province of Antique
- Volunteers

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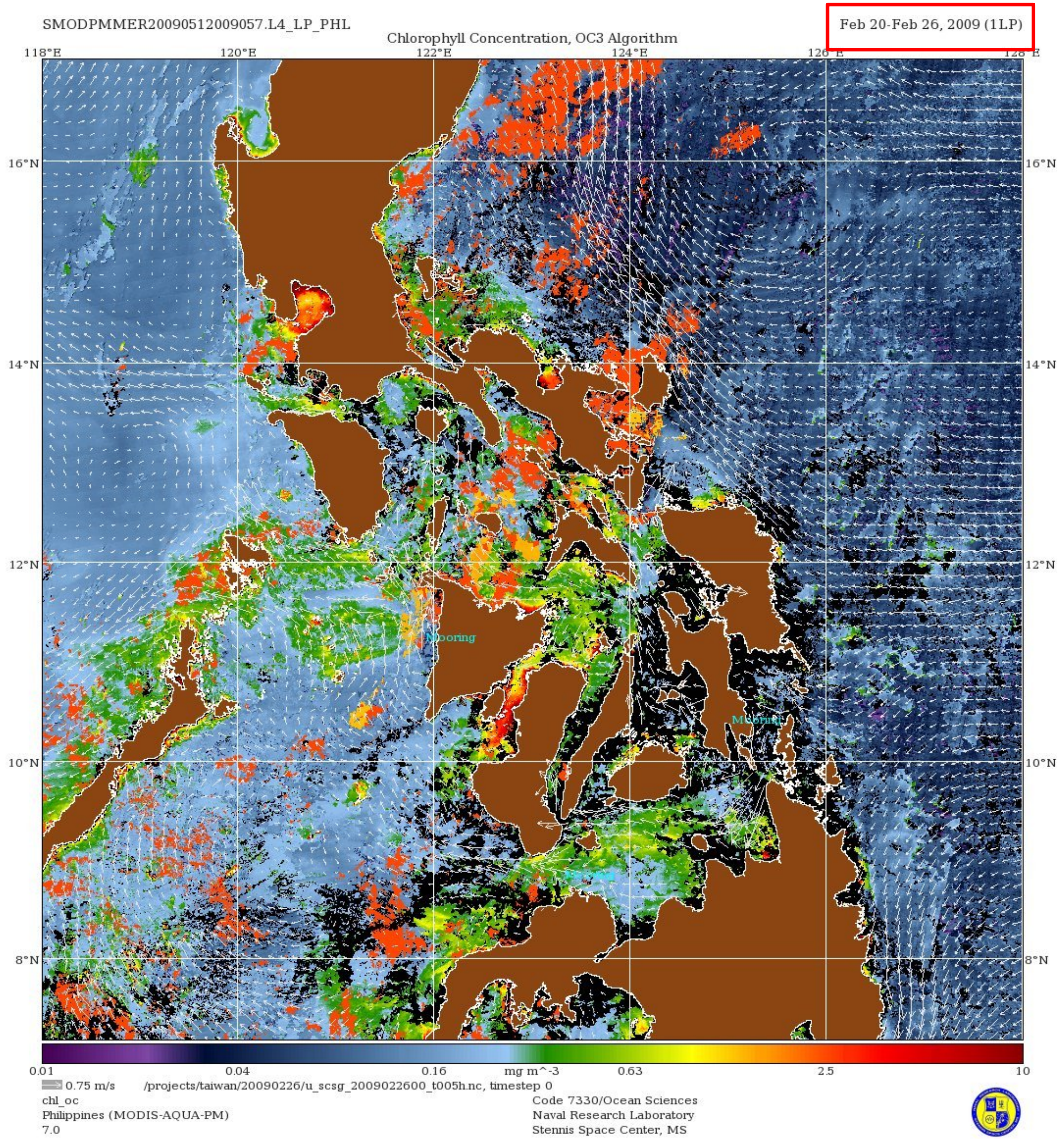
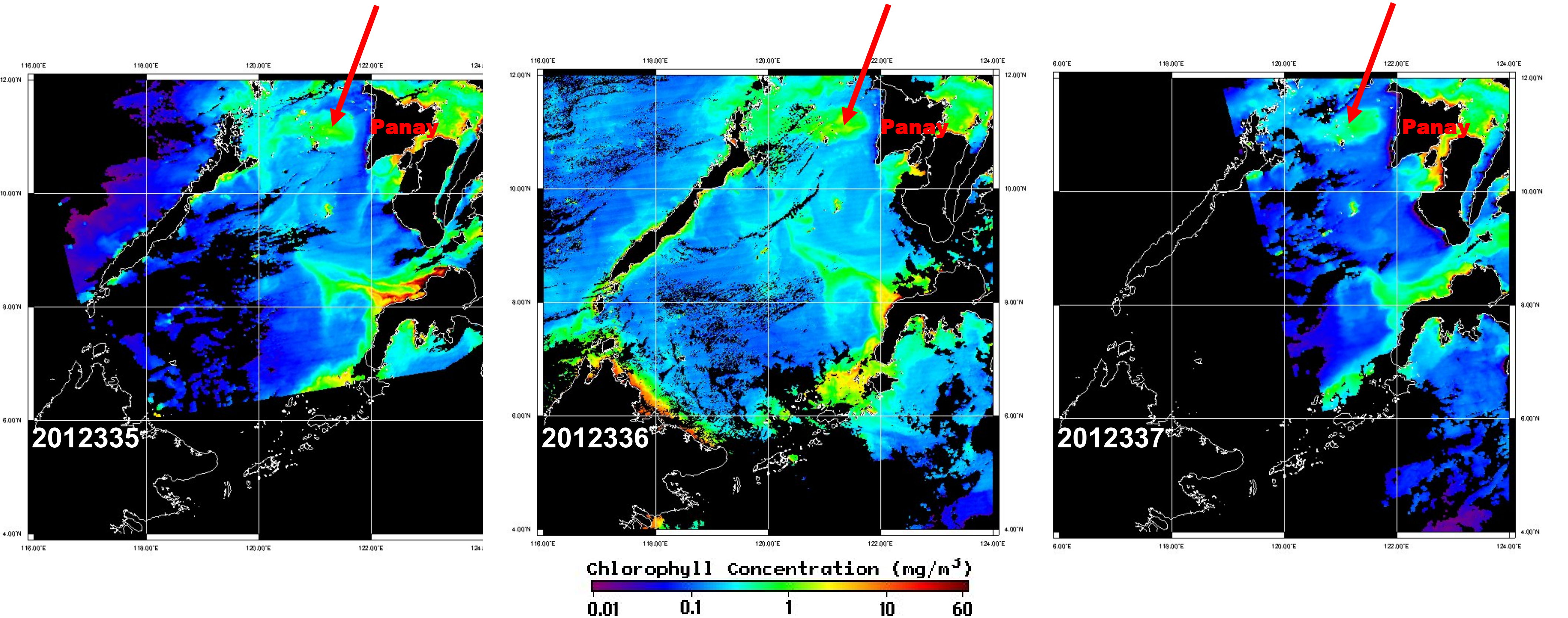
- Professors and fellow graduate students
- Victoria, Lindsey and Alma
- Benedicte Dousset
- Eva Washburn-Repollo and Curtis Washburn
- UH Filipino graduate students and friends

