Island wakes

Madeira Archipelago case study

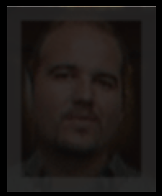
http://wakes.uma.pt

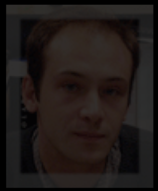
Outline

- Introduction
- Remote Sensing data
- Barotropic (2D) numerical study
- Baroclinic (3D) numerical study
- New hypothesis
- Future work

People

Euclides Luis, CEMAT - IST
Dmitri Boutov, IO - FCUL
Alain Chelius, UBordeaux 1
Aires dos Santos, MARETEC - IST
Juha Videman, CEMAT - IST
Pablo Sangrà, ULPGC
Rui Caldeira, CIIMAR - UP / CCM





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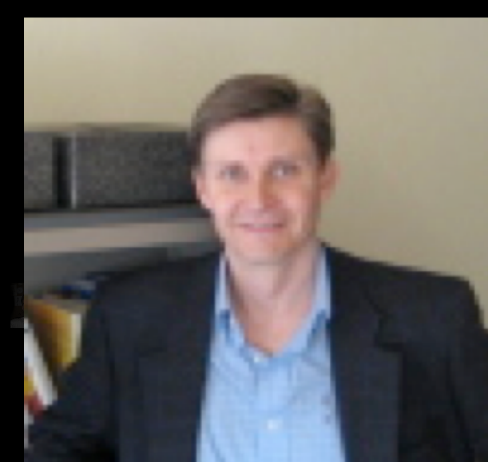

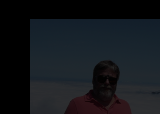

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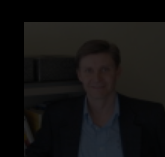

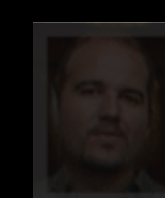

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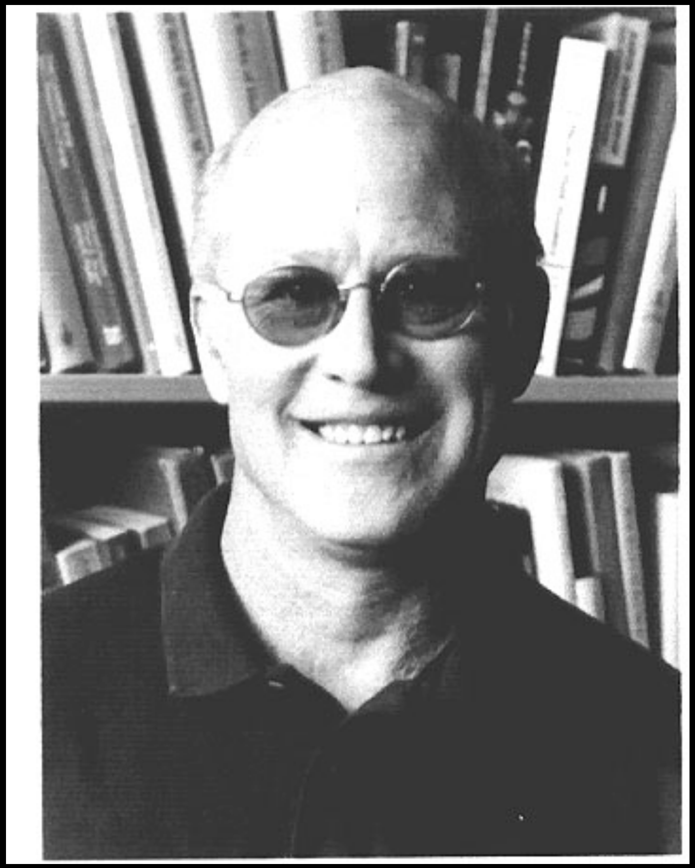
Acknowledgements

- FCT: POCI/MAR/57265/2004
- CIIMAR
- Changming Dong, UCLA, USA

Philosophy

"Never trust an observation without without a supporting theory."

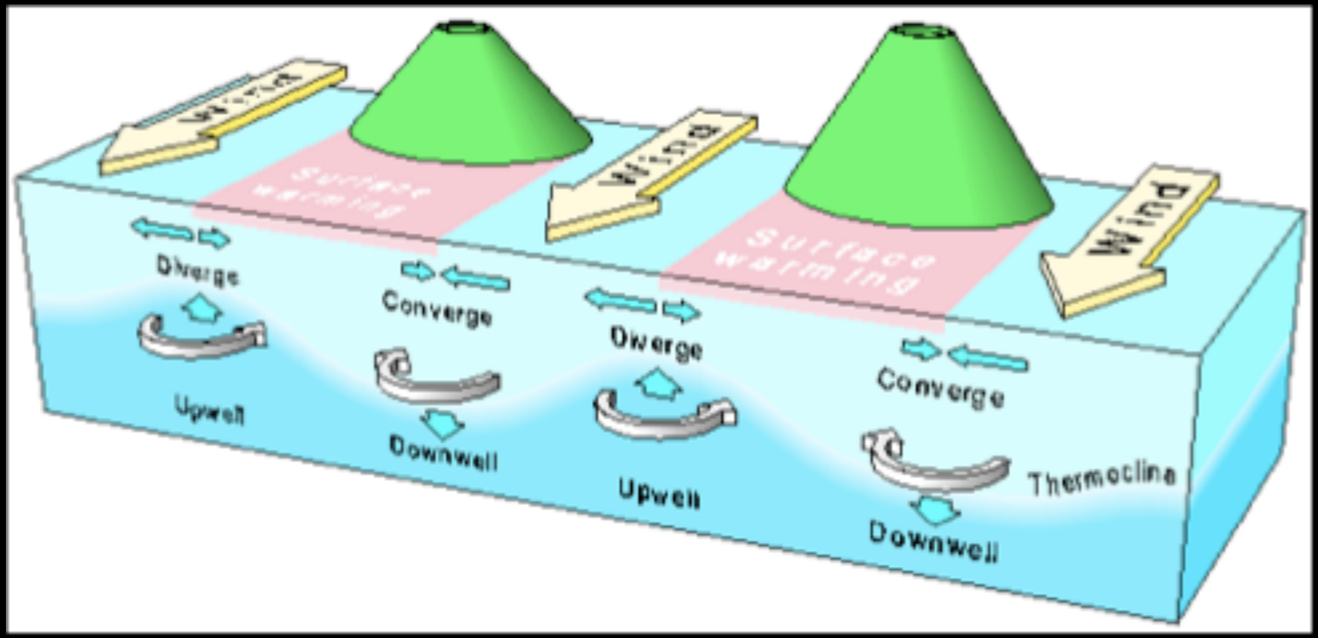
Arthur Eddington, 1822-1944



"In geophysics, never trust a fact, or a simulation, without a supporting interpretation."

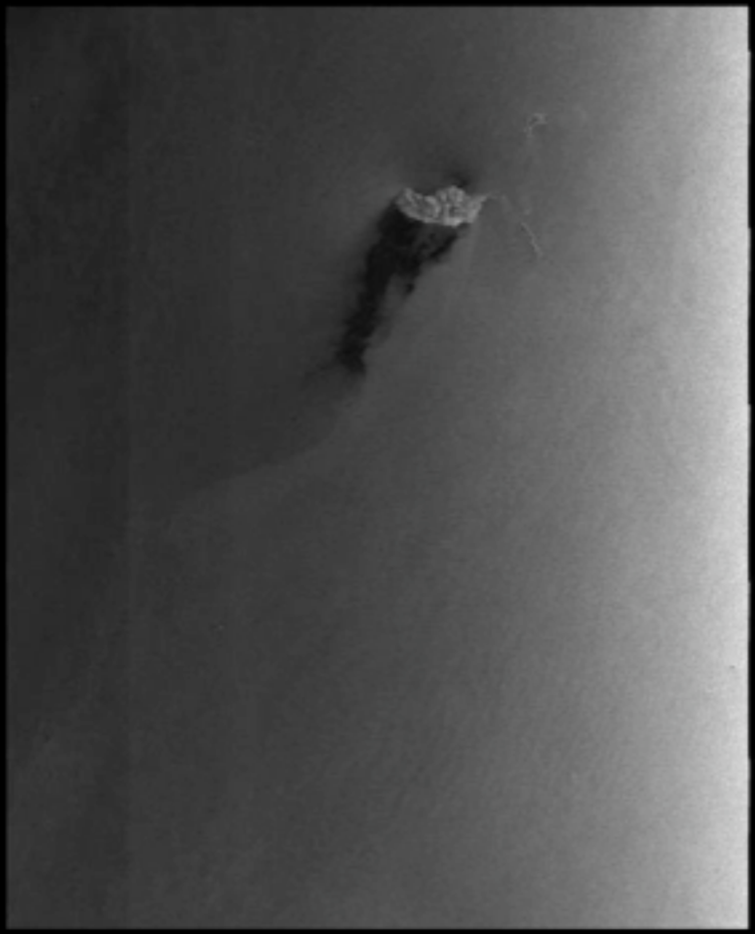
James McWilliams, 2006

Definition



Wind
Wind
Wind
Surface warming
Surface warming
Diverge
Converge
Diverge
Converge
Upwell
Downwell
Upwell
Downwell
Thermocline

Definition



Definition

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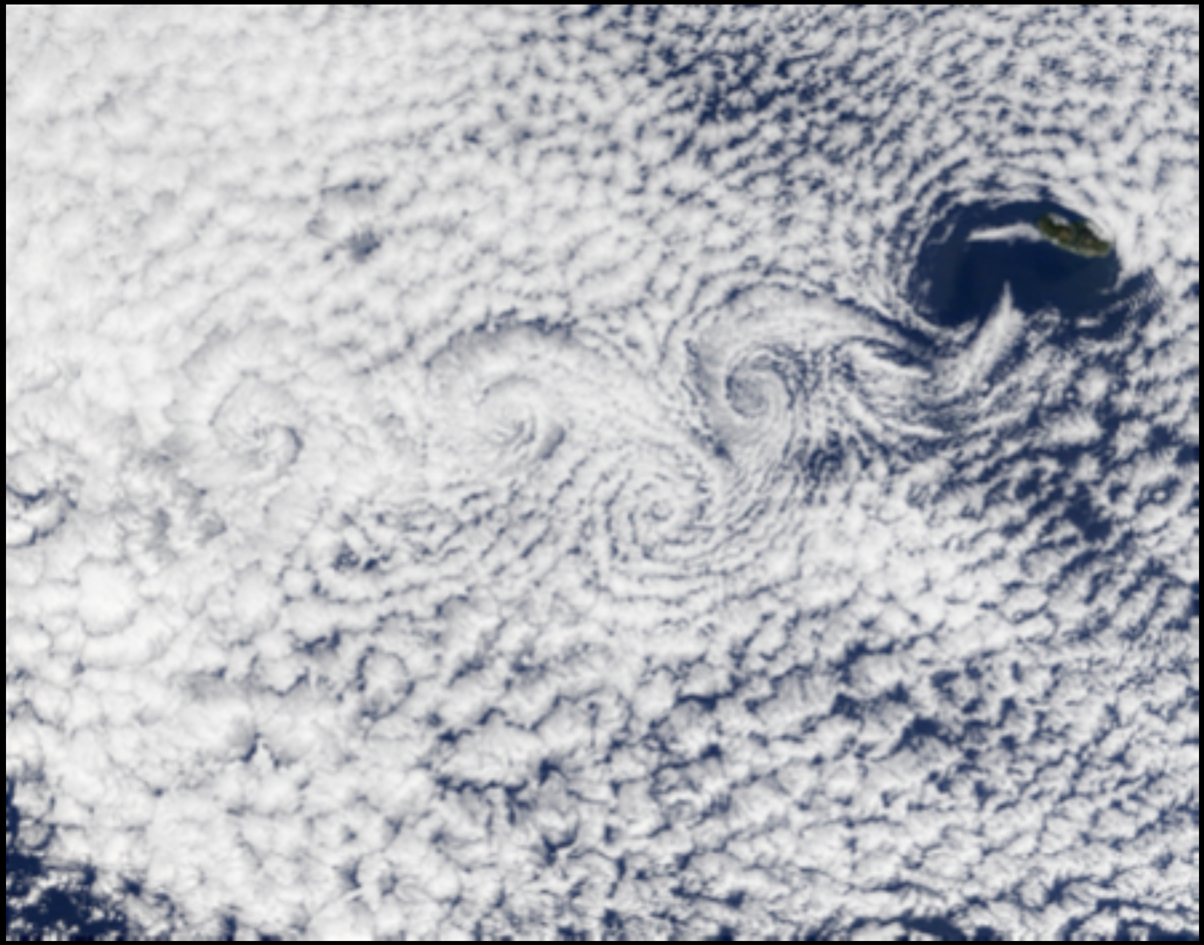
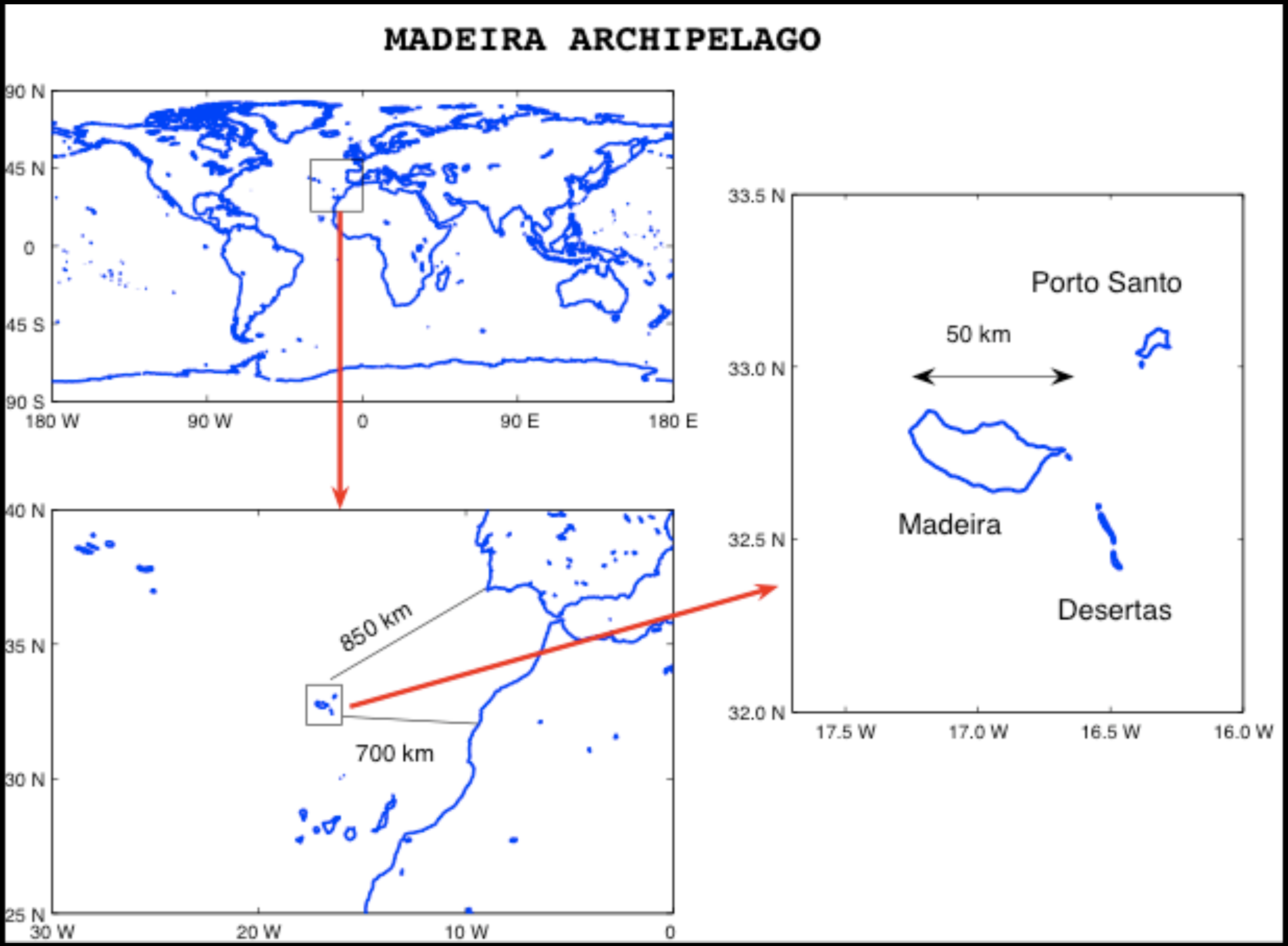


Geographic setting



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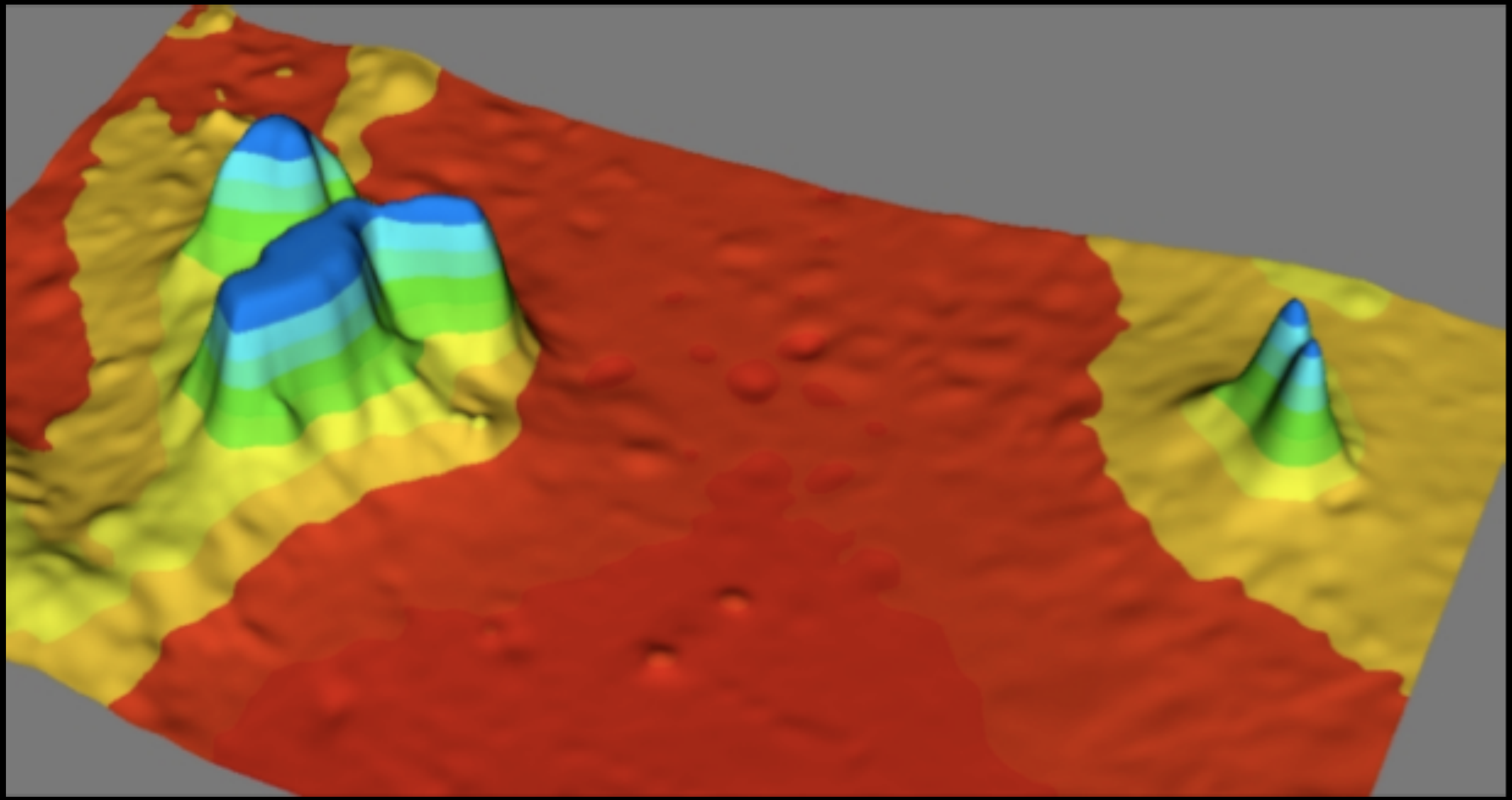
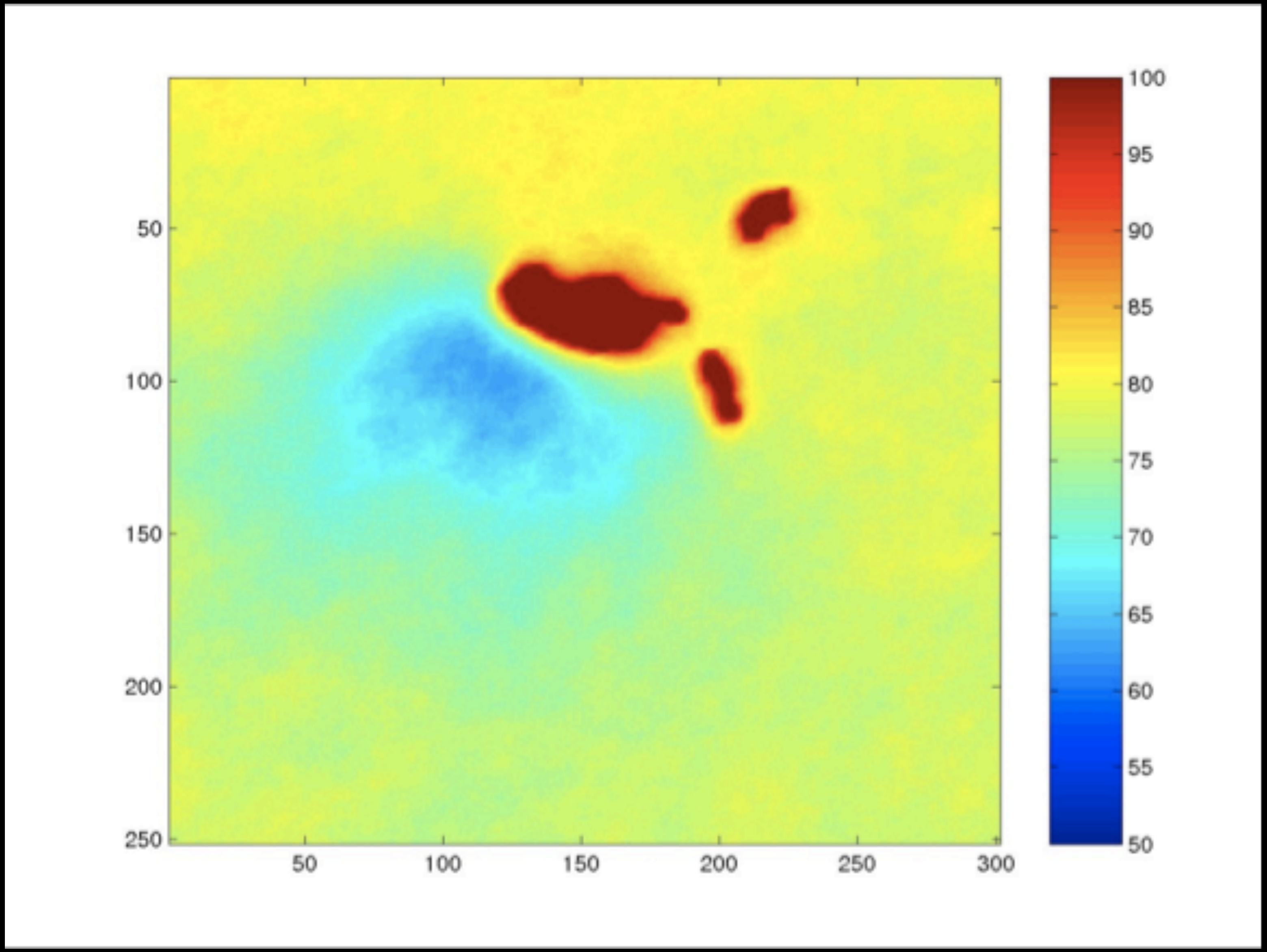
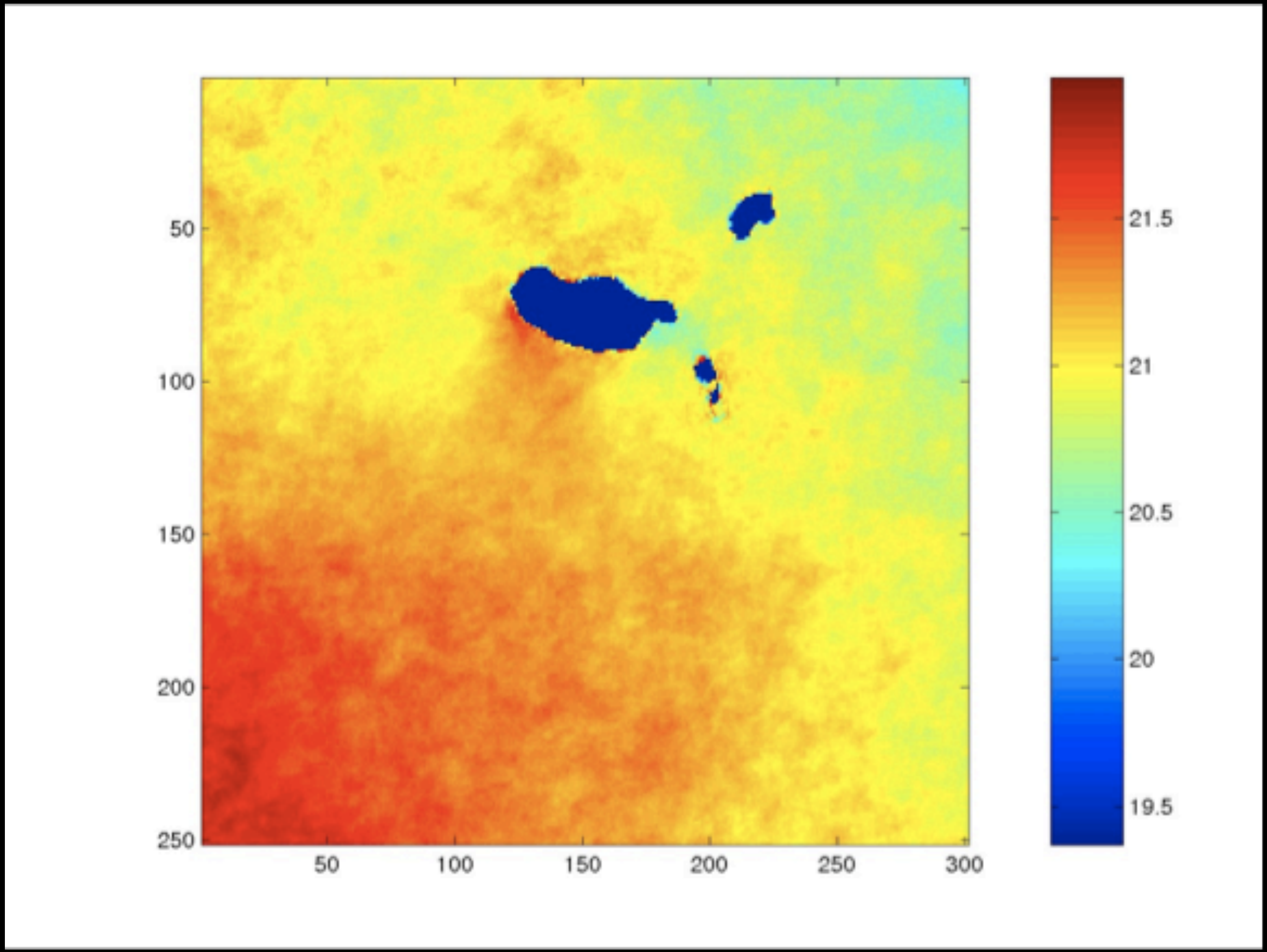


Remote sensing data
2001-2008

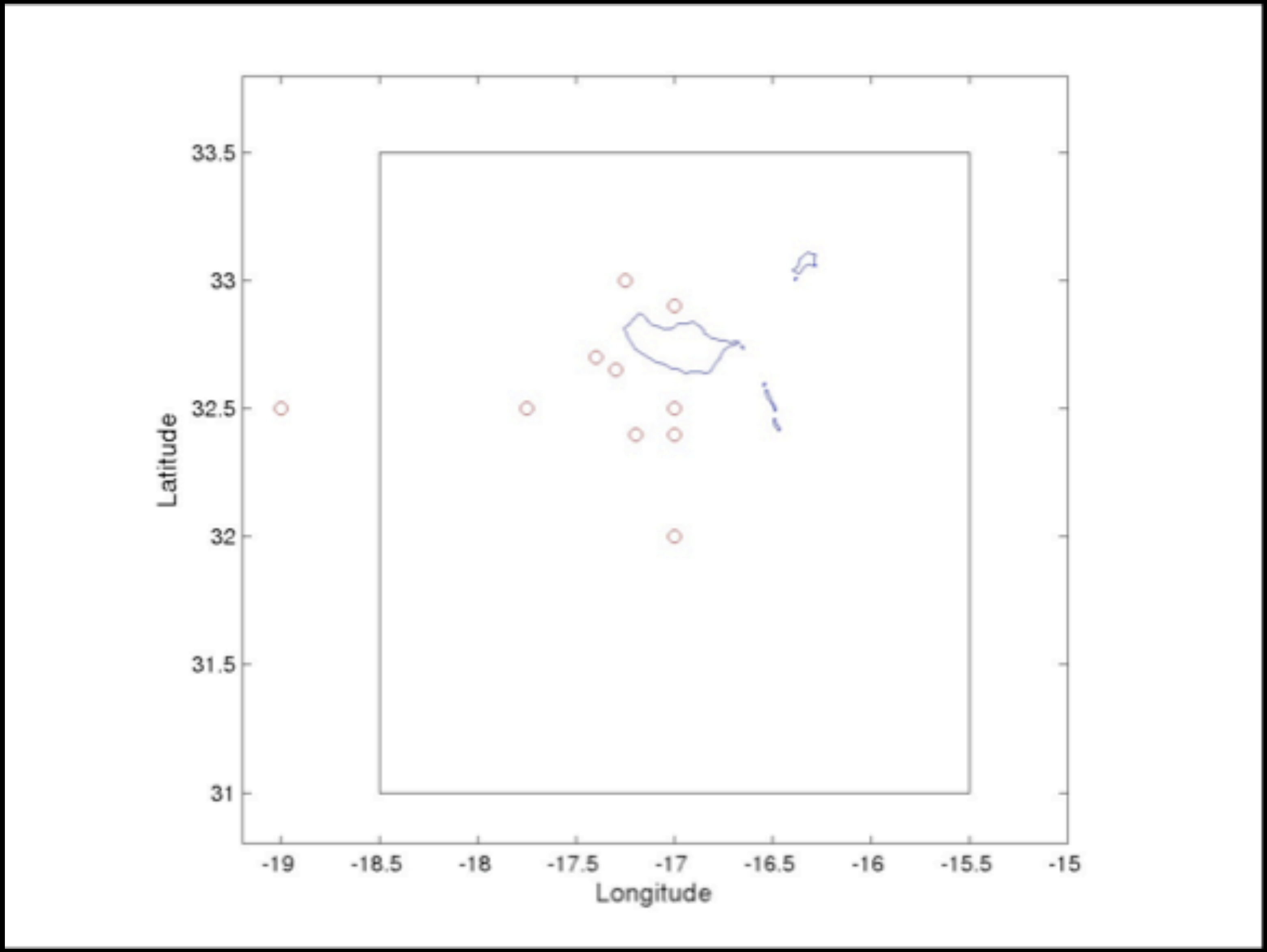
Remote sensing data
2001-2008



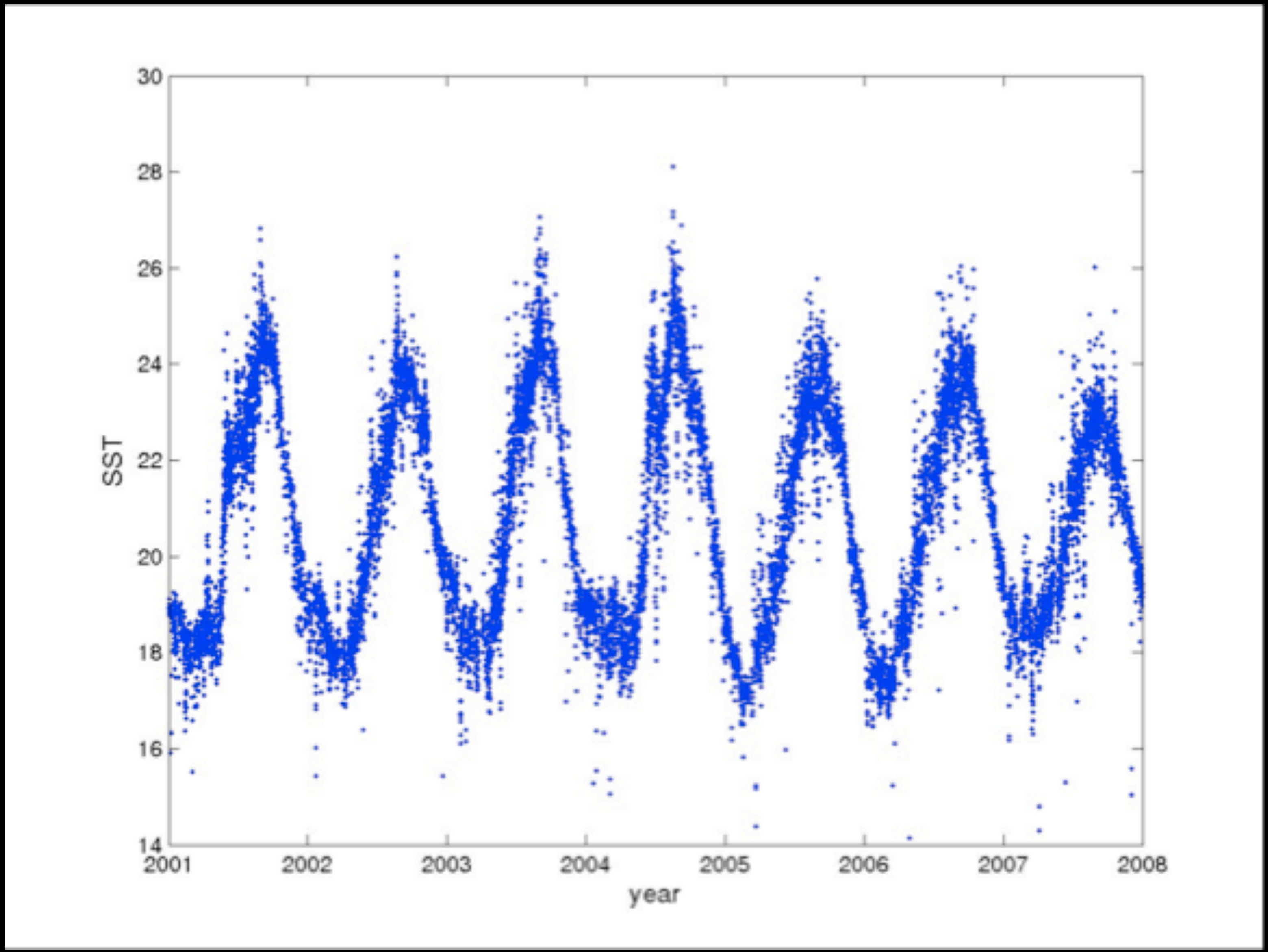
Remote sensing data
2001-2008



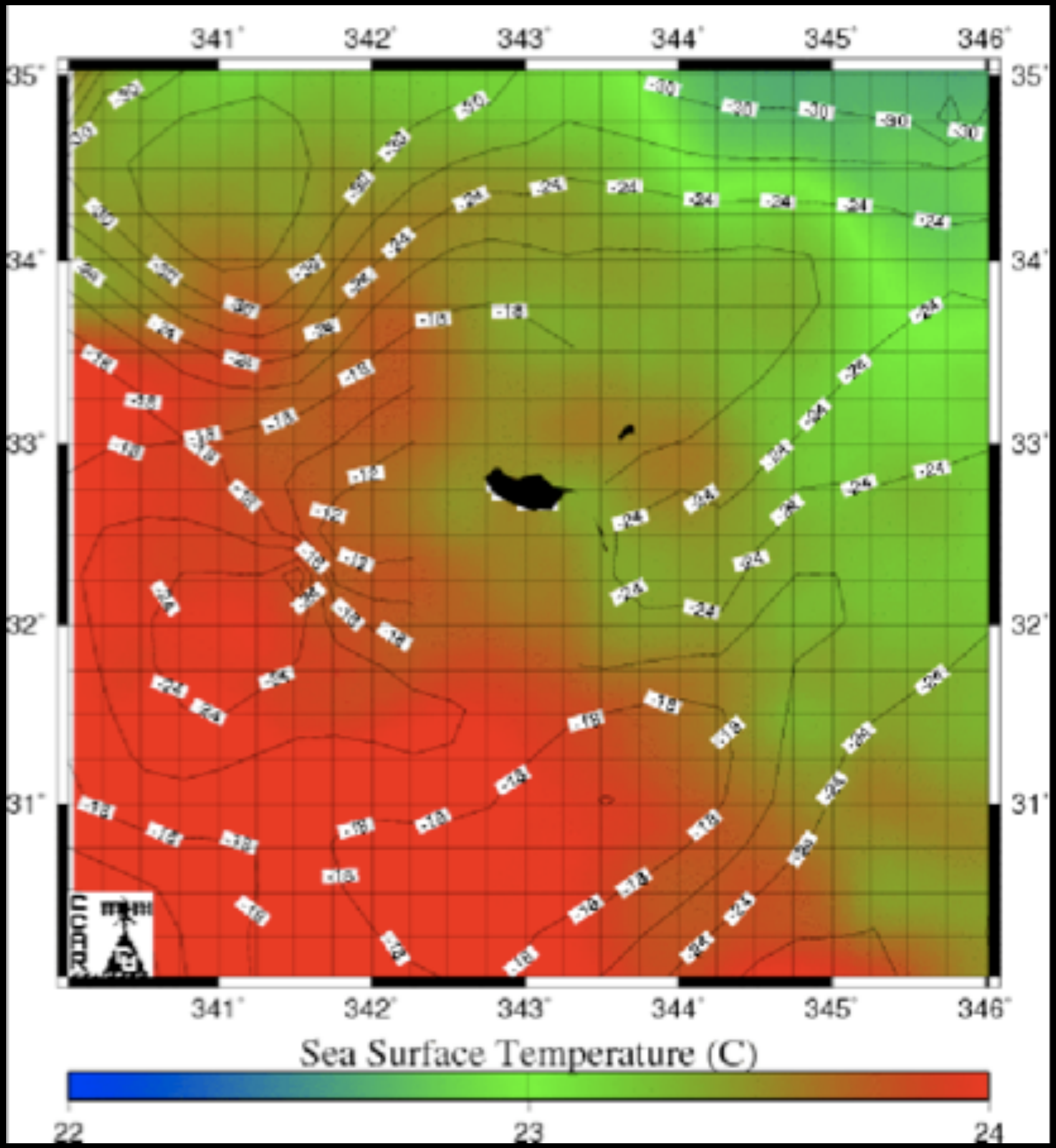
Remote sensing data
2001-2008



Remote sensing data
2001-2008



Remote Sensing
09-11 2006 episode



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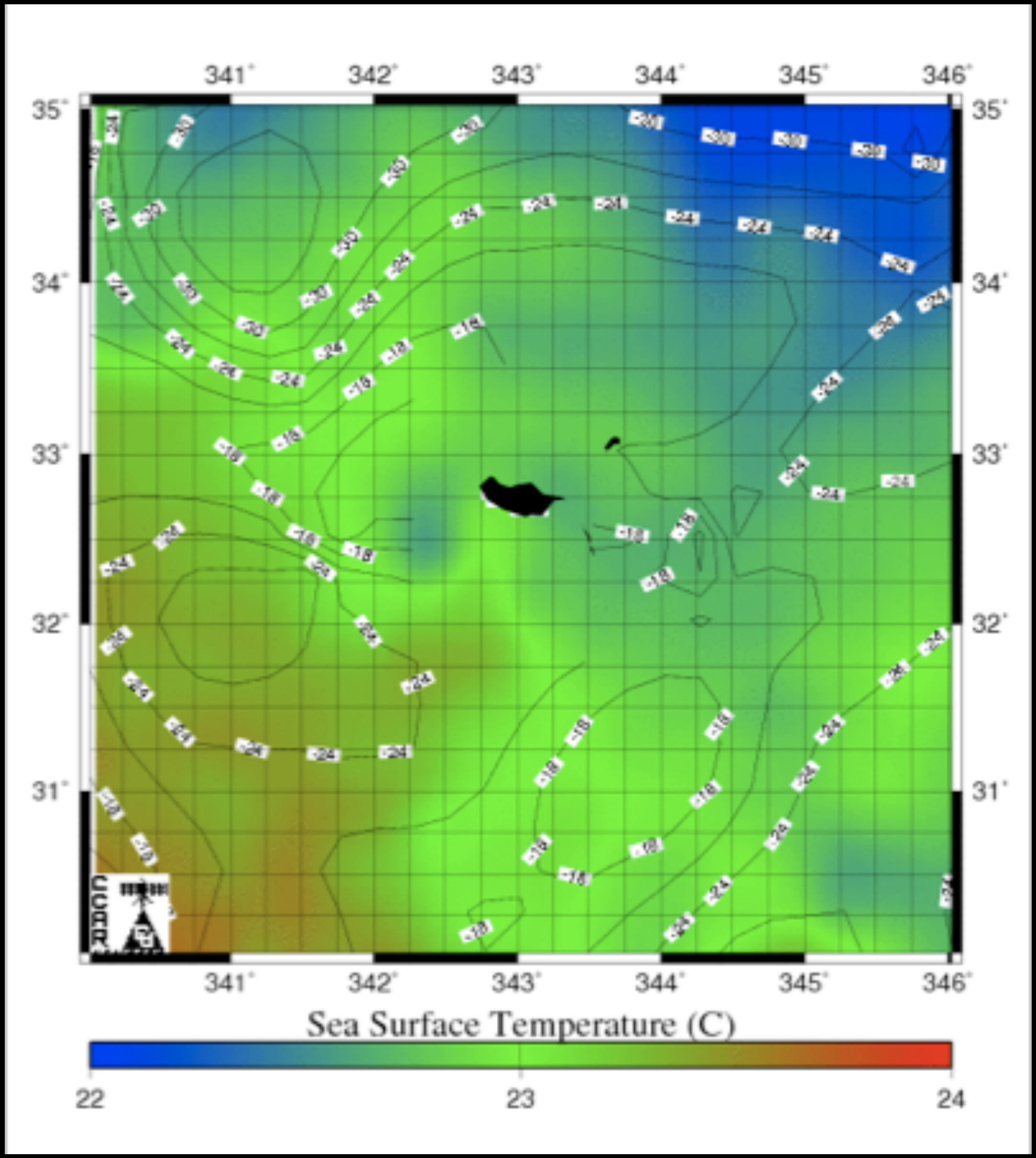

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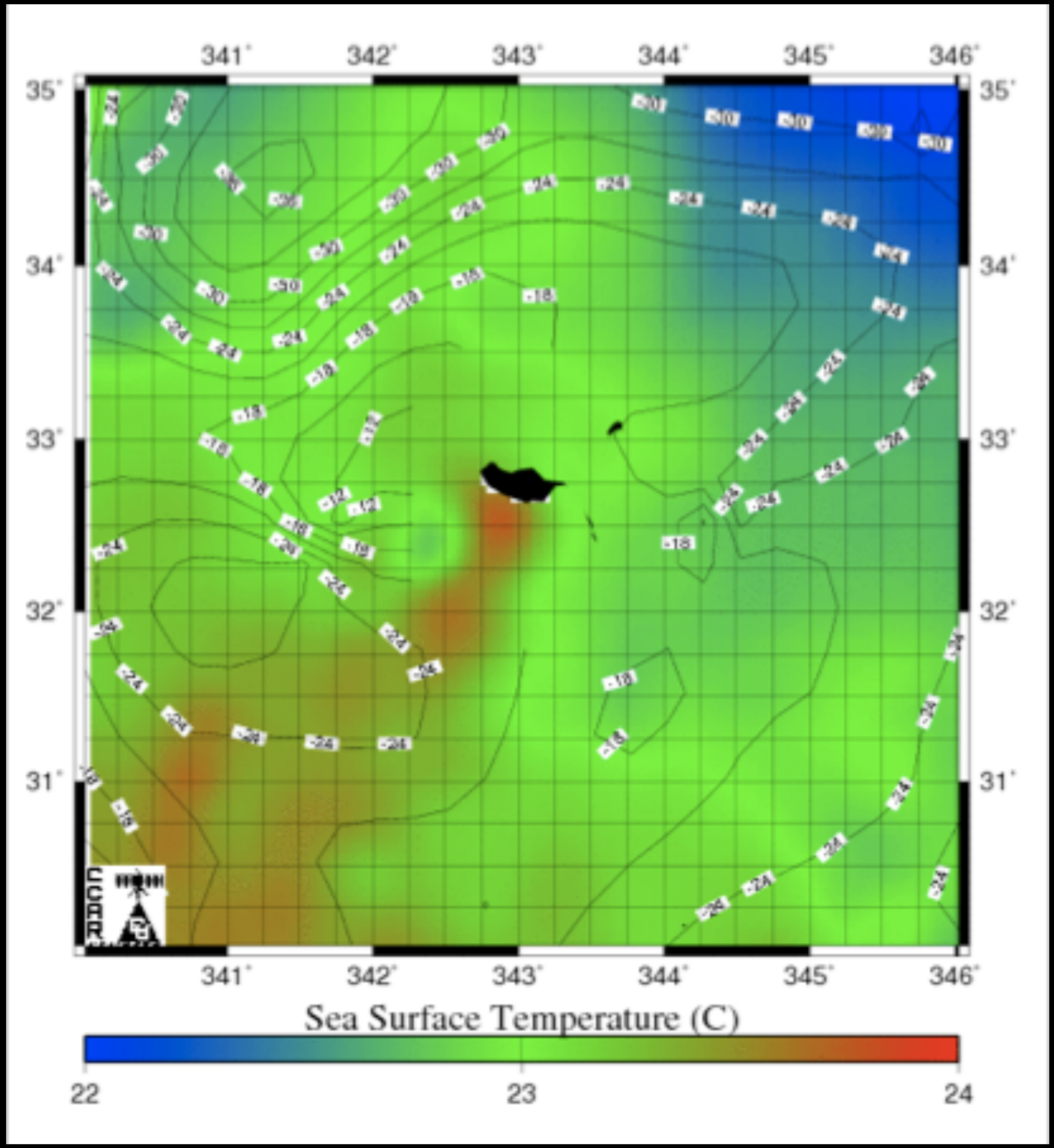

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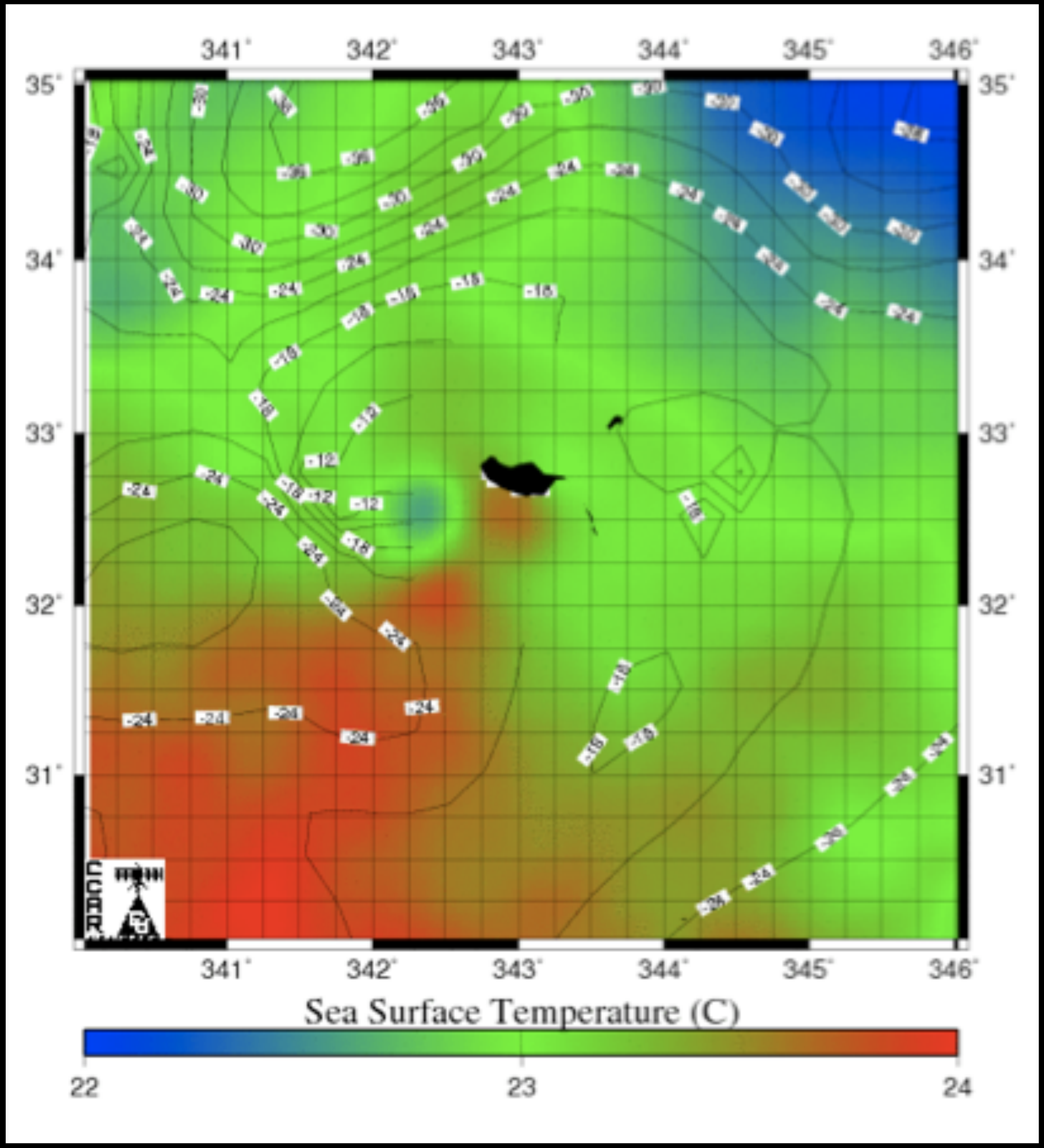