Thank you!

Questions?

Chlorophyll concentration merged 7-day composite image




Panay
2012335
Panay
2012336
Panay
2012337
Chlorophyll Concentration (mg/m3)
0.01
0.1
1
10
60

Dynamical analysis of the cyclonic eddy

Surface Vorticity Balance

$$\frac{D\left(f+\zeta\right)}{Dt}+\left(f+\zeta\right)\delta=R$$

Rate of change of vorticity following the fluid motion

Stretching (divergence term)

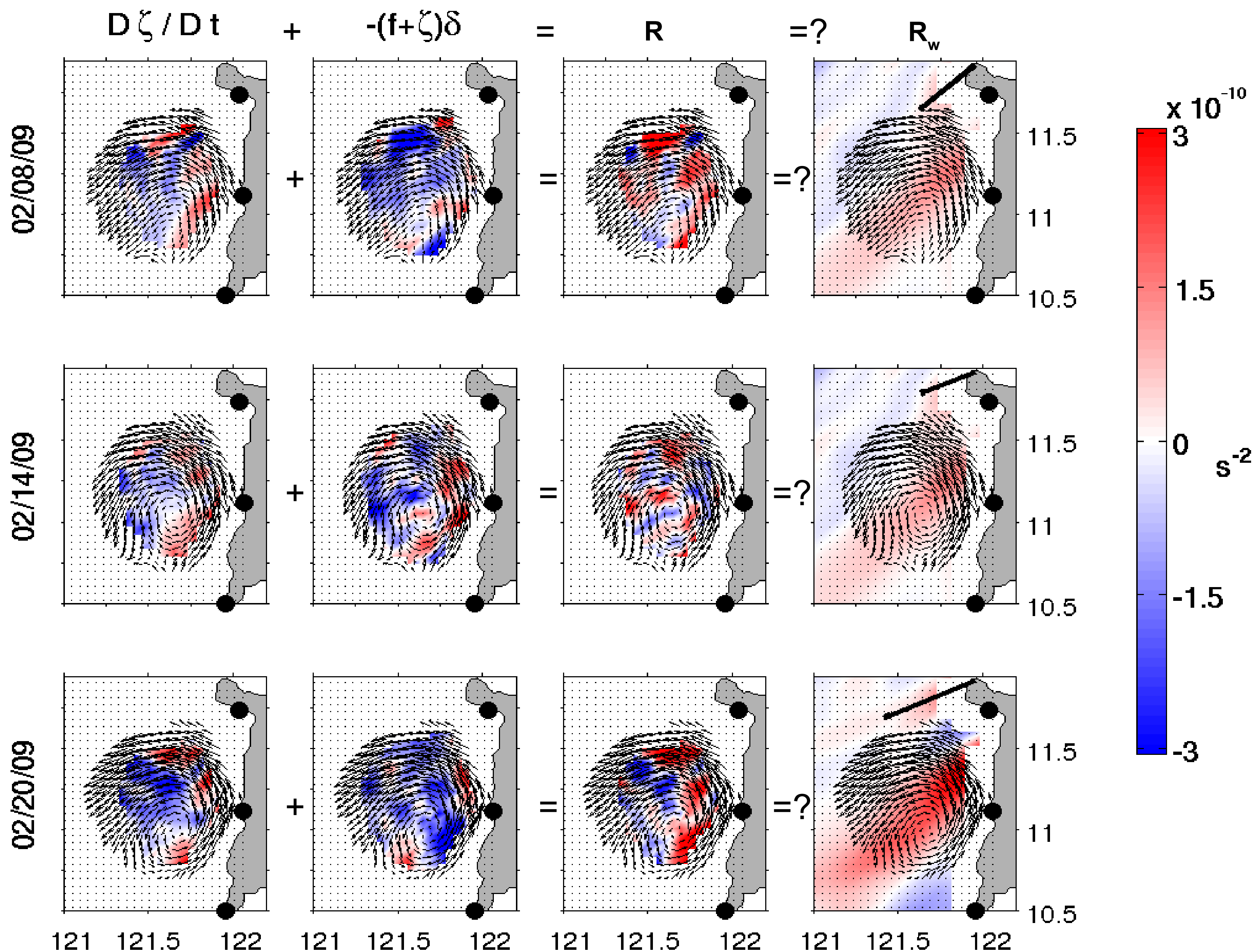
Residual (noise + wind forcing)

Wind stress curl forcing

$$R_w=\frac{curl\tau}{\rho H_E}$$

ρ – 1025kgm^{-3}, density of seawater
H_E – 32m, Ekman depth

Snapshots of terms



Evolution of vorticity dominated by residual term which corresponds to wind stress curl forcing + noise -------> need to average spatially