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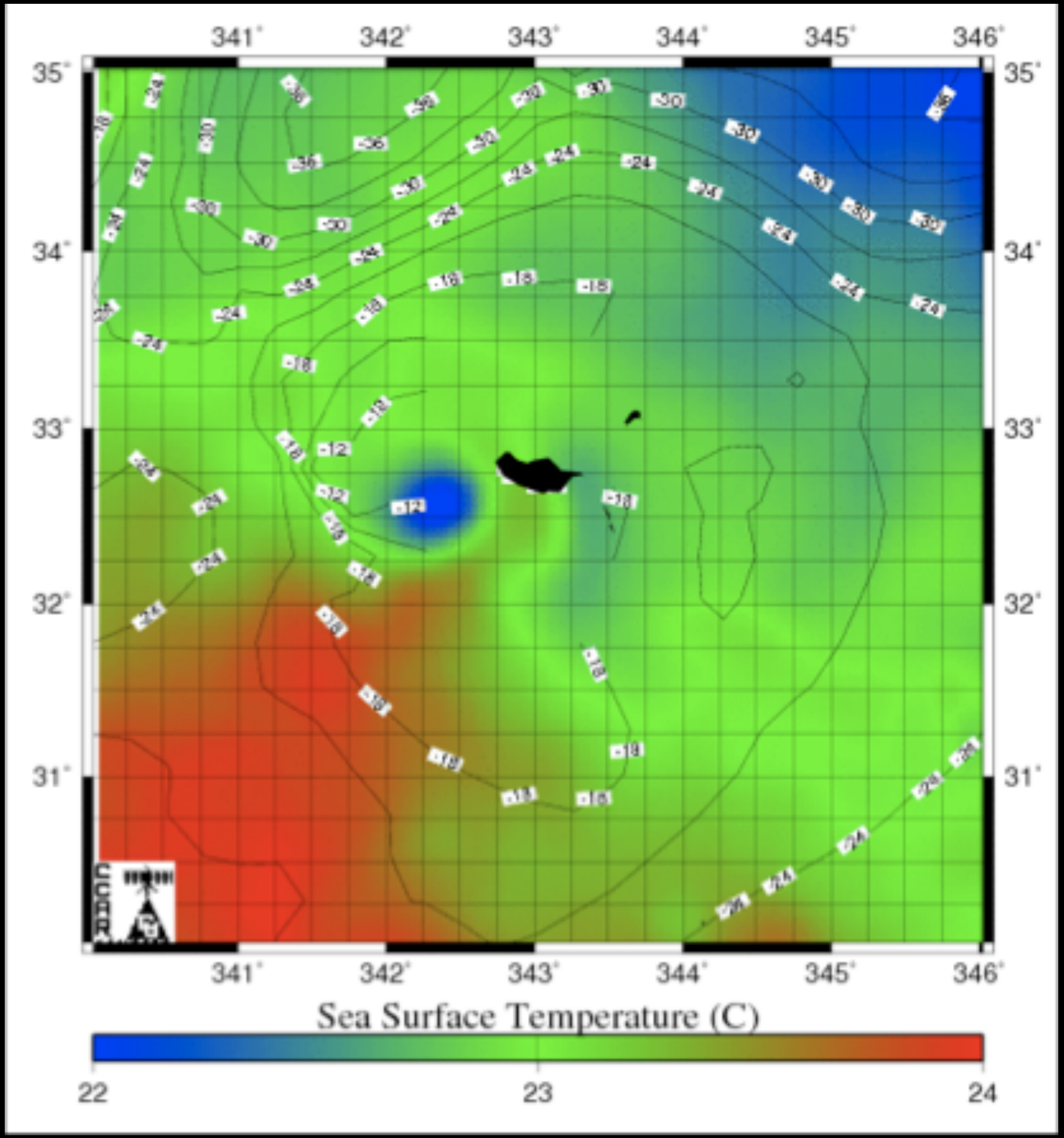

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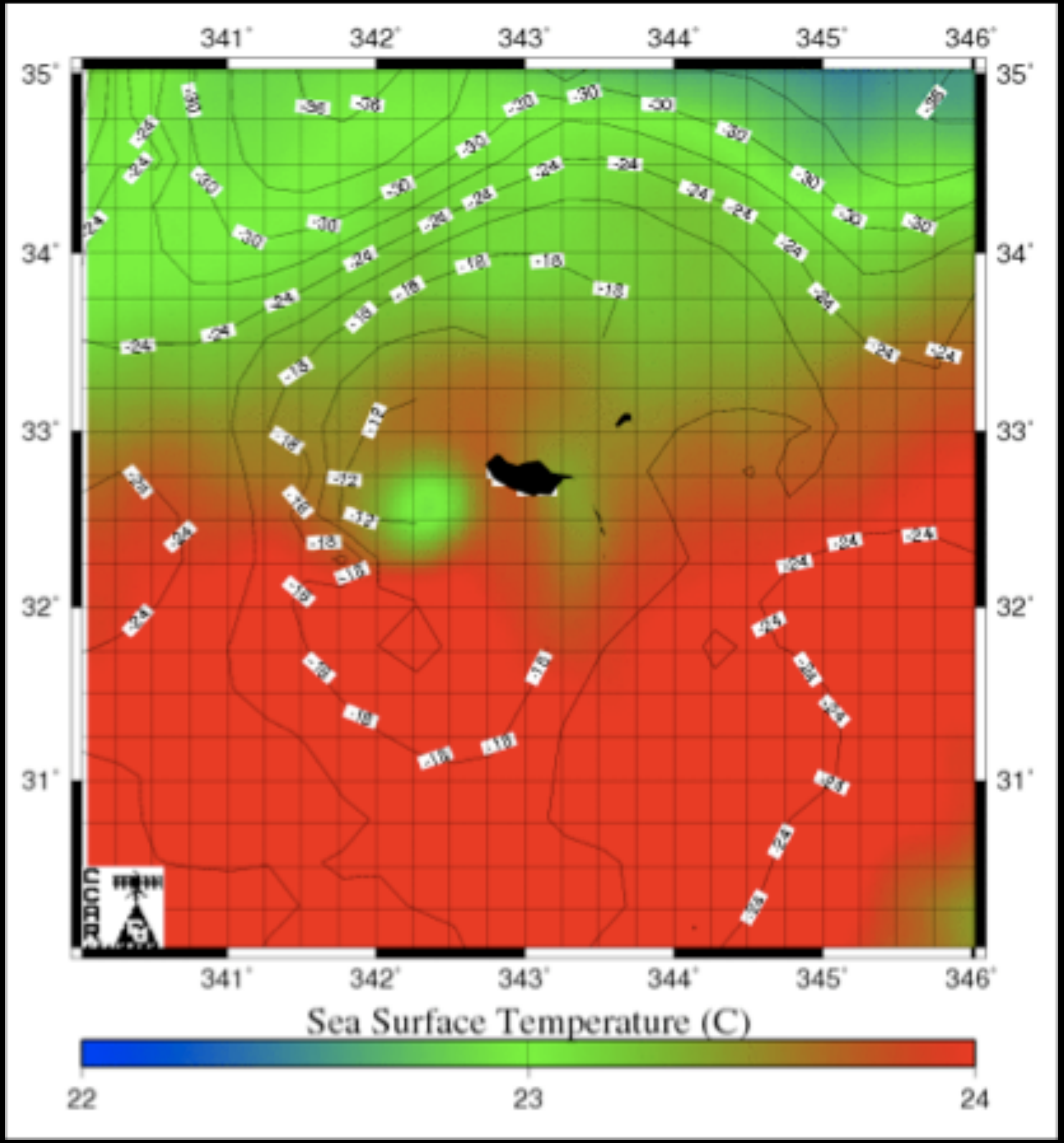

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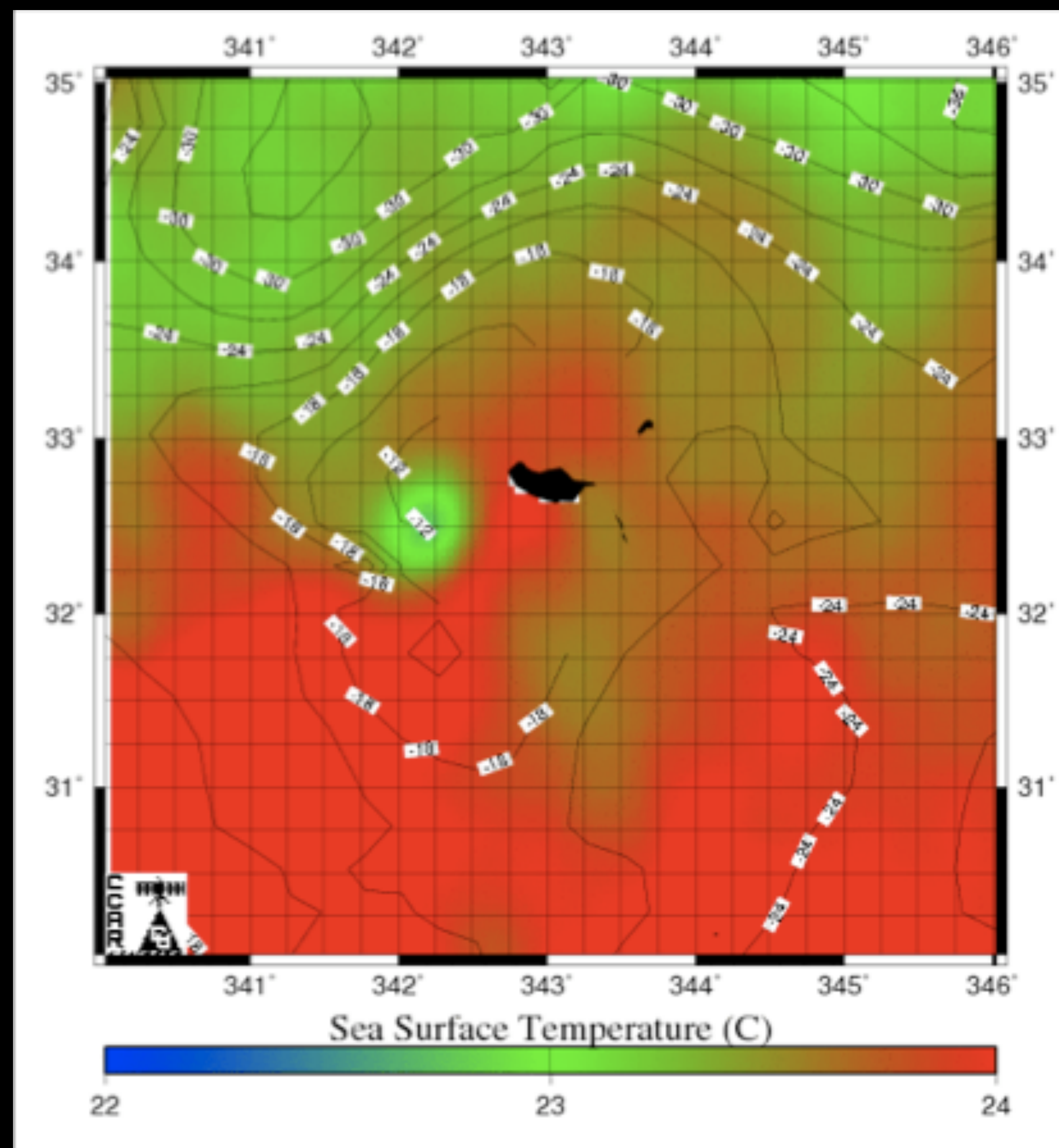

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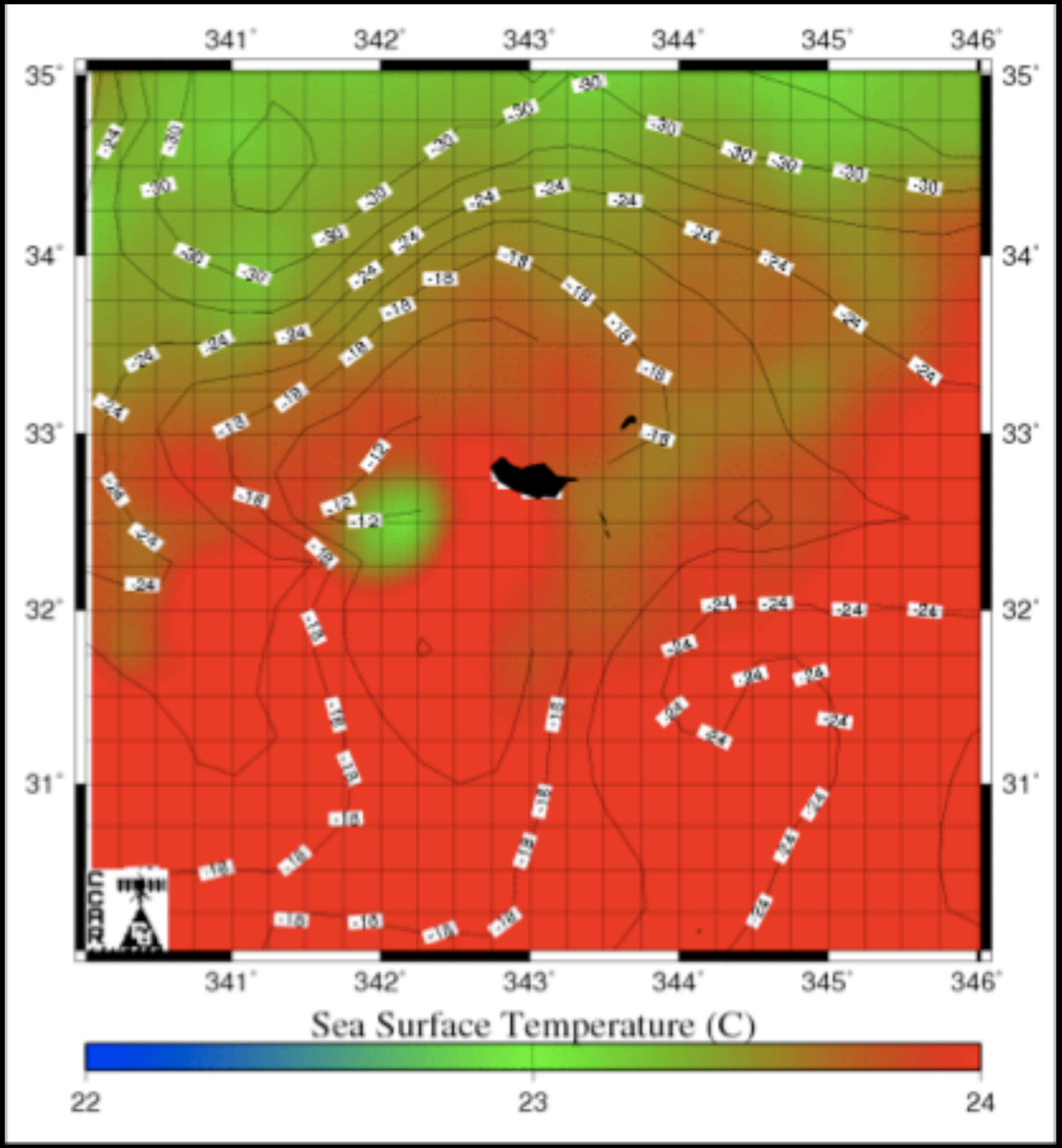

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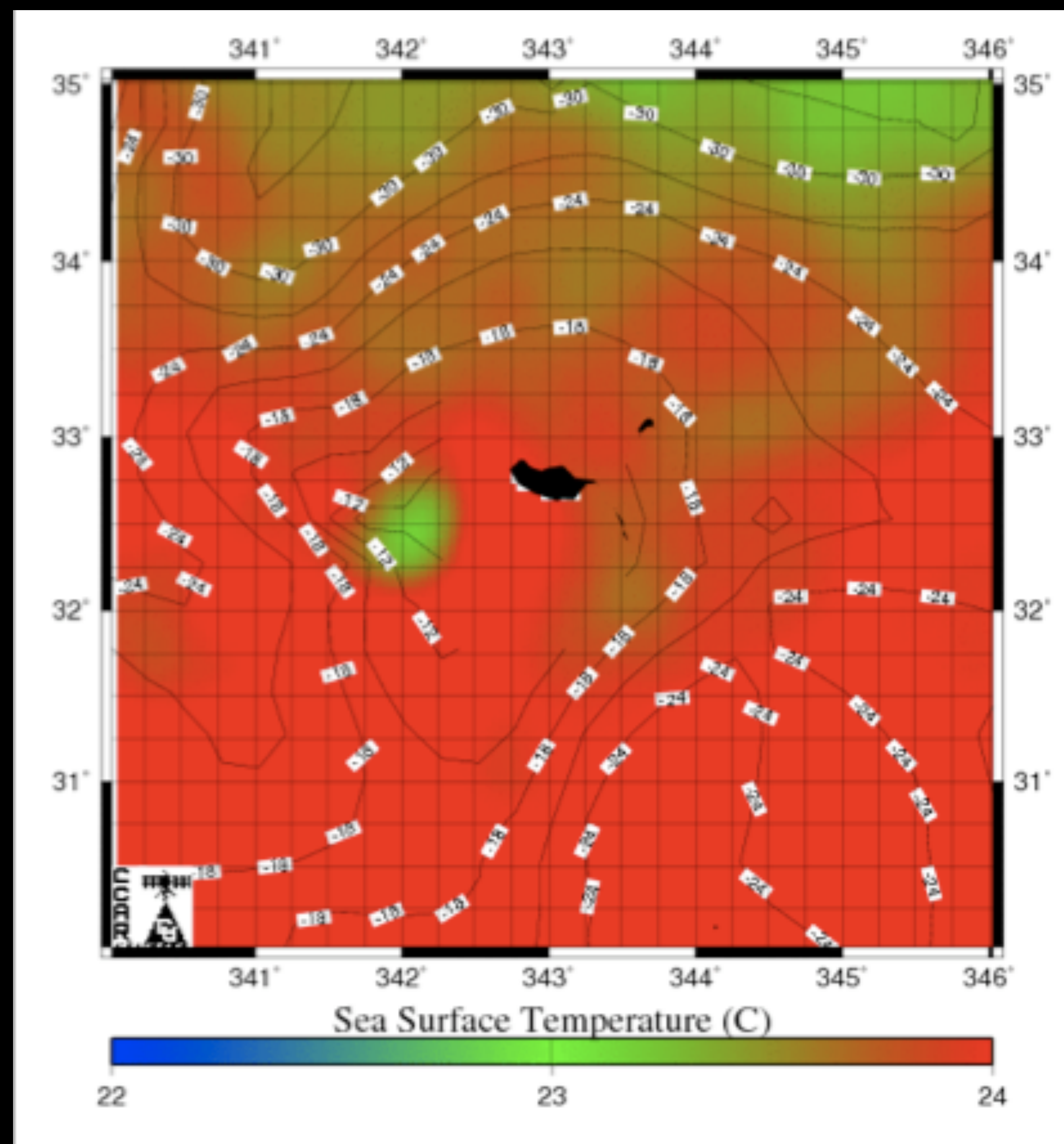

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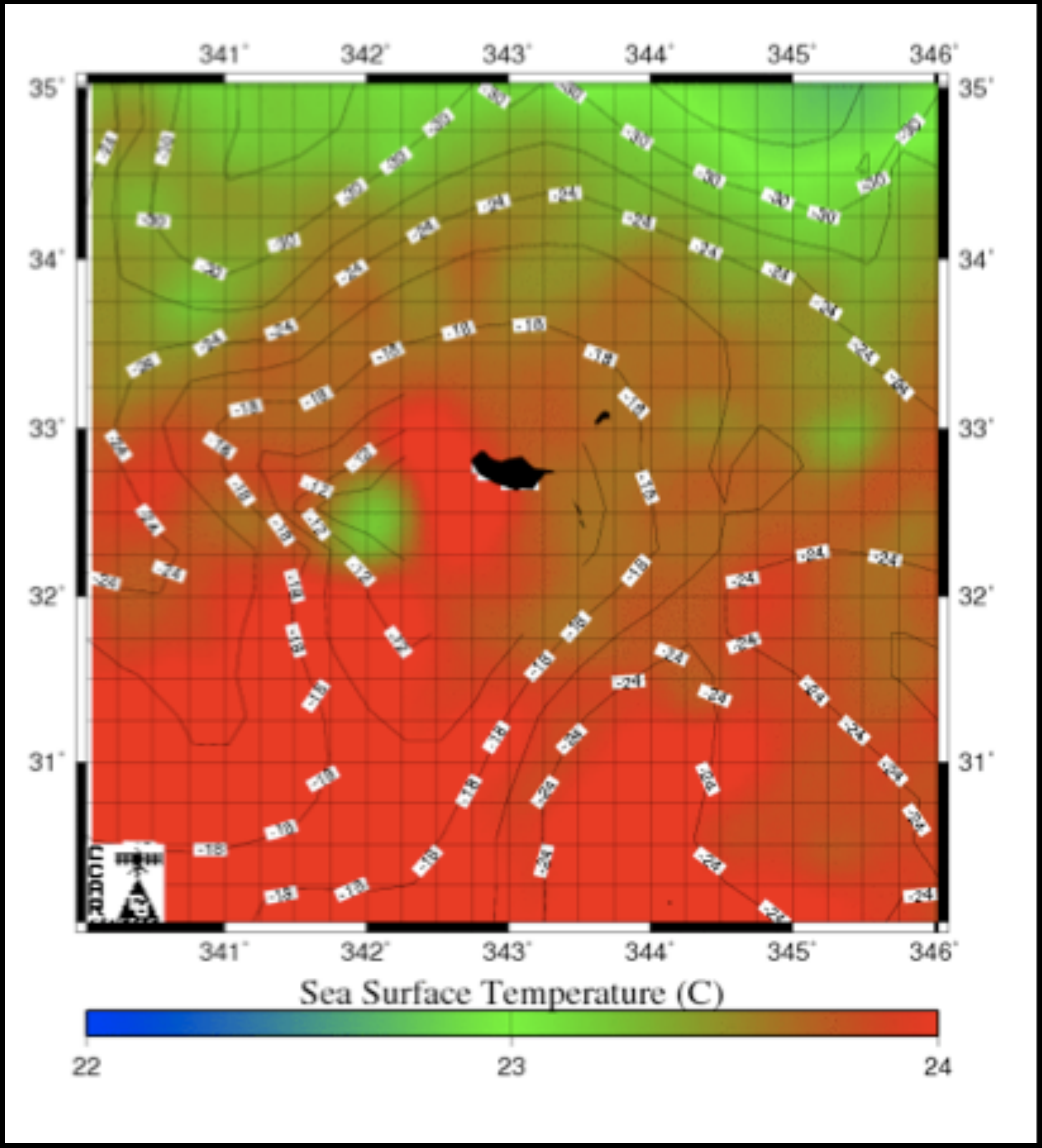

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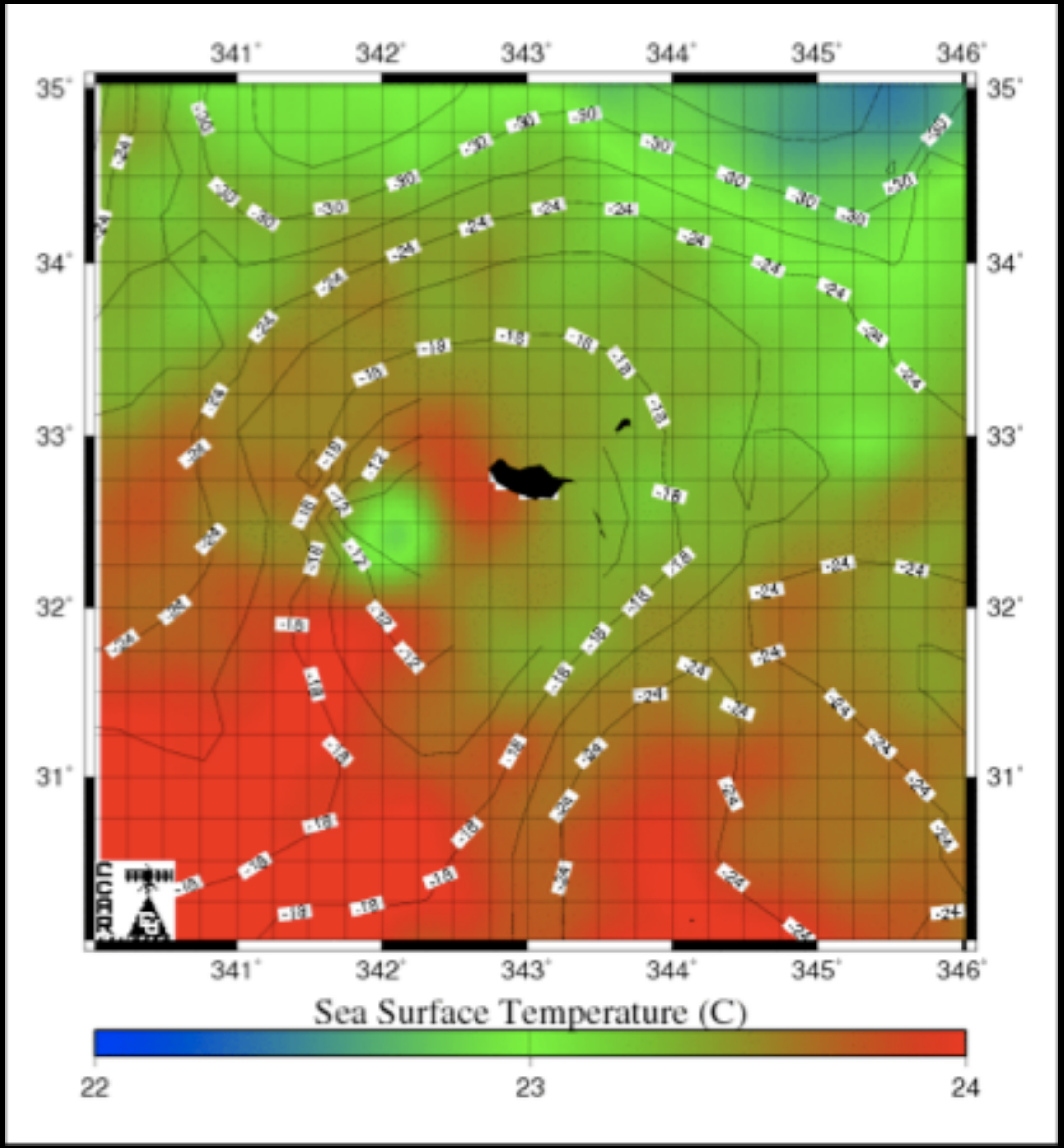

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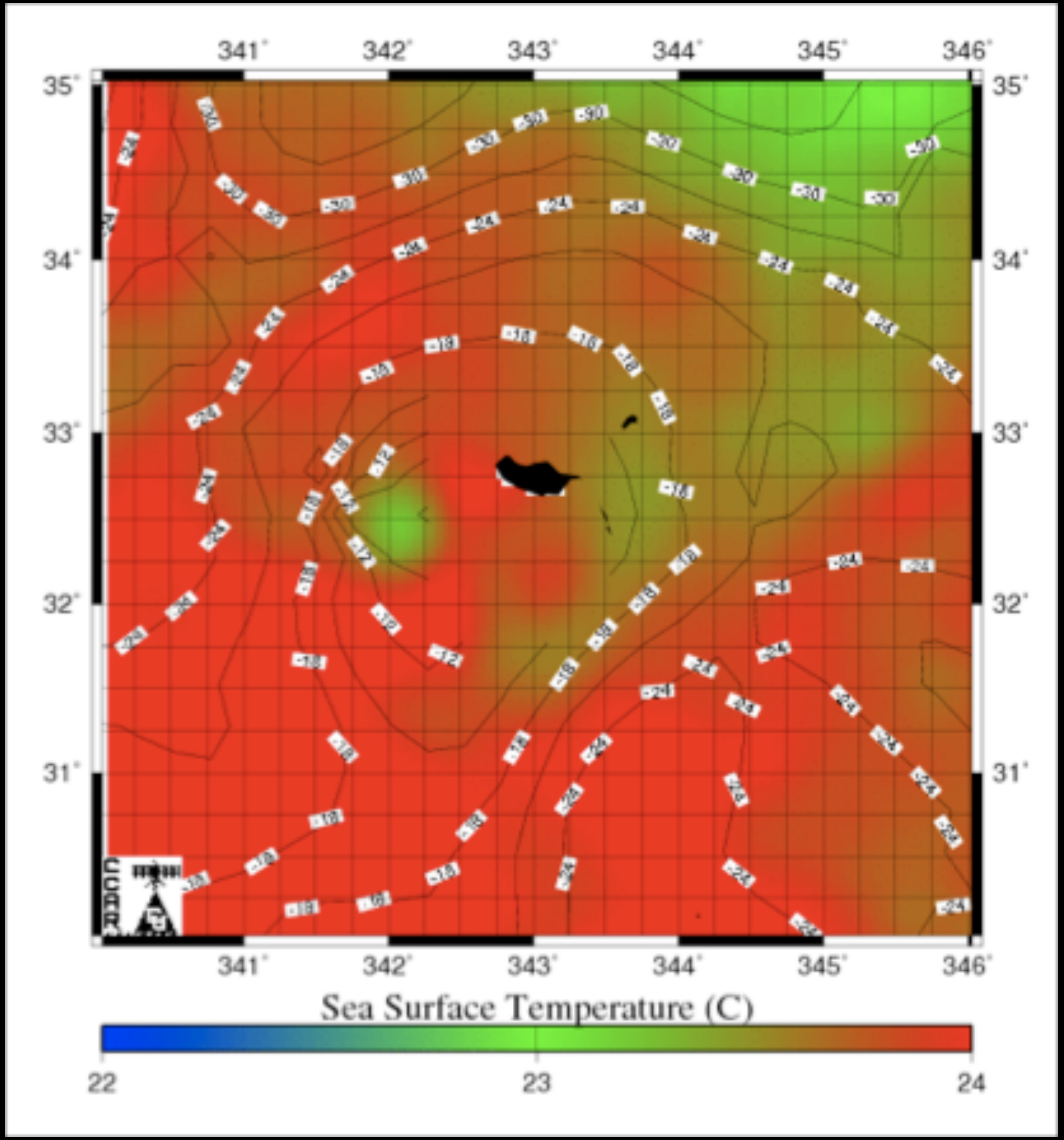

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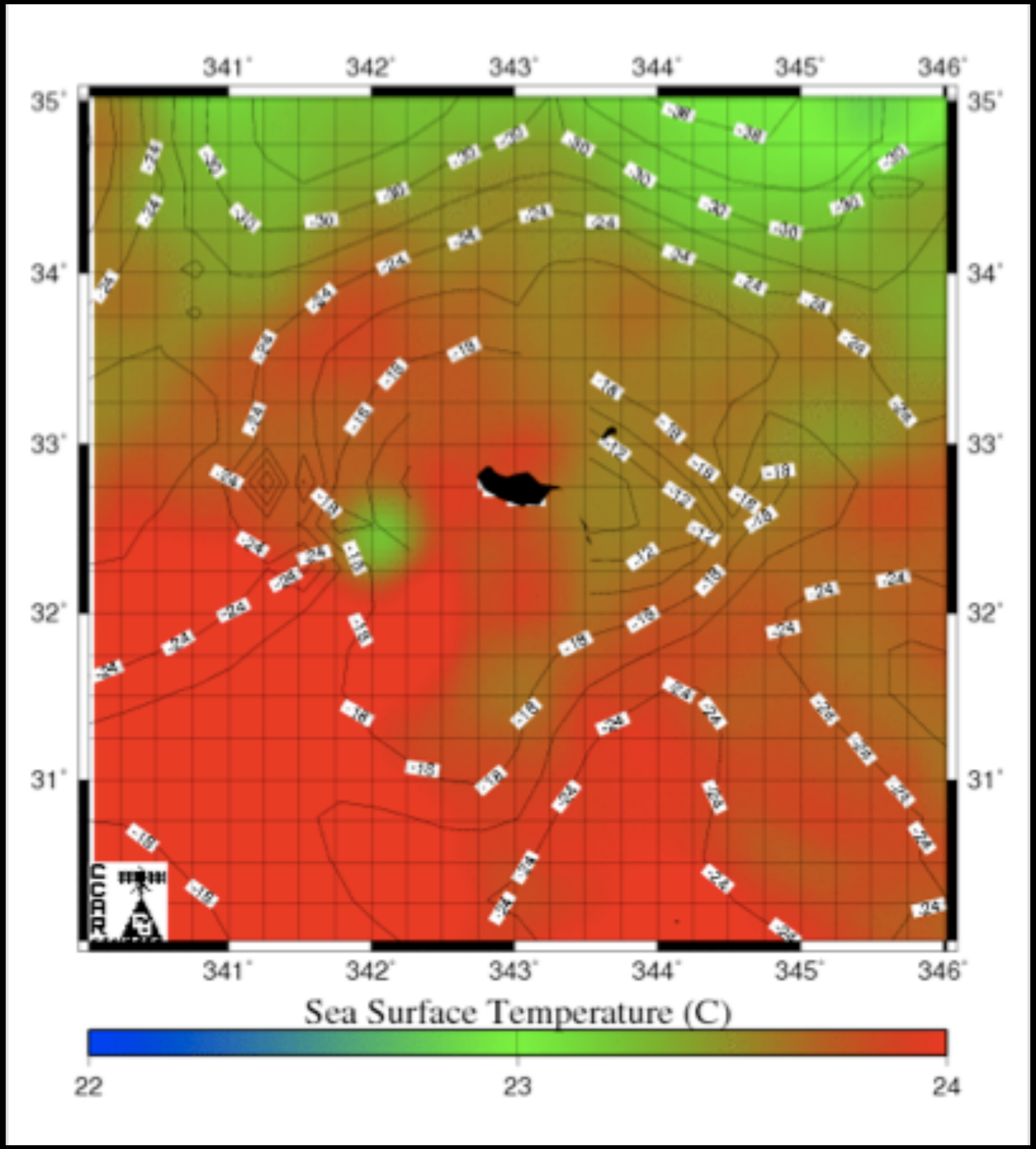

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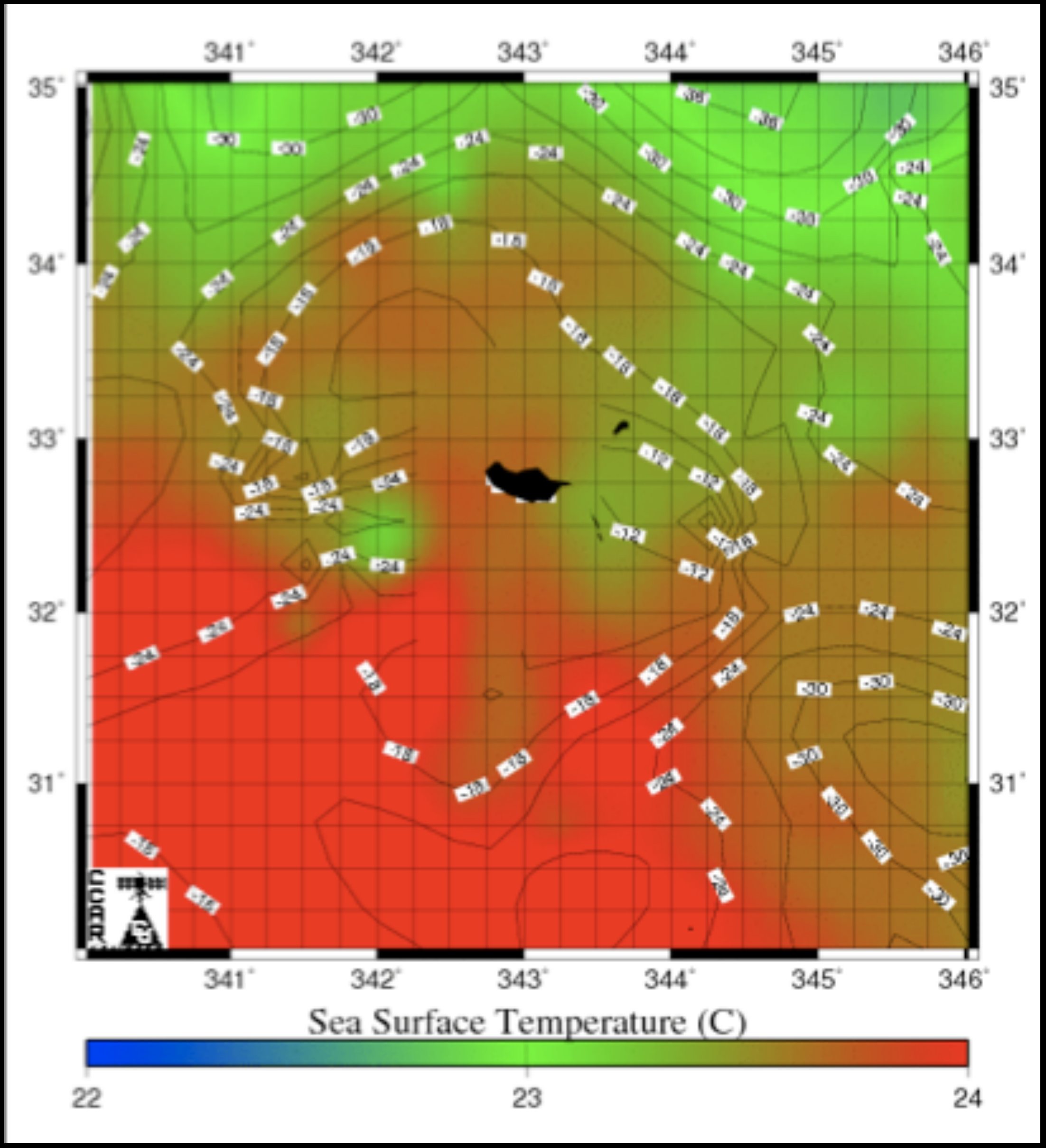

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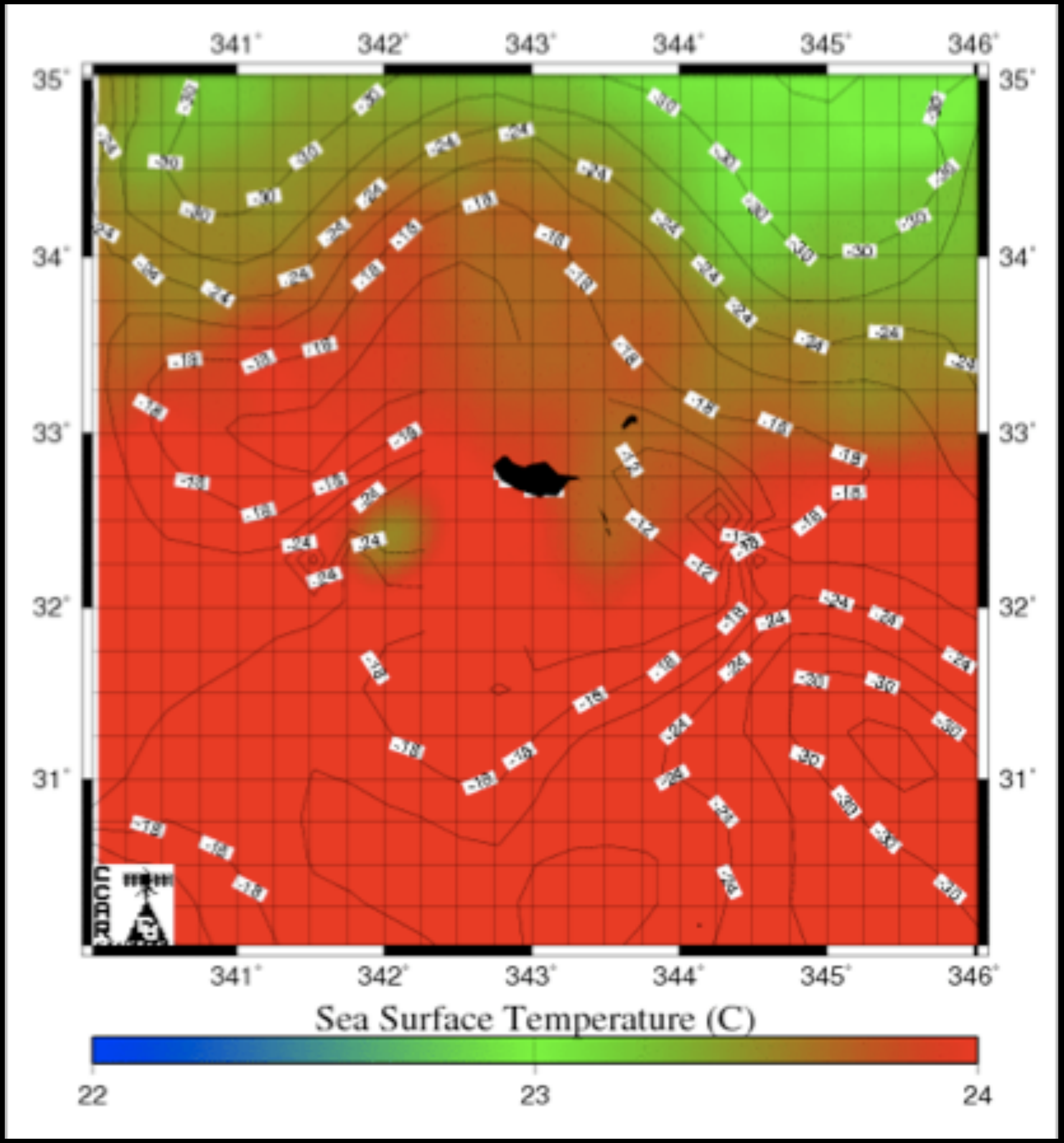

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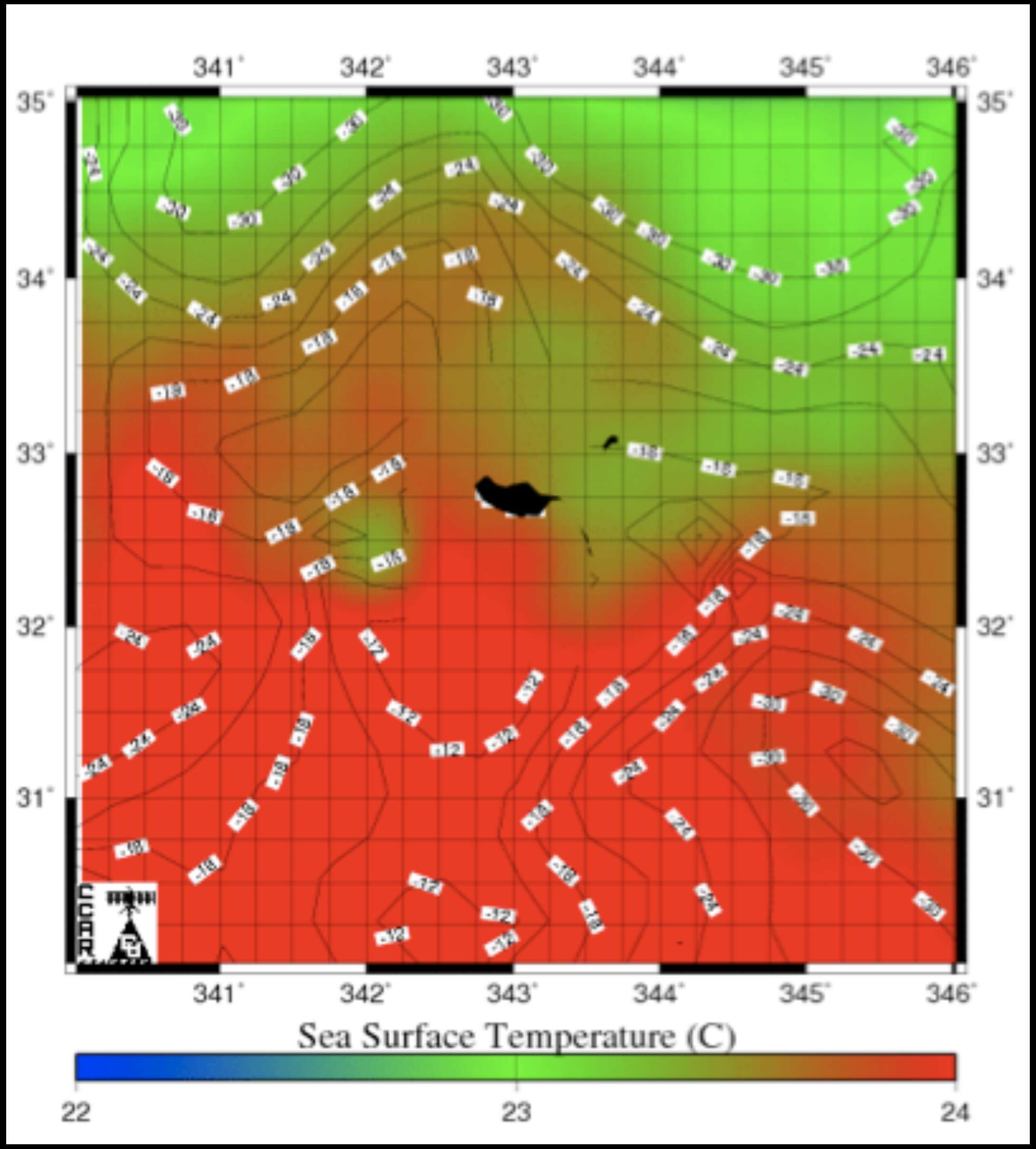

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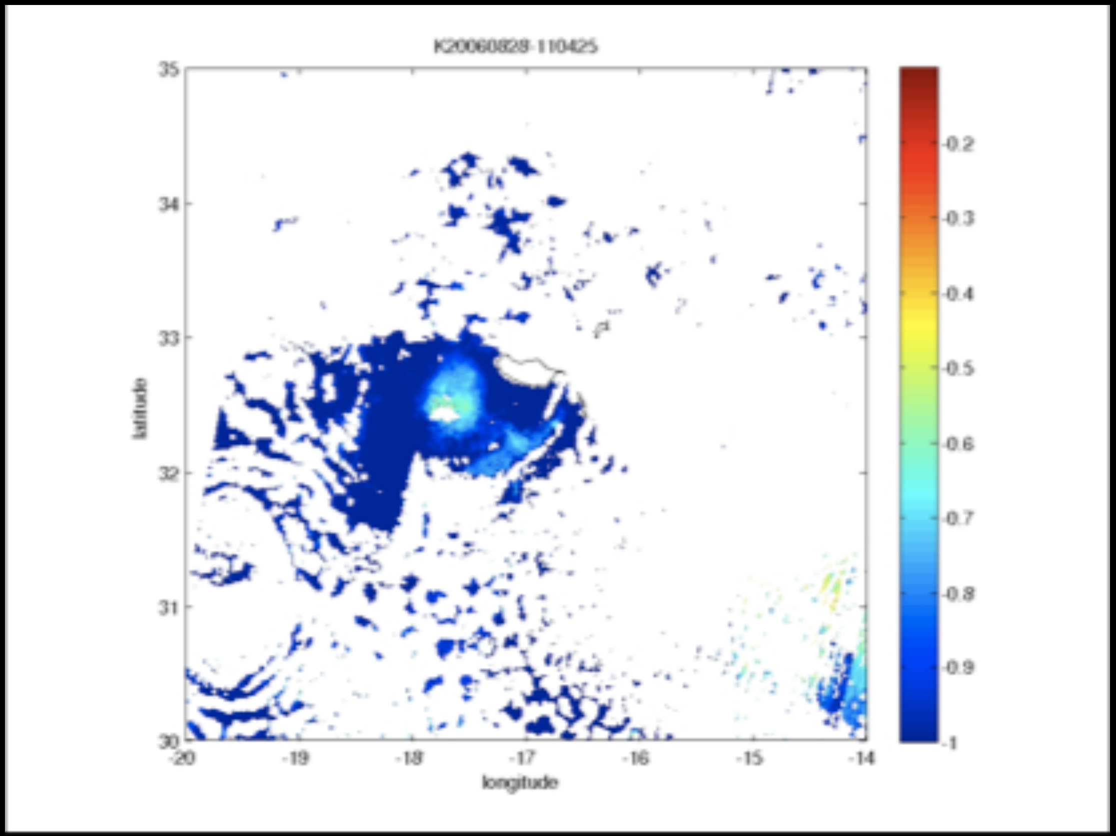

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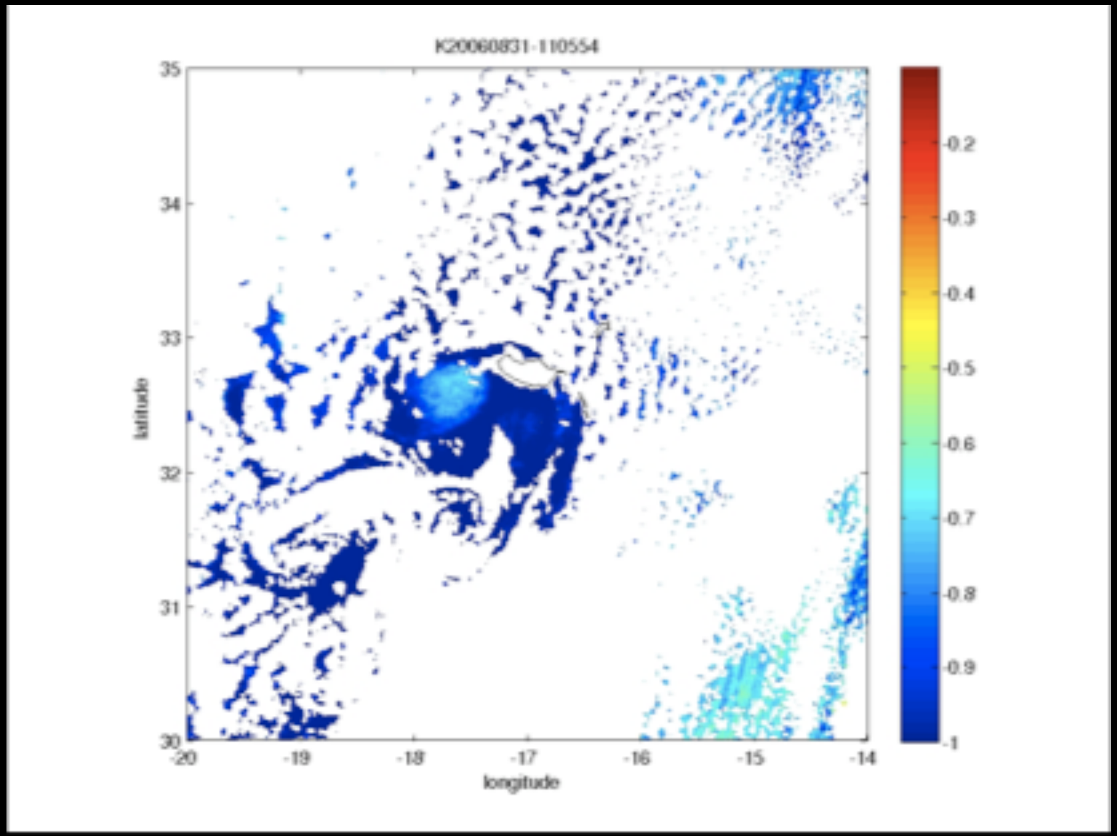

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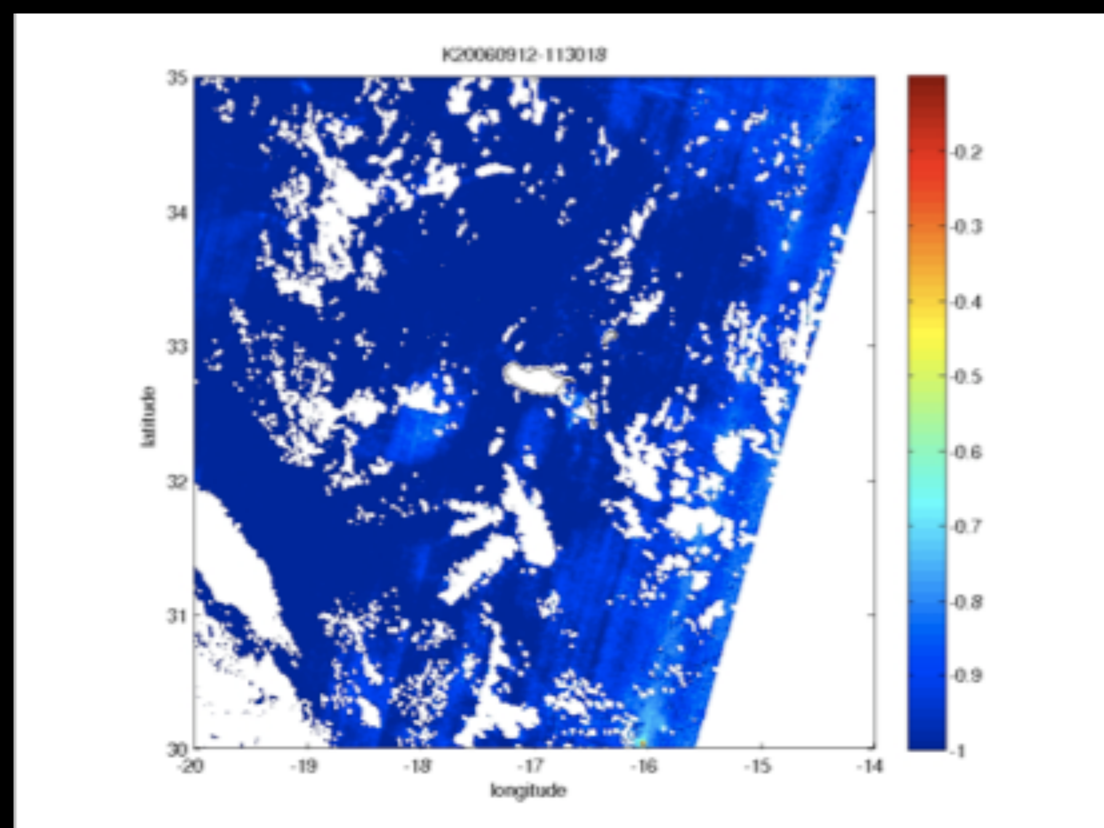

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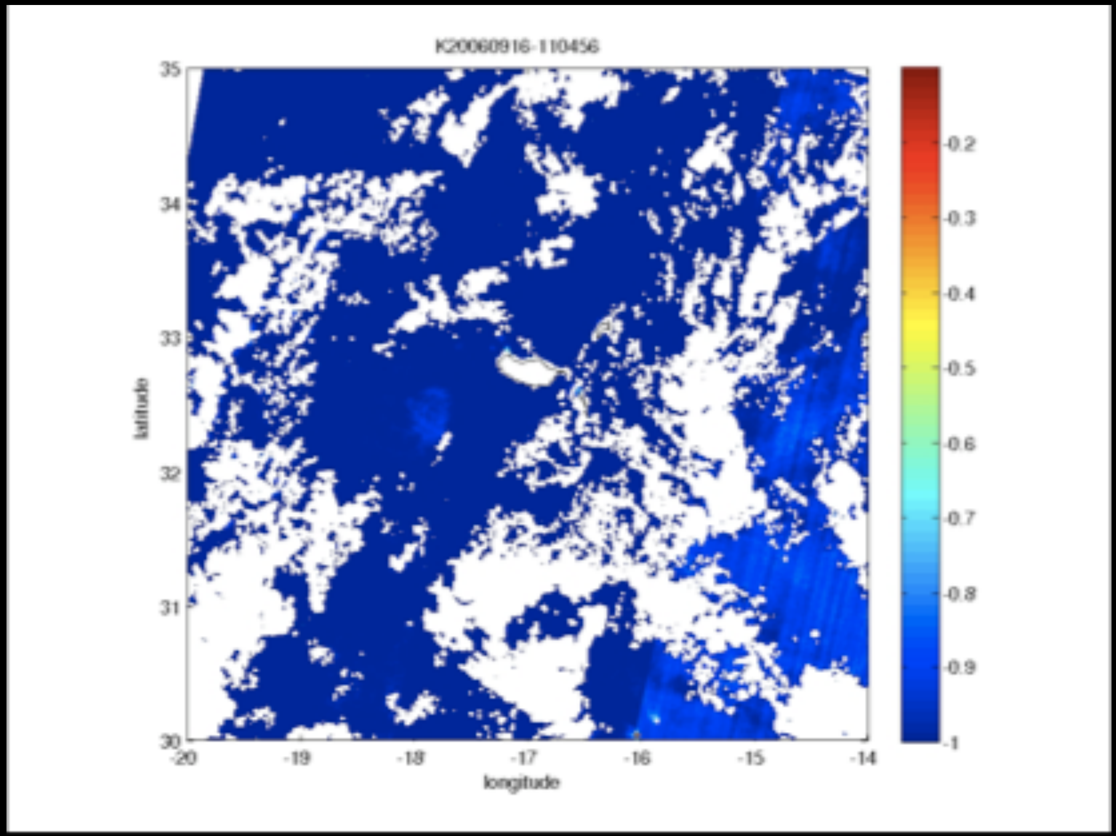


Data INterpolating Empirical Orthogonal Functions

$$d(\varphi,\lambda,t) = \bar{d}(\varphi,\lambda) + \sum_{j=1}^{n} \underbrace{m_j(\varphi,\lambda)}_{\text{spatial comp.}} \cdot \underbrace{e_j(t)}_{\text{temporal comp.}}$$

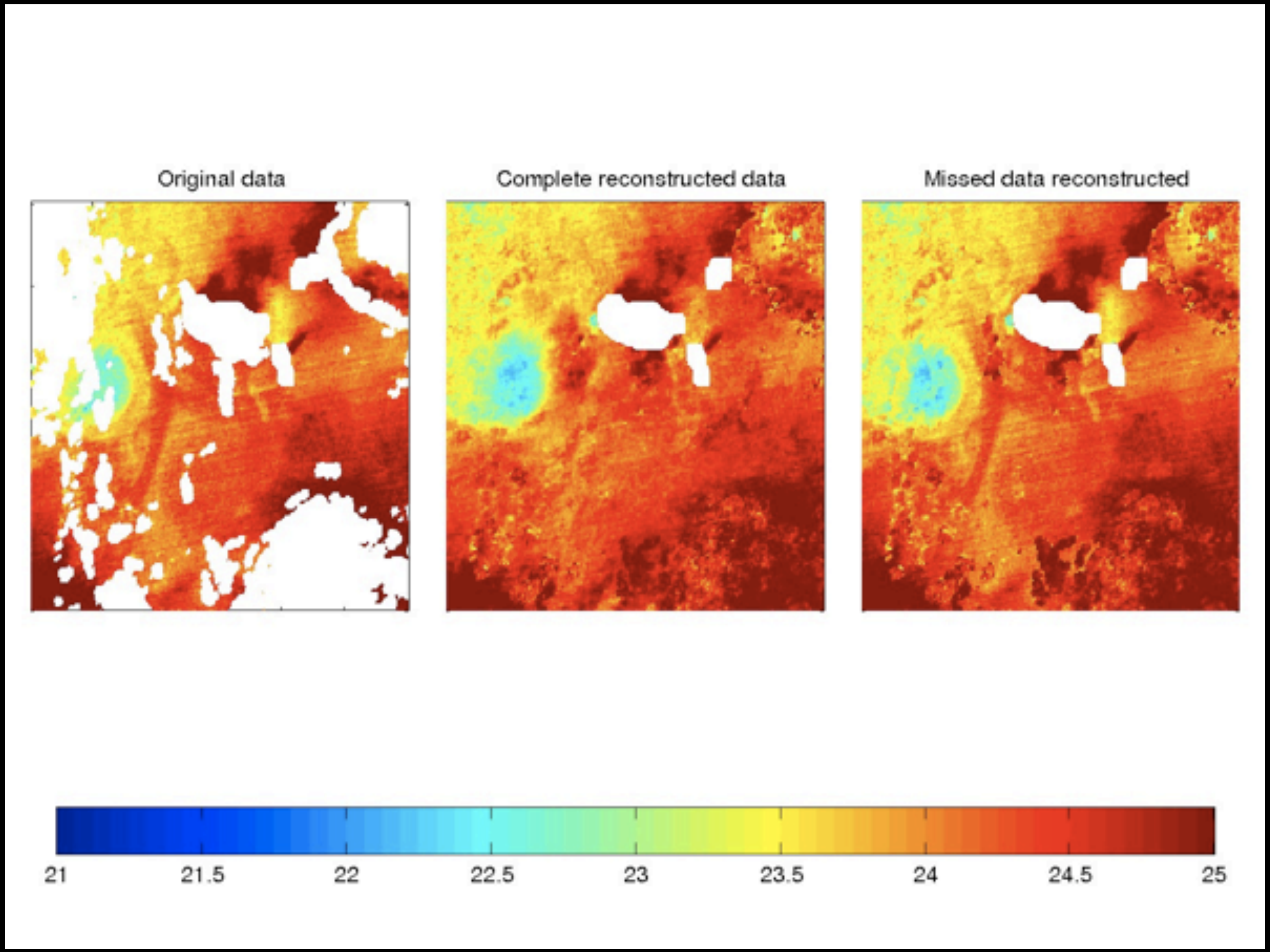
$$\Rightarrow d(\varphi,\lambda,t) - \bar{d}(\varphi,\lambda) = \underbrace{\sum_{j=1}^{k} m_j(\varphi,\lambda) e_j(t)}_{\text{dominant modes}} + \underbrace{\sum_{j=k+1}^{n} m_j(\varphi,\lambda) e_j(t)}_{\text{secondary modes}}$$

Writing time varying data $d(\varphi,\lambda,t)$ as a matrix $\mathcal{D} \in \mathbb{R}^{m\times n}$ where each row is associated with one point (φ,λ) and each column - with one epoch t we have linear algebra problem

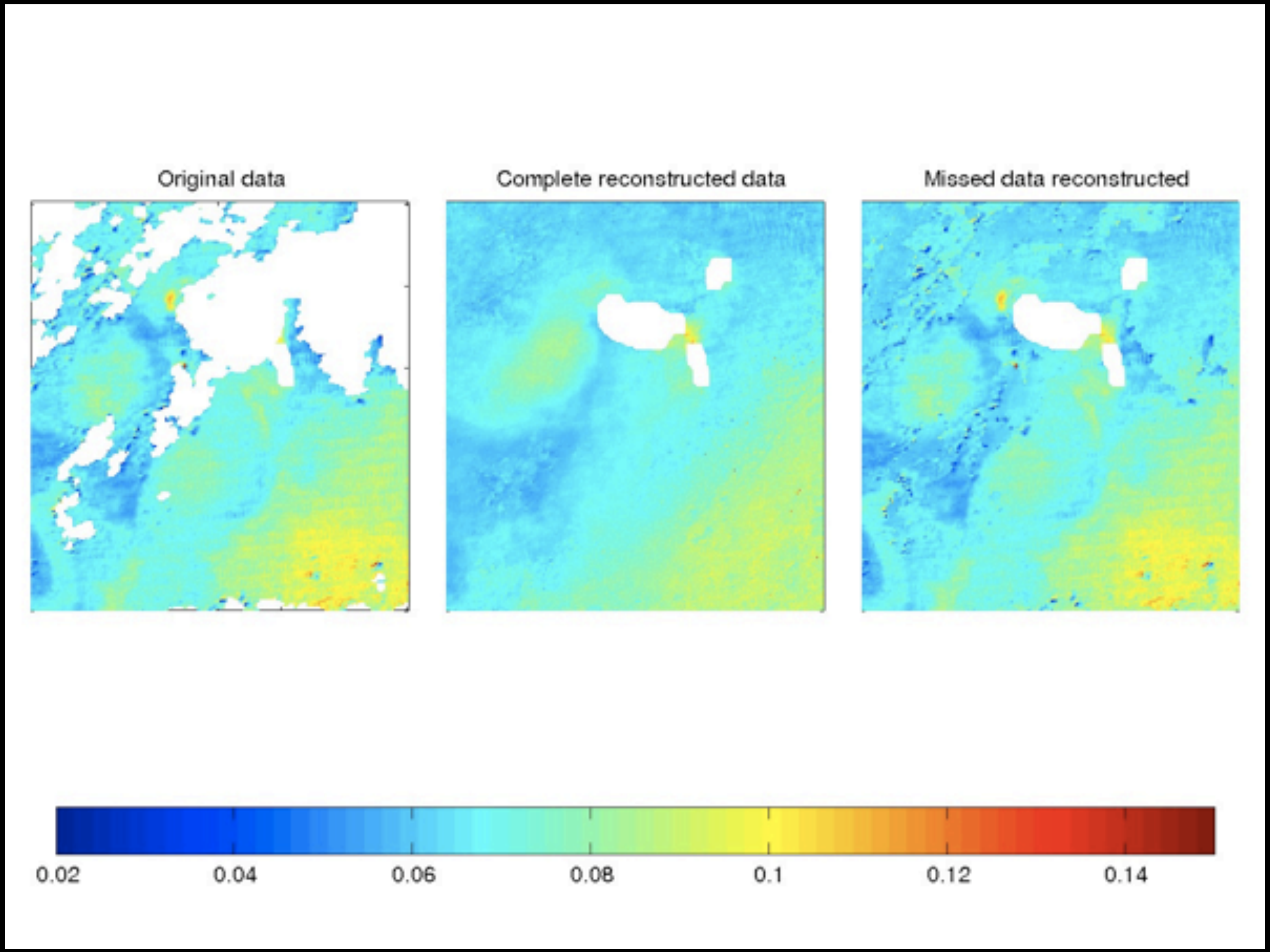
$$\mathrm{D{=}USV}^T$$

Beckers, J.-M. and Rixen, M. 2003. EOF calculations and data filling from incomplete oceanographic data sets. Journal of Atmospheric and Oceanic Technology, vol 20 (12), pp 1839-1856.

Reconstructed data

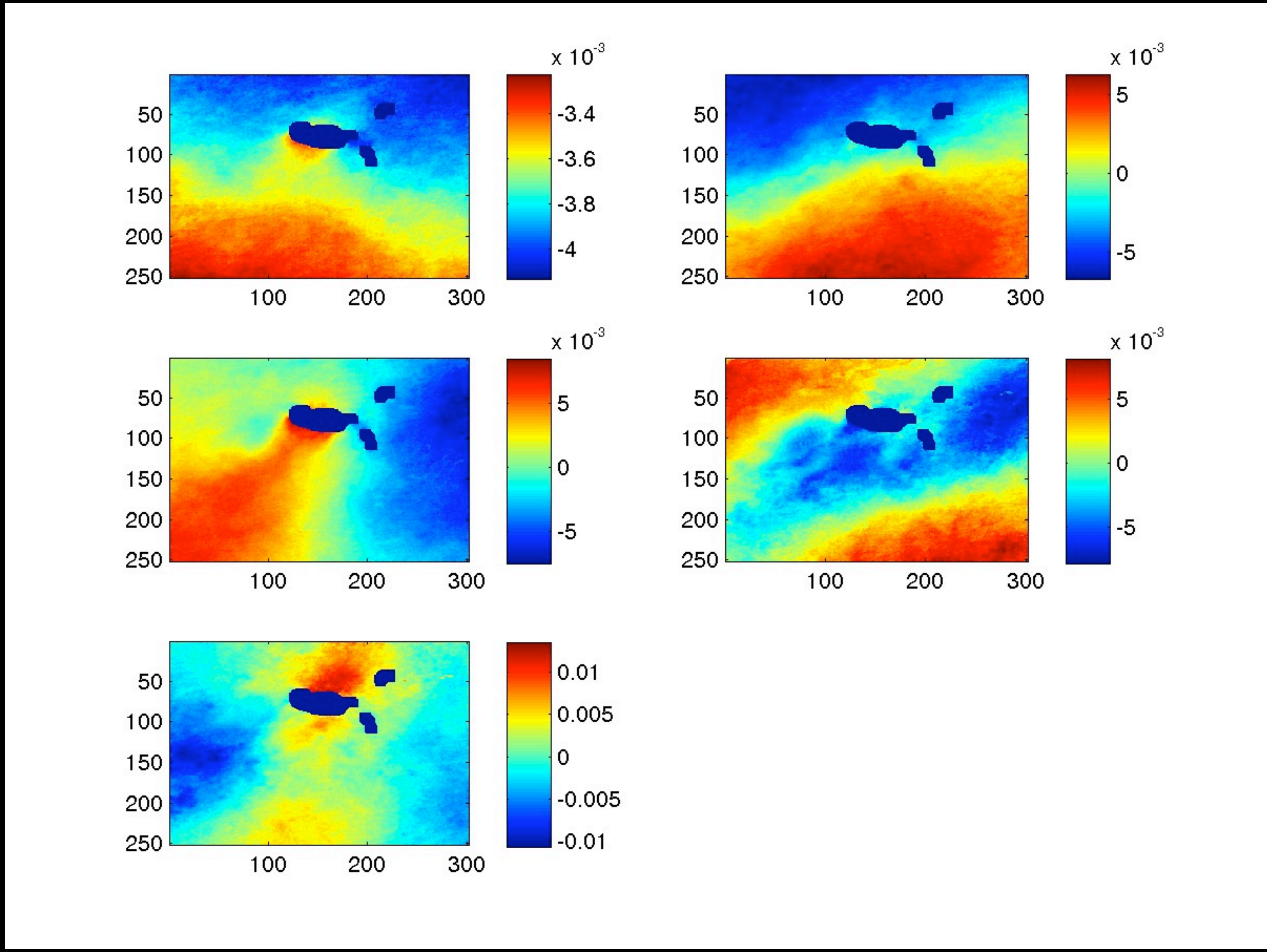


Reconstructed data



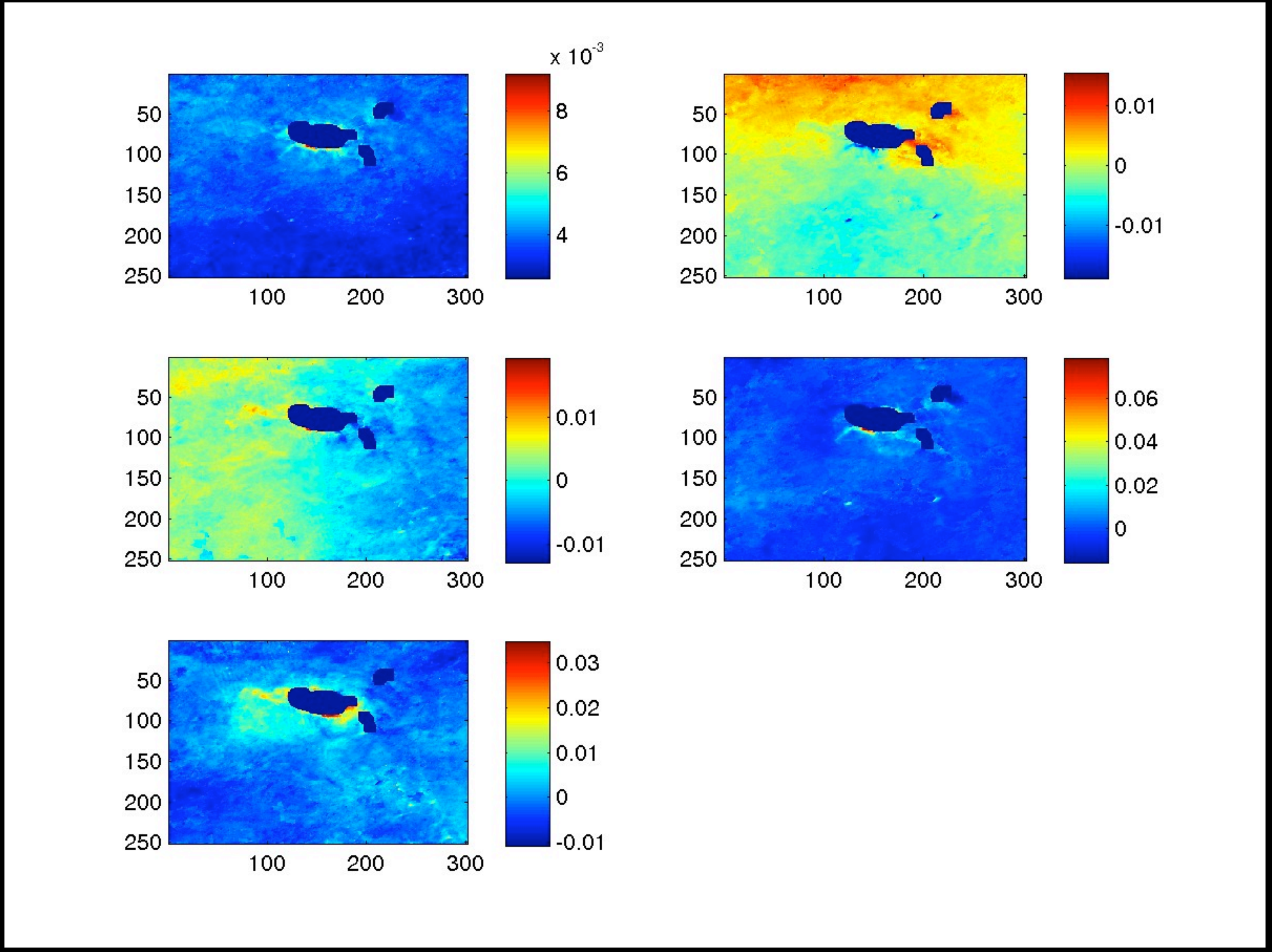
SST Dominant modes
2005-2007

Mode 1: 60.27%
Mode 2: 8.11%
Mode 3: 6.51%
Mode 4: 4.21%
Mode 5: 3.29%



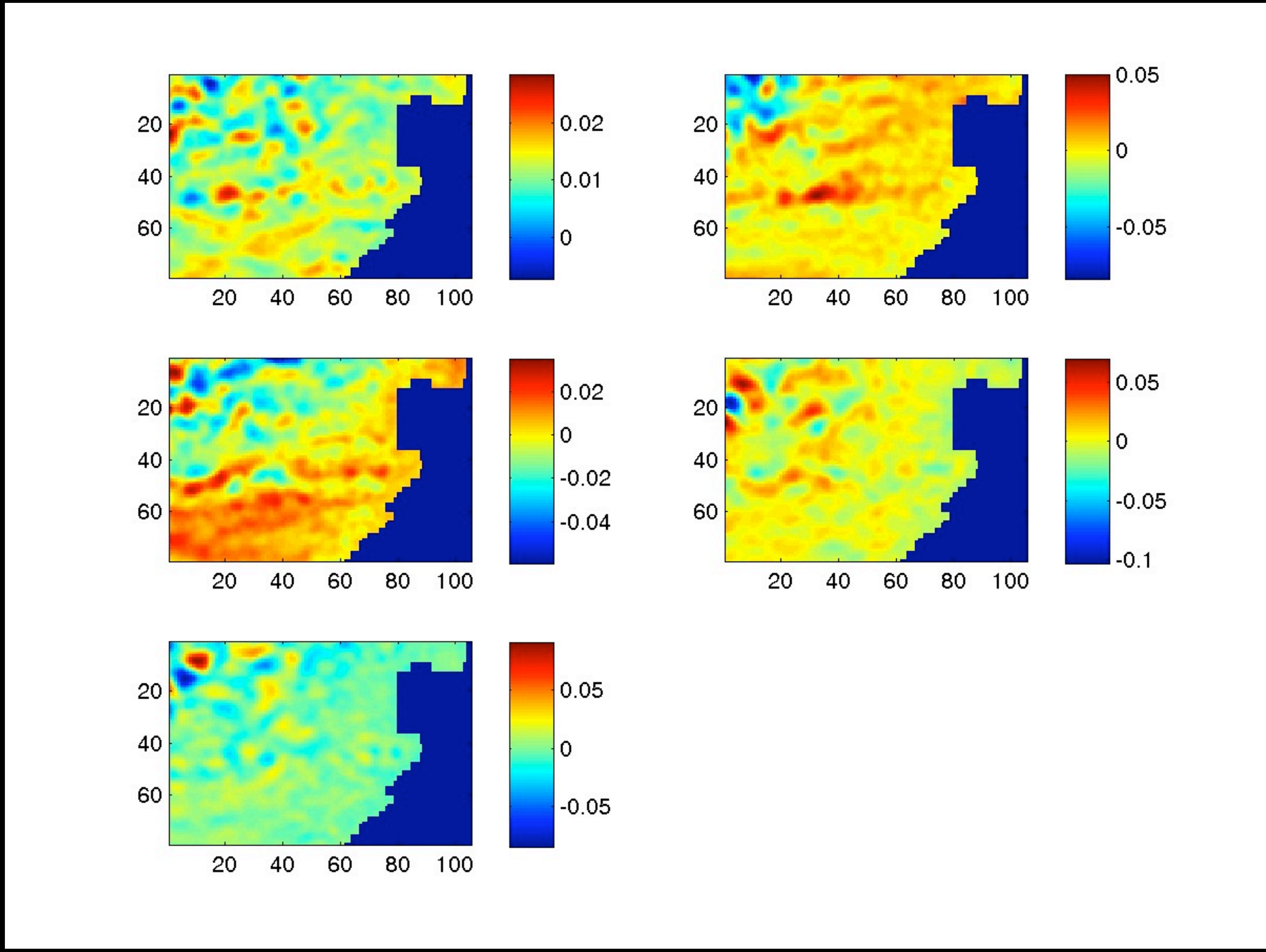
CHL Dominant modes
2005-2007

Mode 1: 34.71%
Mode 2: 13.02%
Mode 3: 8.20%
Mode 4: 6.38%
Mode 5: 6.24%



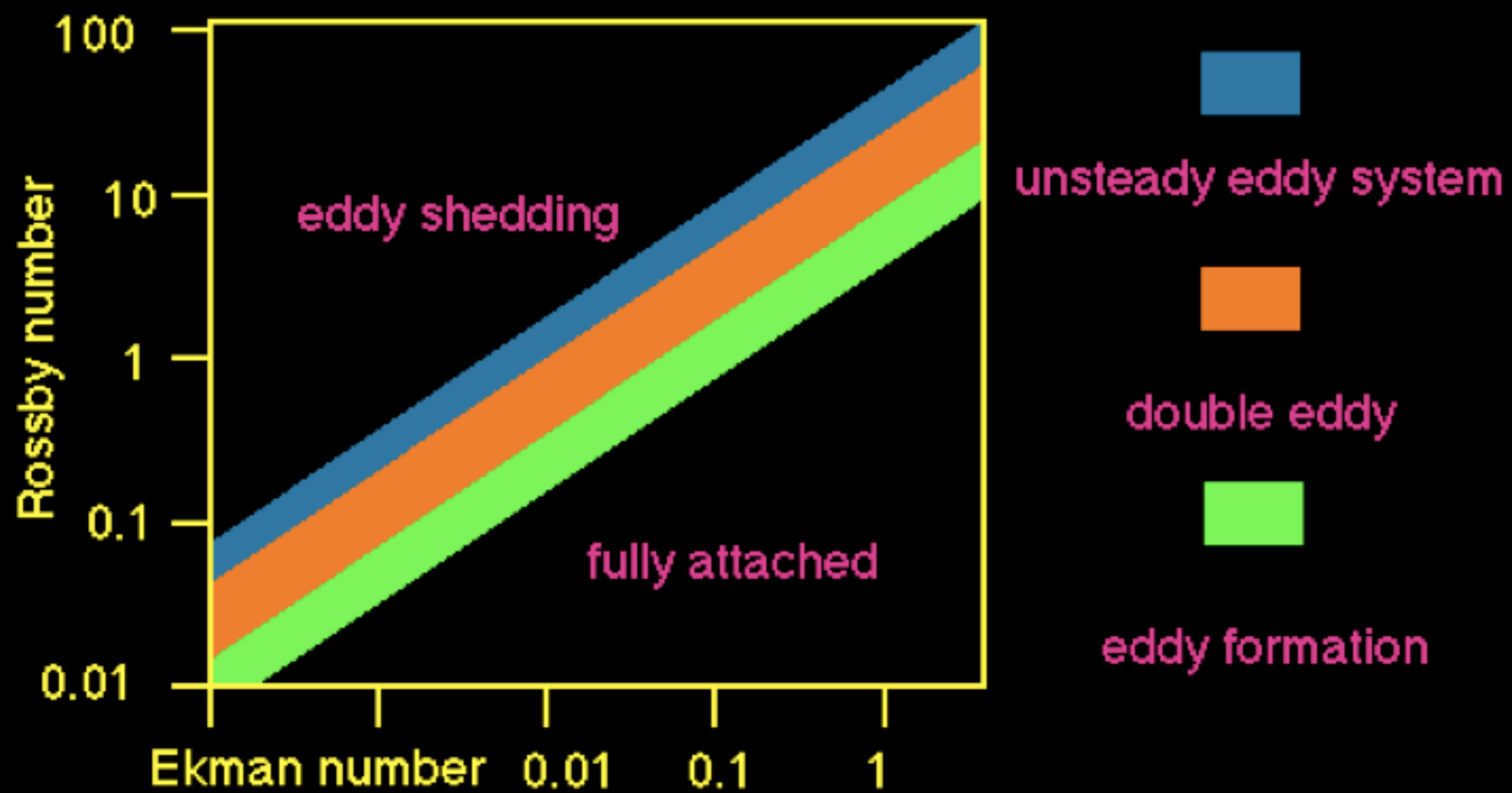
SLA Dominant modes
2001-2007

Mode 1: 16.29%
Mode 2: 8.4%
Mode 3: 6.6%
Mode 4: 5.66%
Mode 5: 5.27%



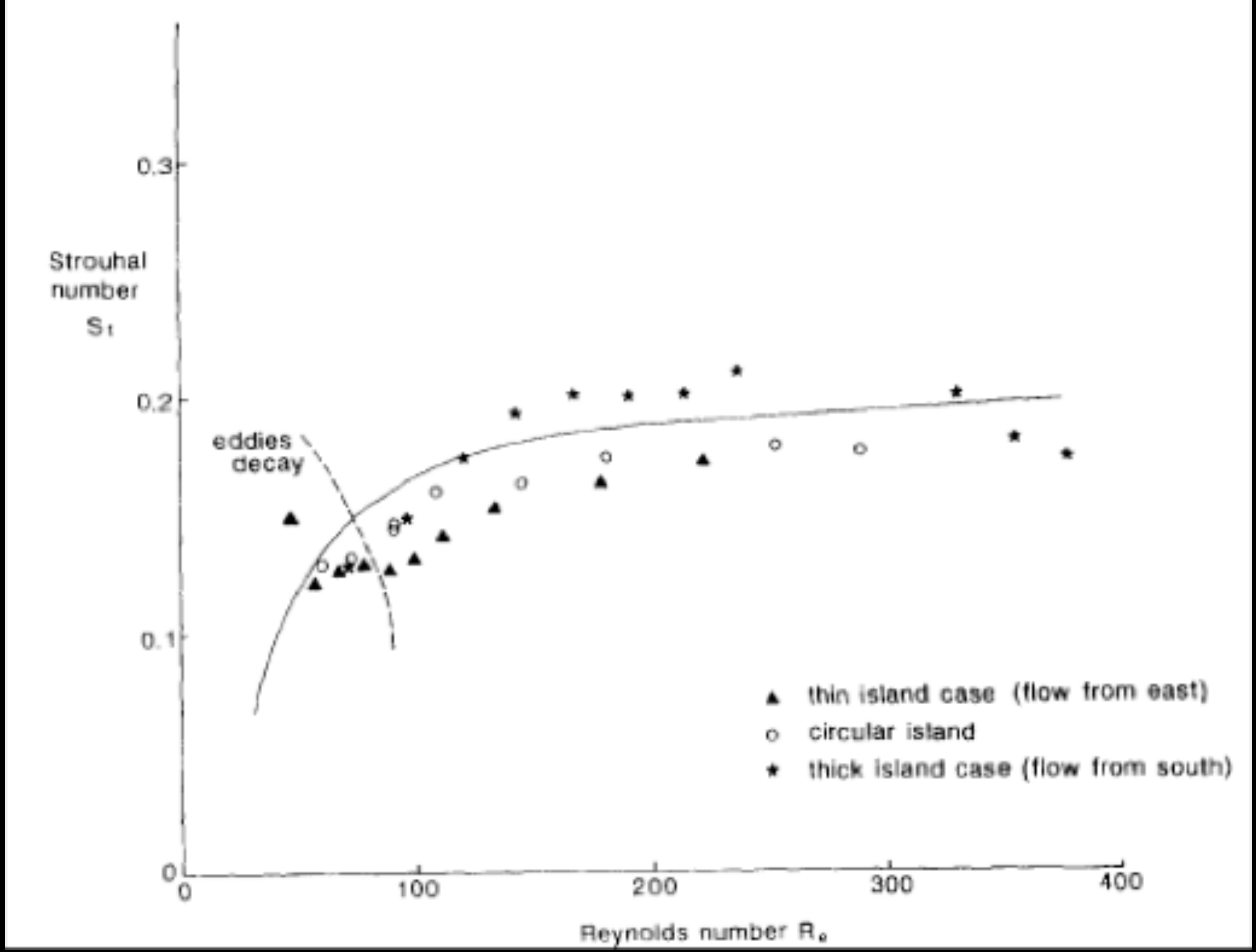
Wake regimes

Non-dimensional parameters



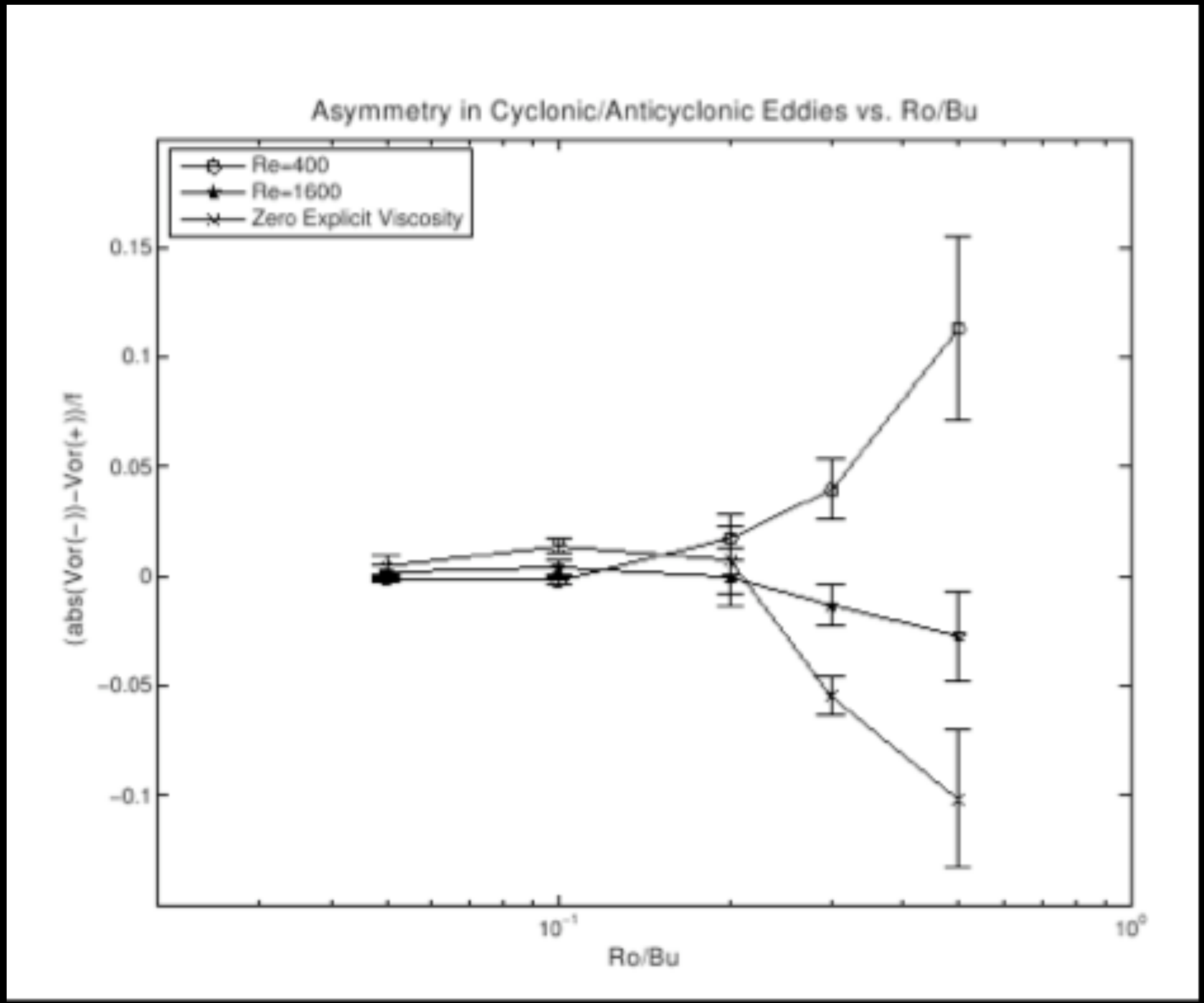
Wake regimes

Non-dimensional parameters



Wake regimes

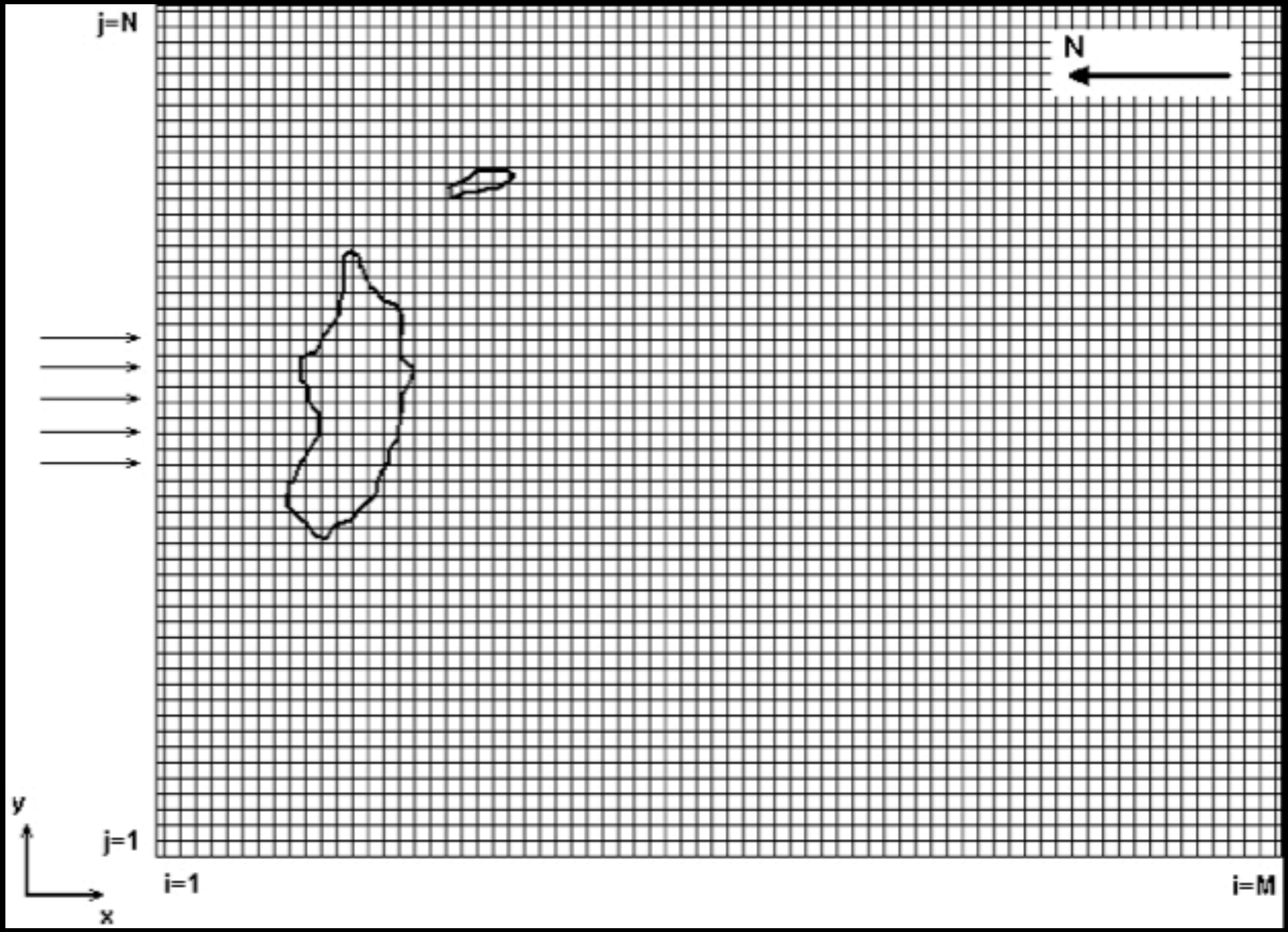
Non-dimensional parameters



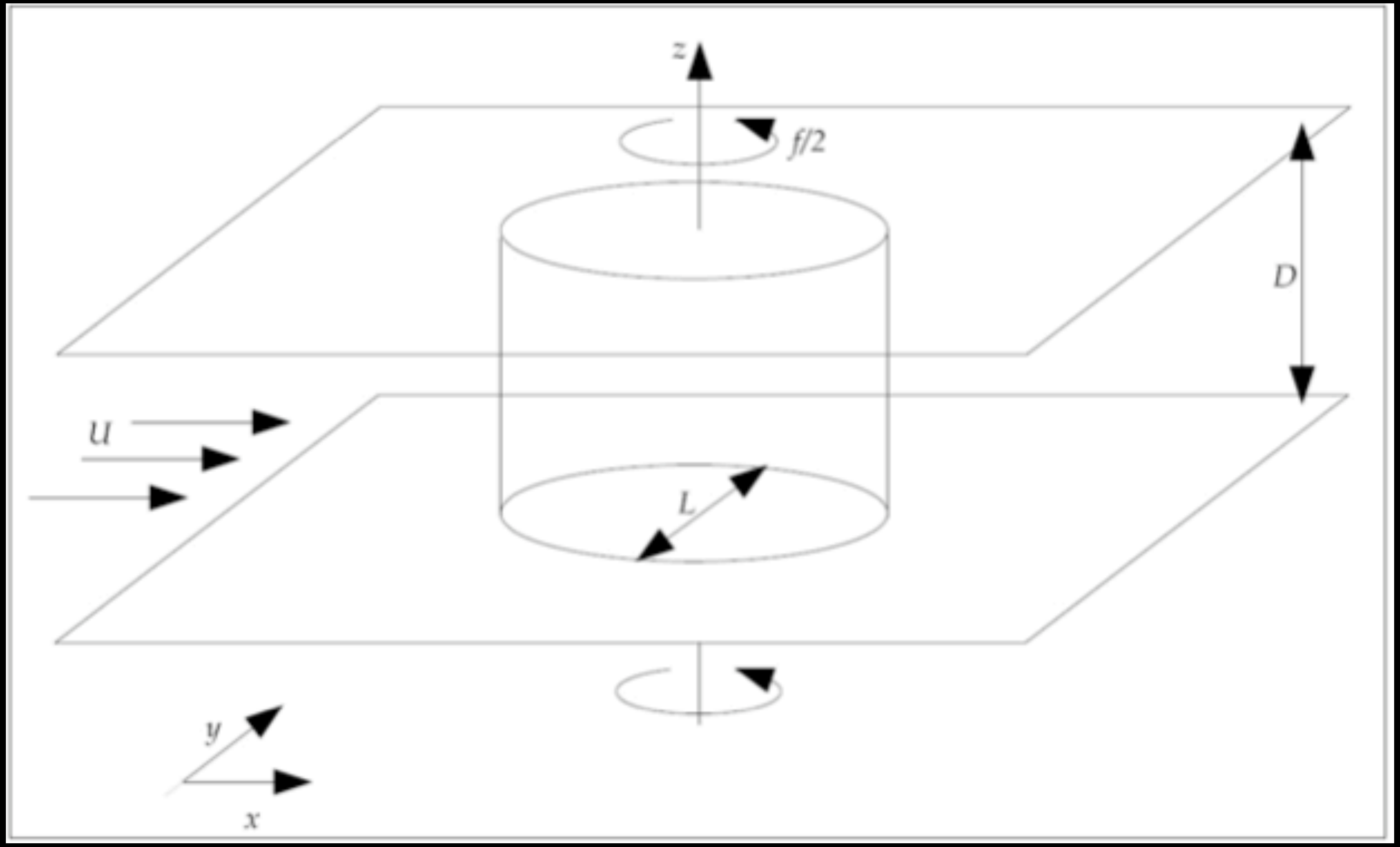
Non-dimensional

$Re = \frac{UL}{\nu_e},$	Reynolds number
$Ro = \frac{U}{Lf},$	Rossby number
$Fr = \frac{U}{NH},$	Froude number
$E_k = \frac{\nu_e}{fL^2},$	Ekman number (horizontal)
$L_d = NH/f,$	Baroclinic deformation radius
$Bu = \left(\frac{L_d}{L}\right)^2,$	Burger number

2D numerical study



2D numerical study



2D numerical setup

- **Quasi-geostrofic approximation**

$$\frac{\partial \zeta_0'}{\partial t'} + J\left(p_0', \zeta_0'\right) = \frac{1}{Re}\nabla^2 \zeta_0'$$

- **Initial conditions**

$$\zeta_0' = \nabla^2 p_0'$$

$$x' = 0,\ \text{inflow} \rightarrow \begin{cases} \zeta_0' = 0 \\ u' = -\dfrac{\partial p_0'}{\partial y'} = \text{cte} \end{cases}$$

- **Boundary conditions**

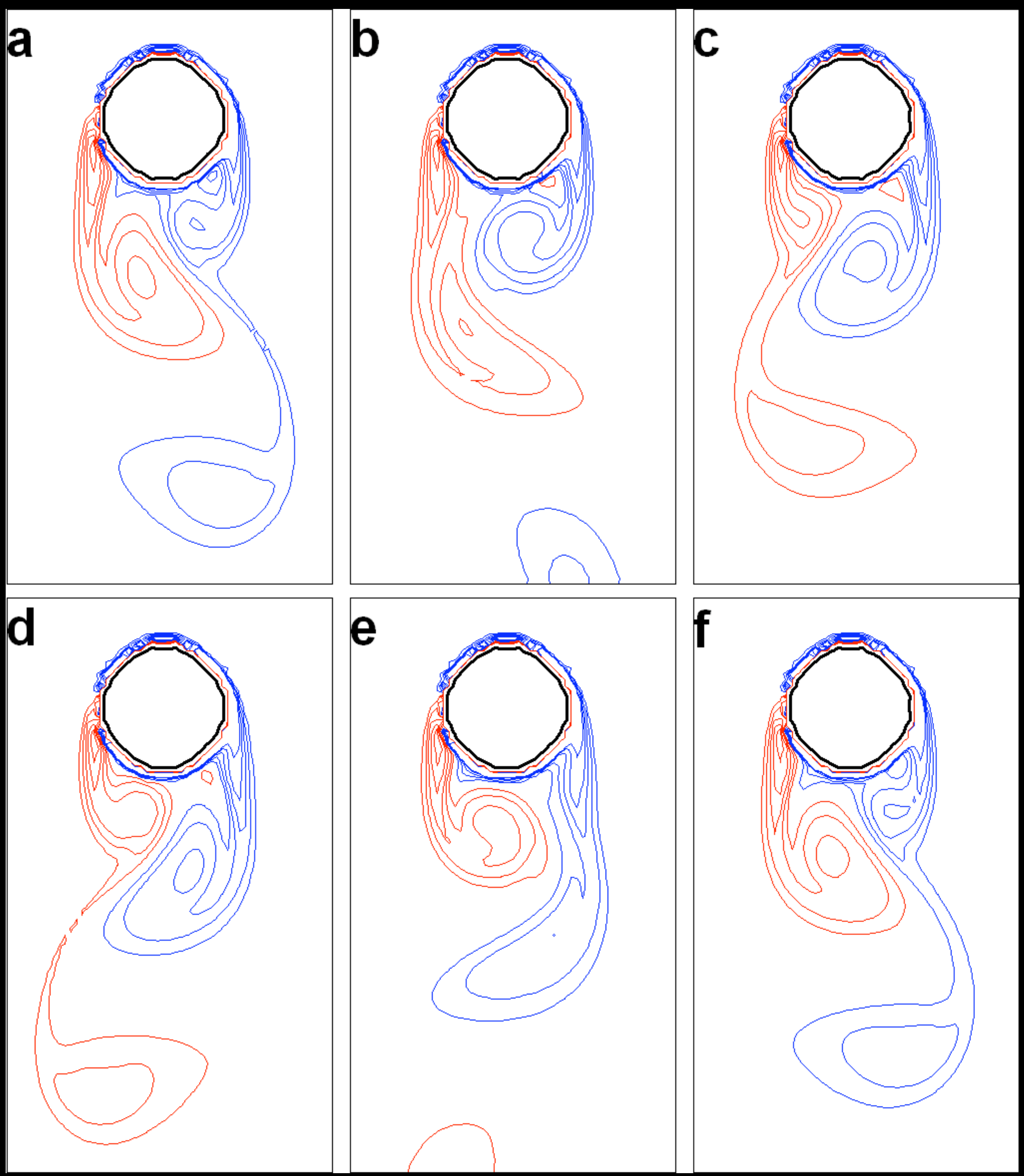
$$\text{obstacle} \rightarrow \begin{cases} \zeta_{\text{obs}}' = 0 \\ u_{\text{obs}}' = -\dfrac{\partial p_0'}{\partial s} = 0 \rightarrow p_0' = \text{cte} \end{cases}$$

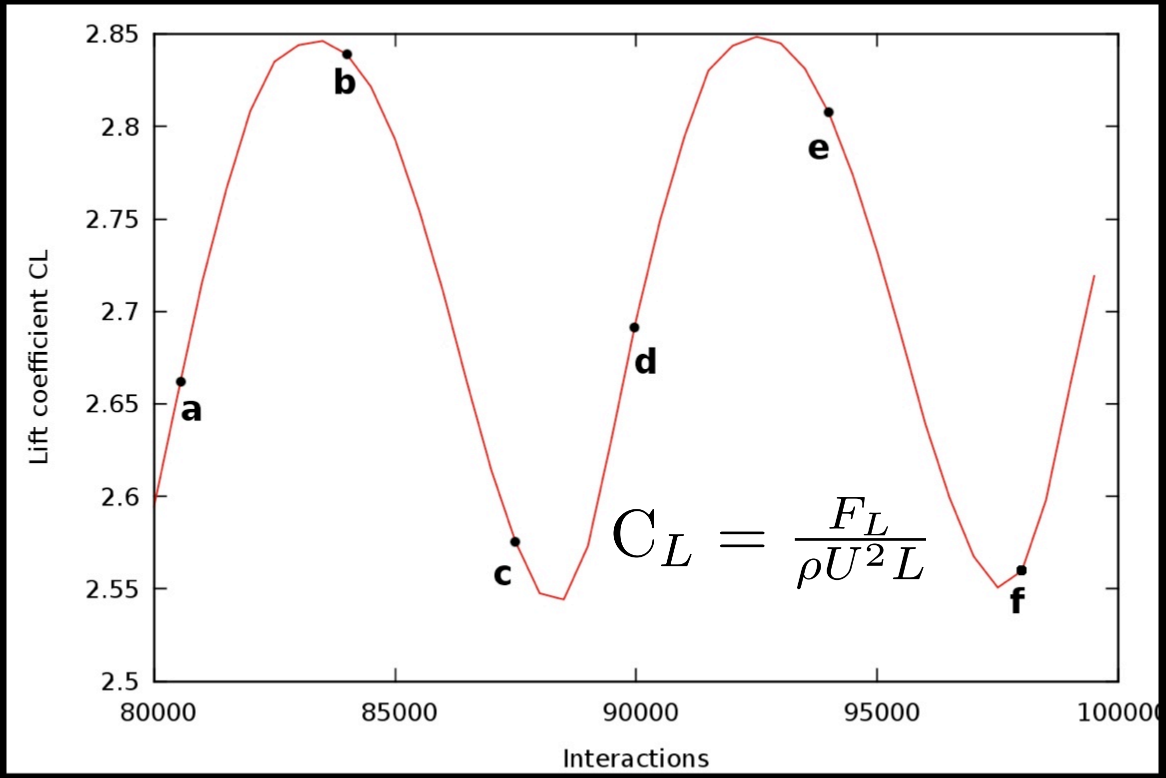
$$y' = 0, y' = n\,\nabla y', \text{walls} \rightarrow \begin{cases} \zeta_0' = 0 \\ p_0' = p_{\text{inflow}}' \end{cases}$$

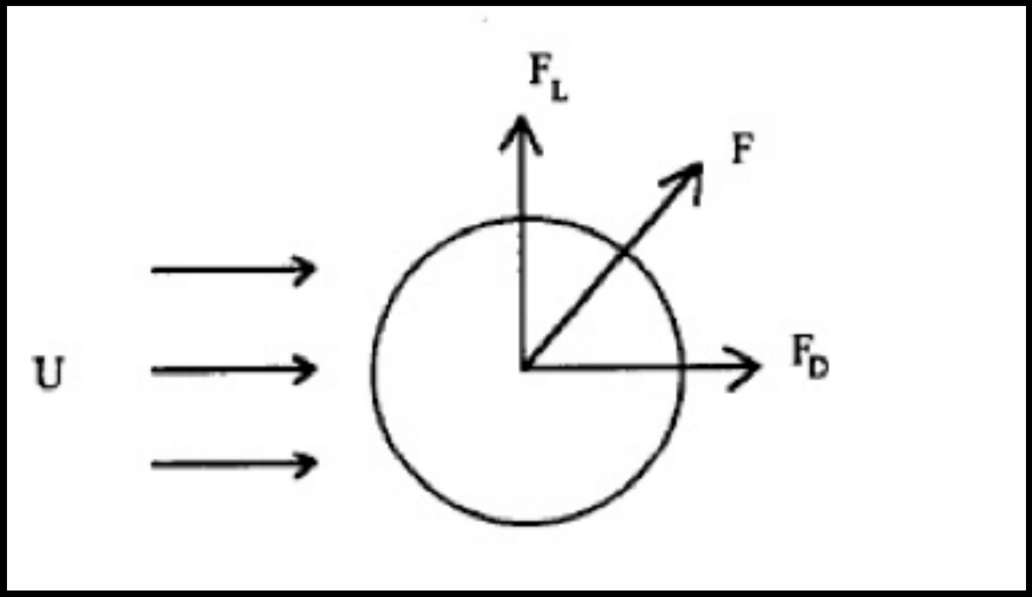
$$x' = m\,\nabla x', \text{outflow} \rightarrow \text{Orlansky}$$

2D Symmetric case

(Classical case)

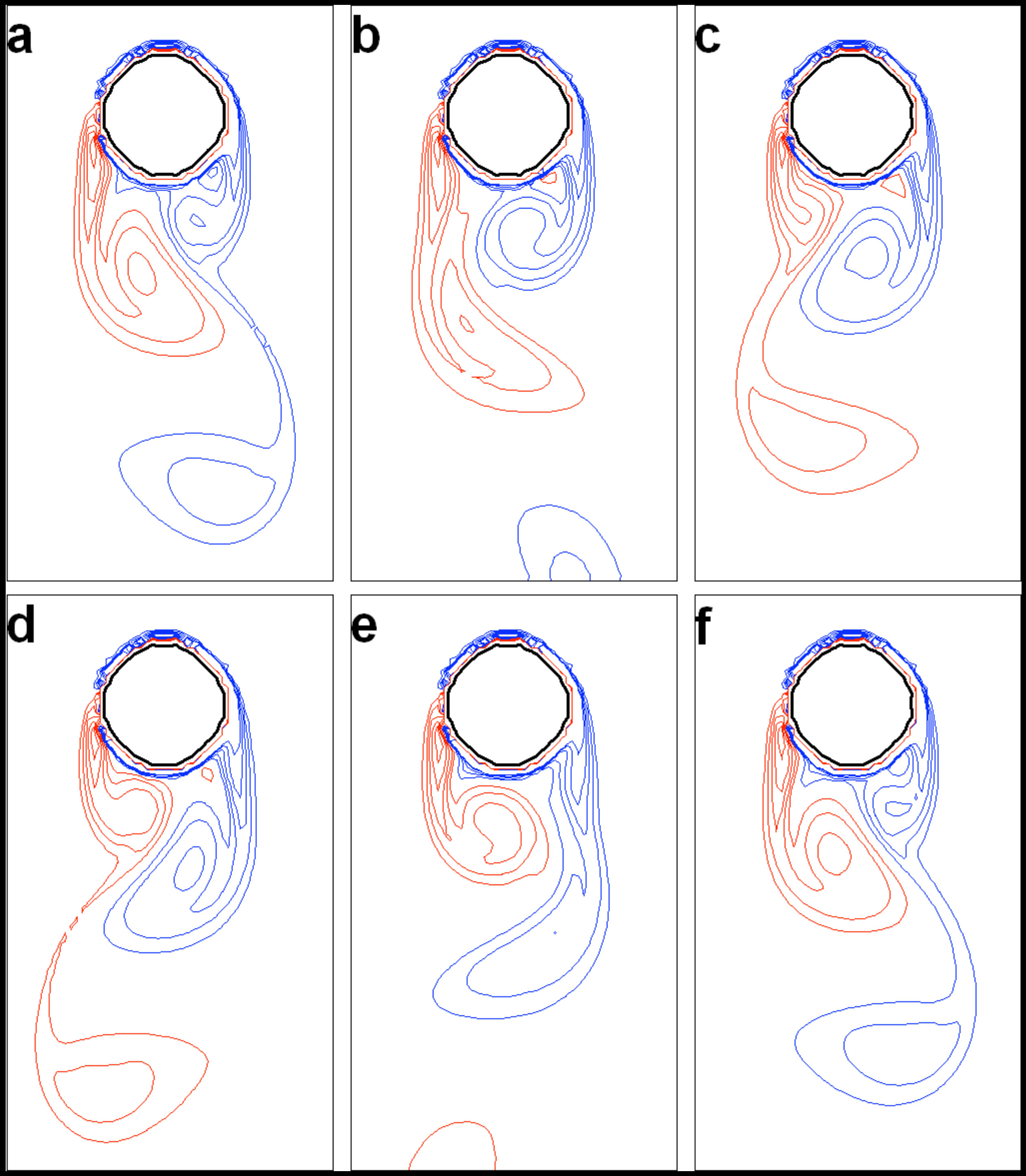


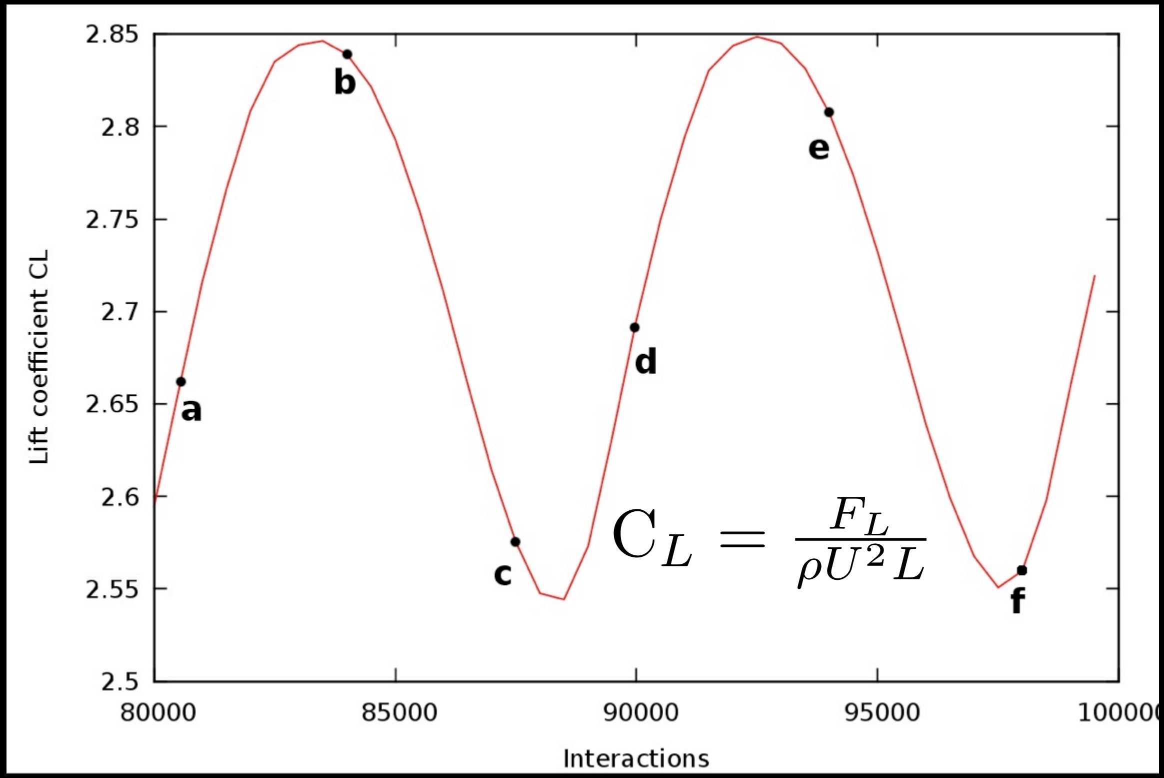


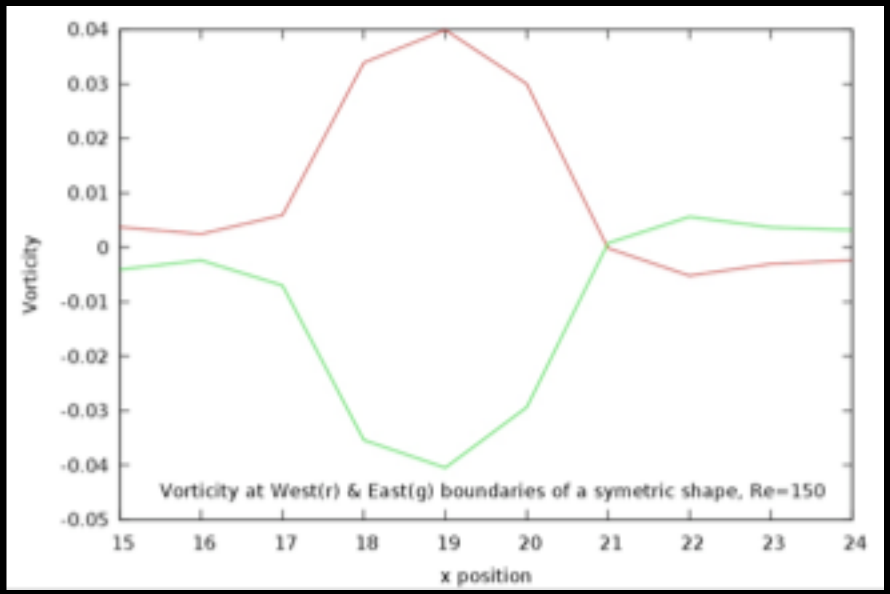


2D Symmetric case

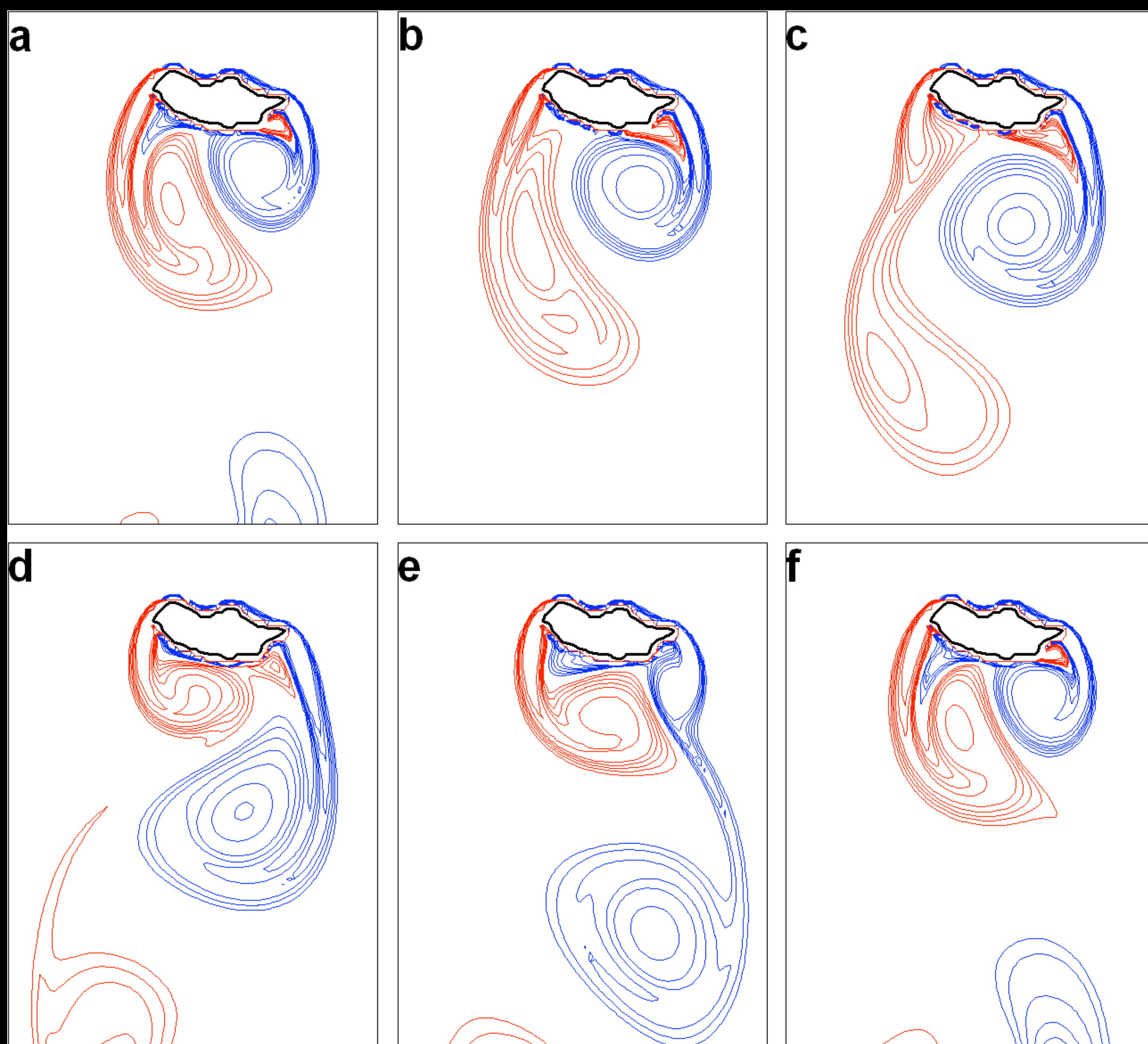
(Classical case)

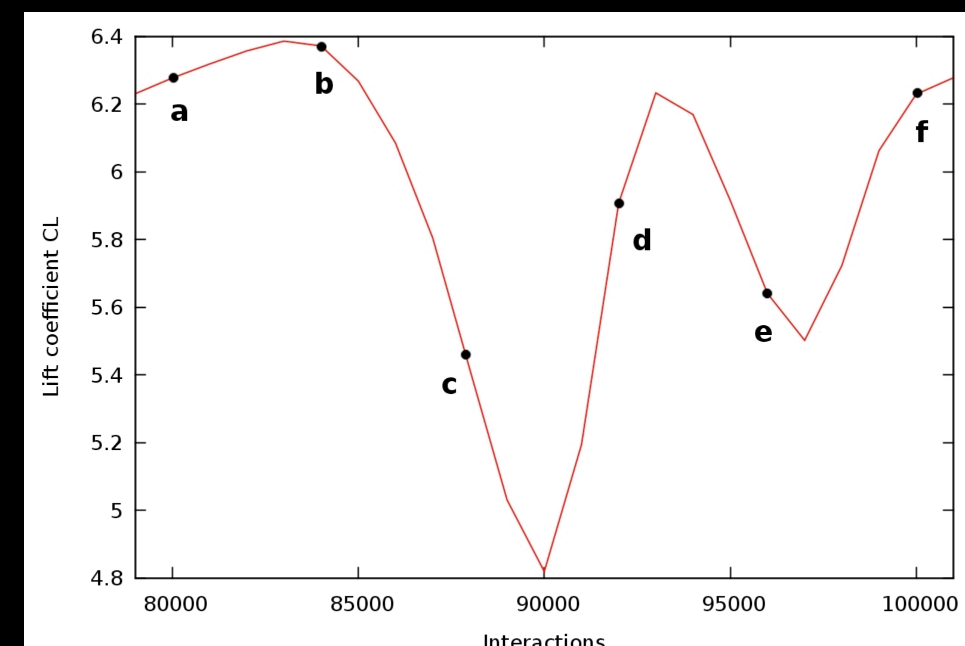






2D Assymmetric case



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13 000000000000000000001111111111111111111111111111102000000000000000
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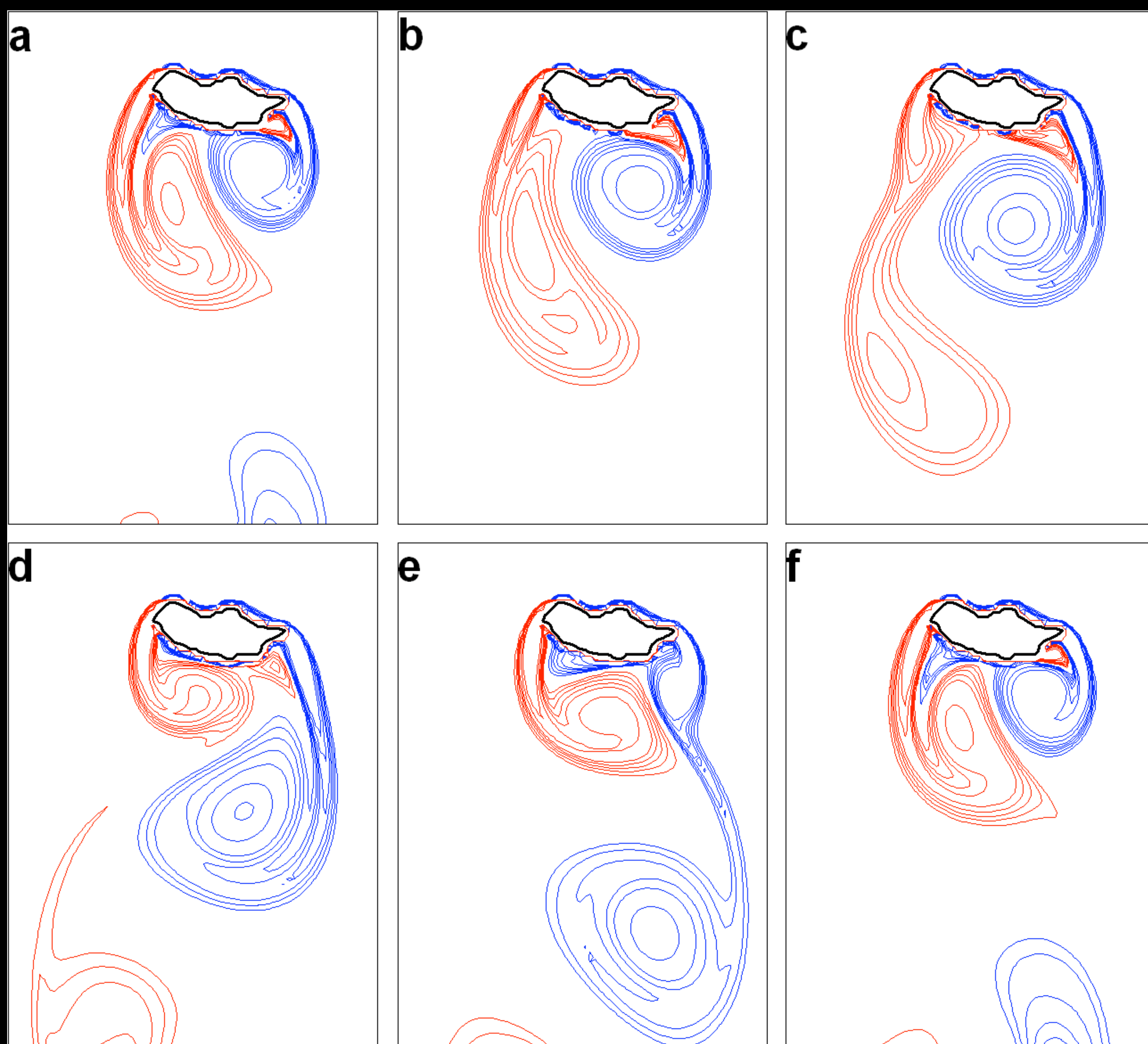
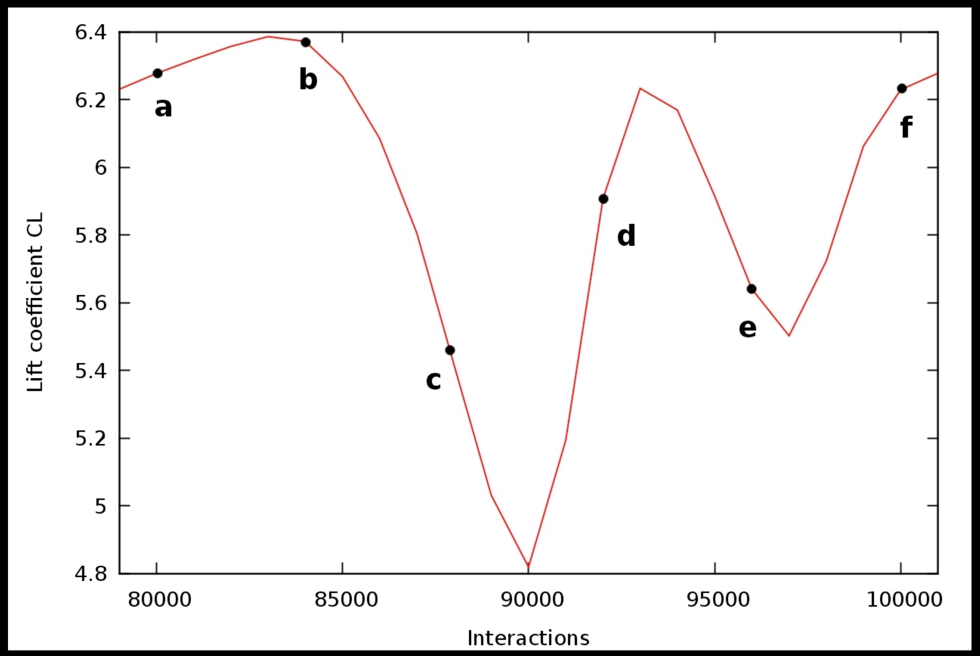
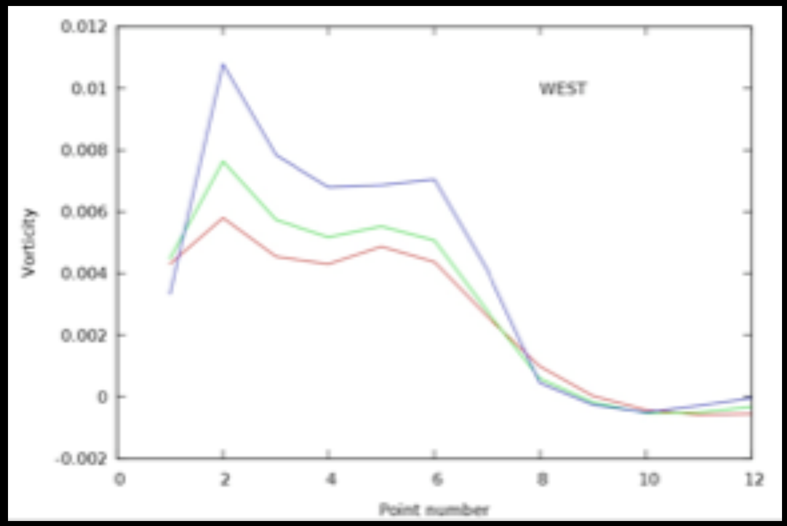
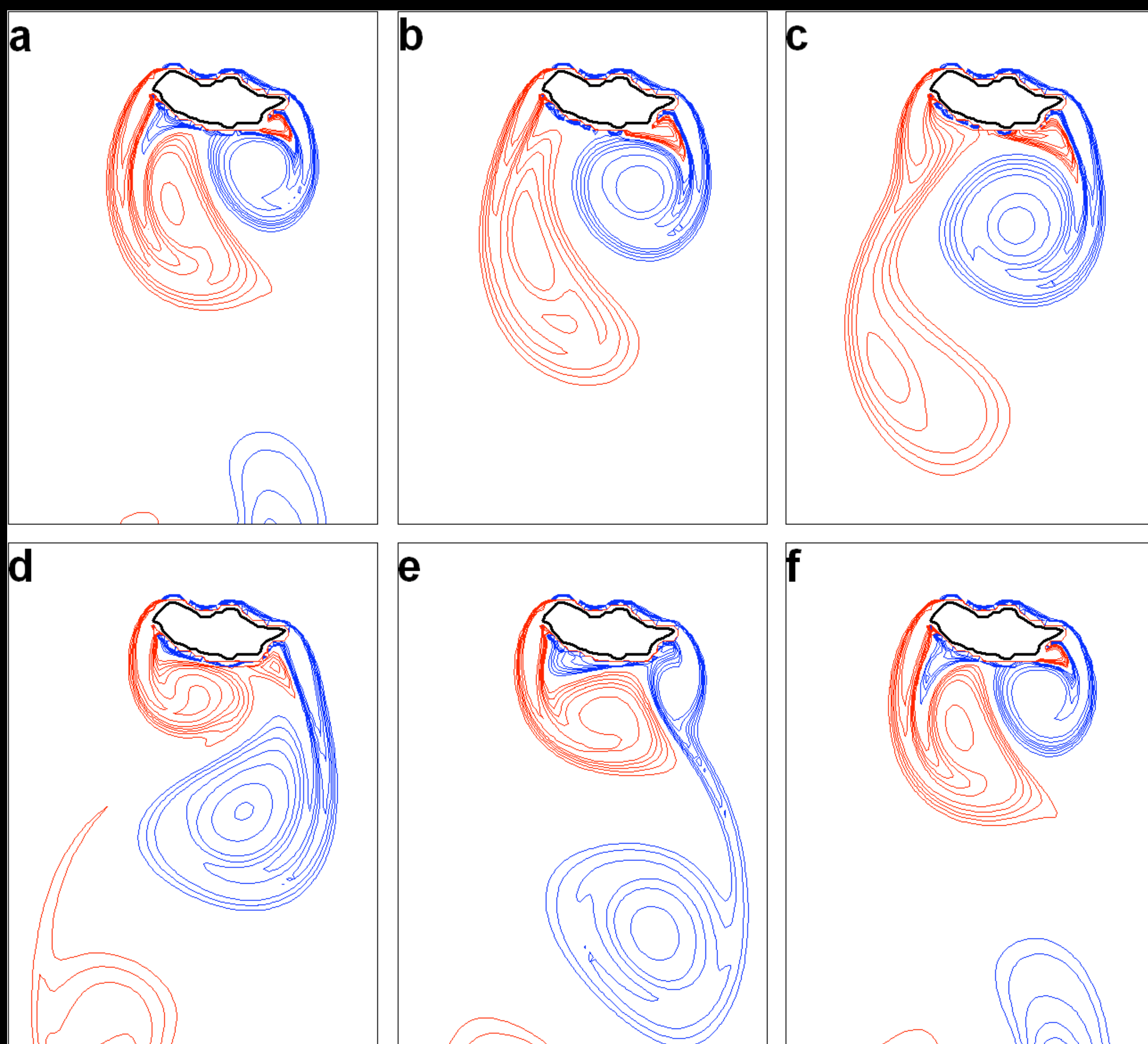
2D Assymmetric case

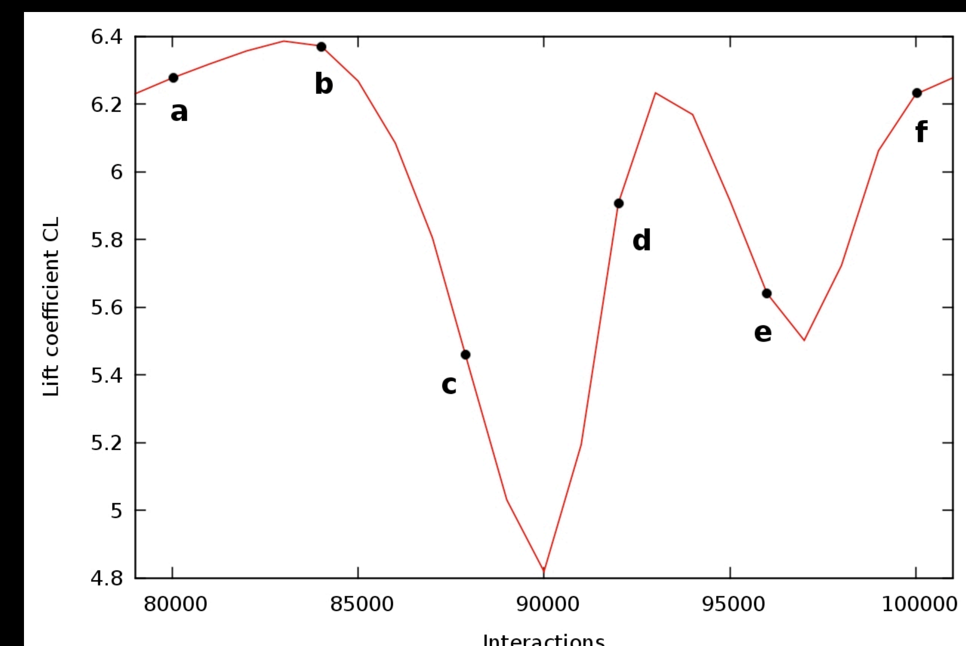


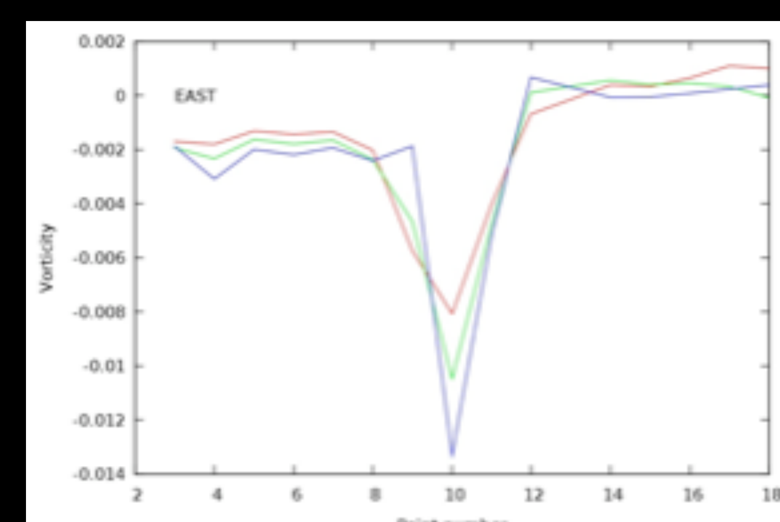




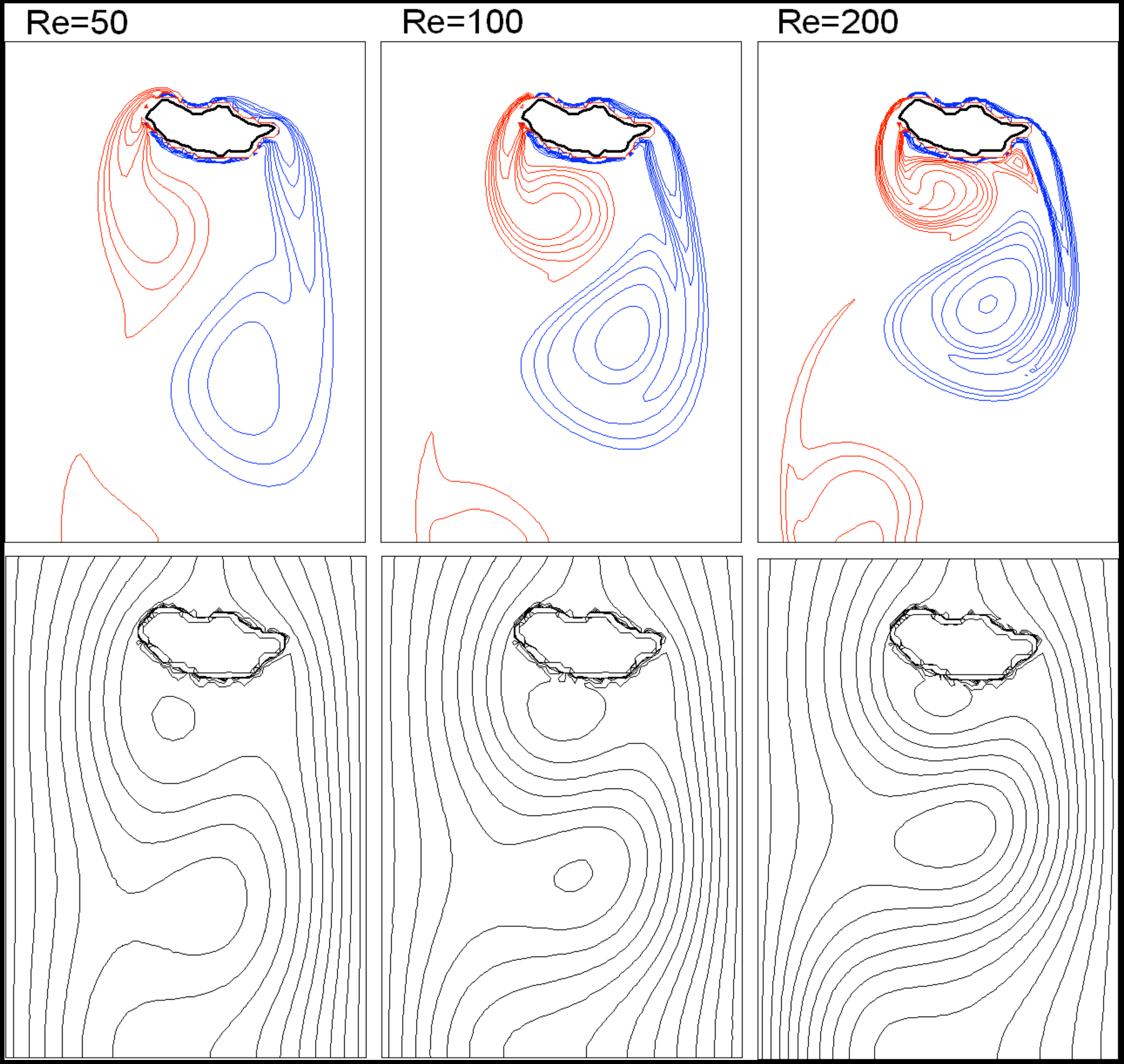
2D Assymmetric case



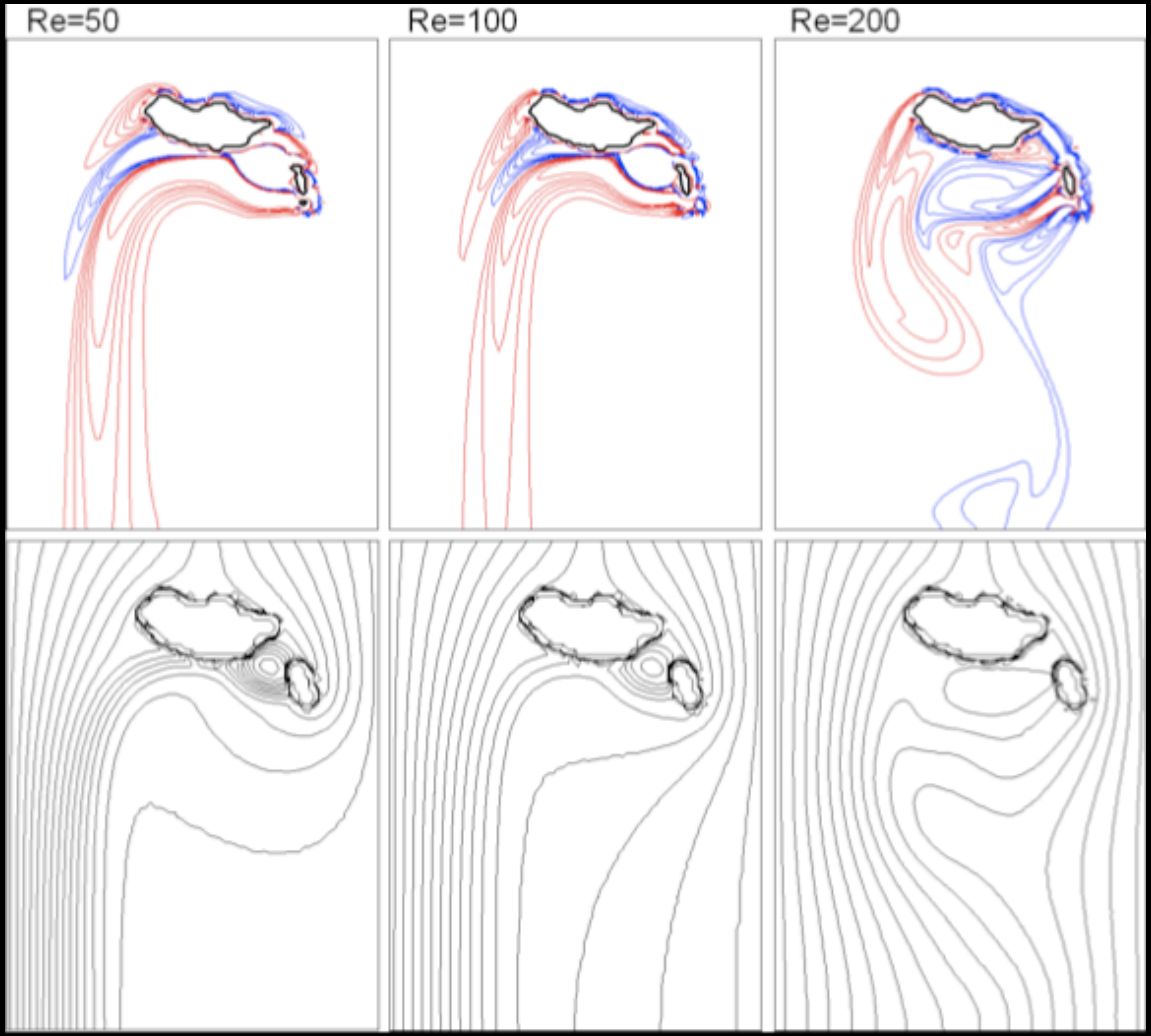




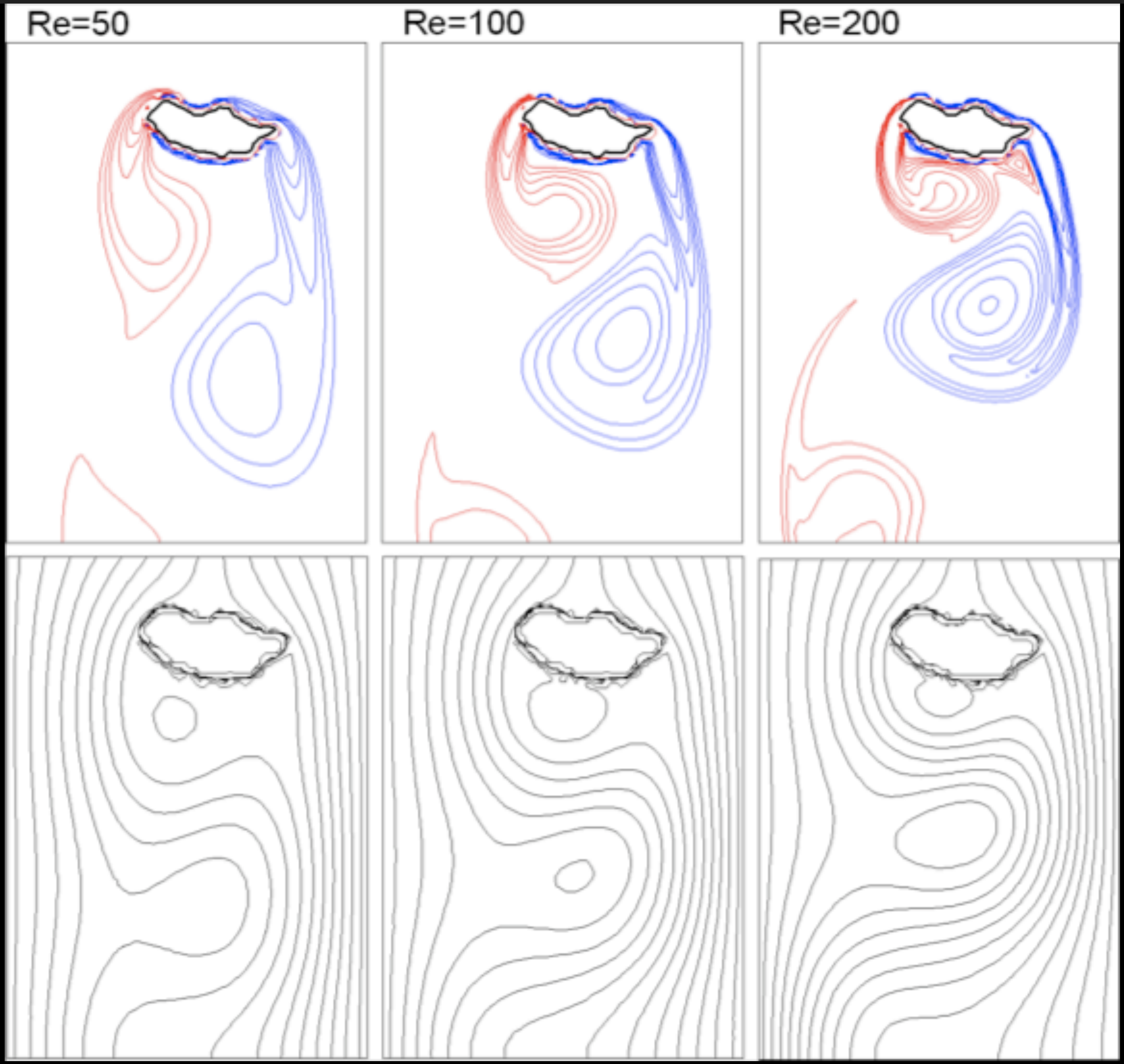
Re study



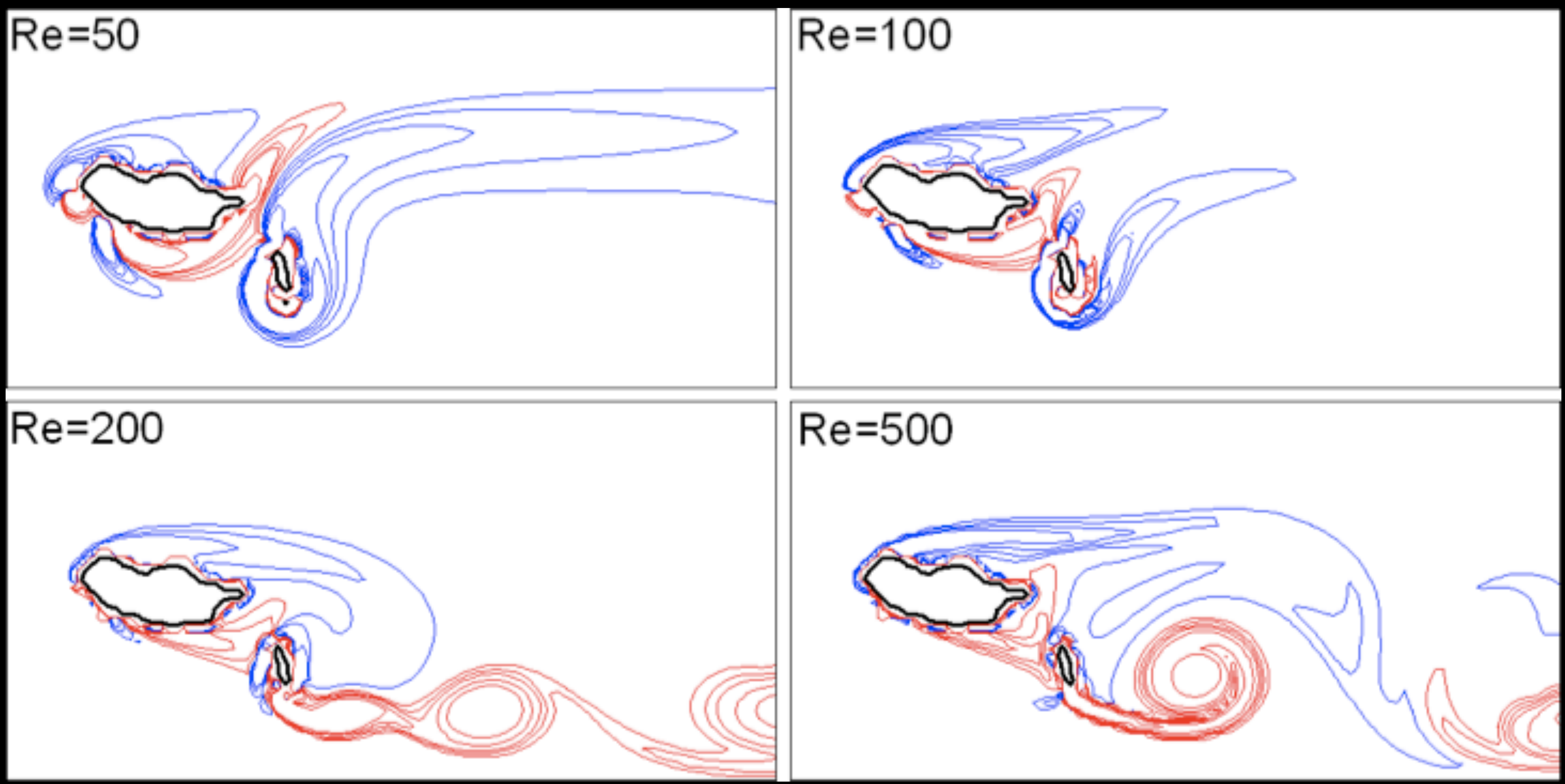
Nearby island effect



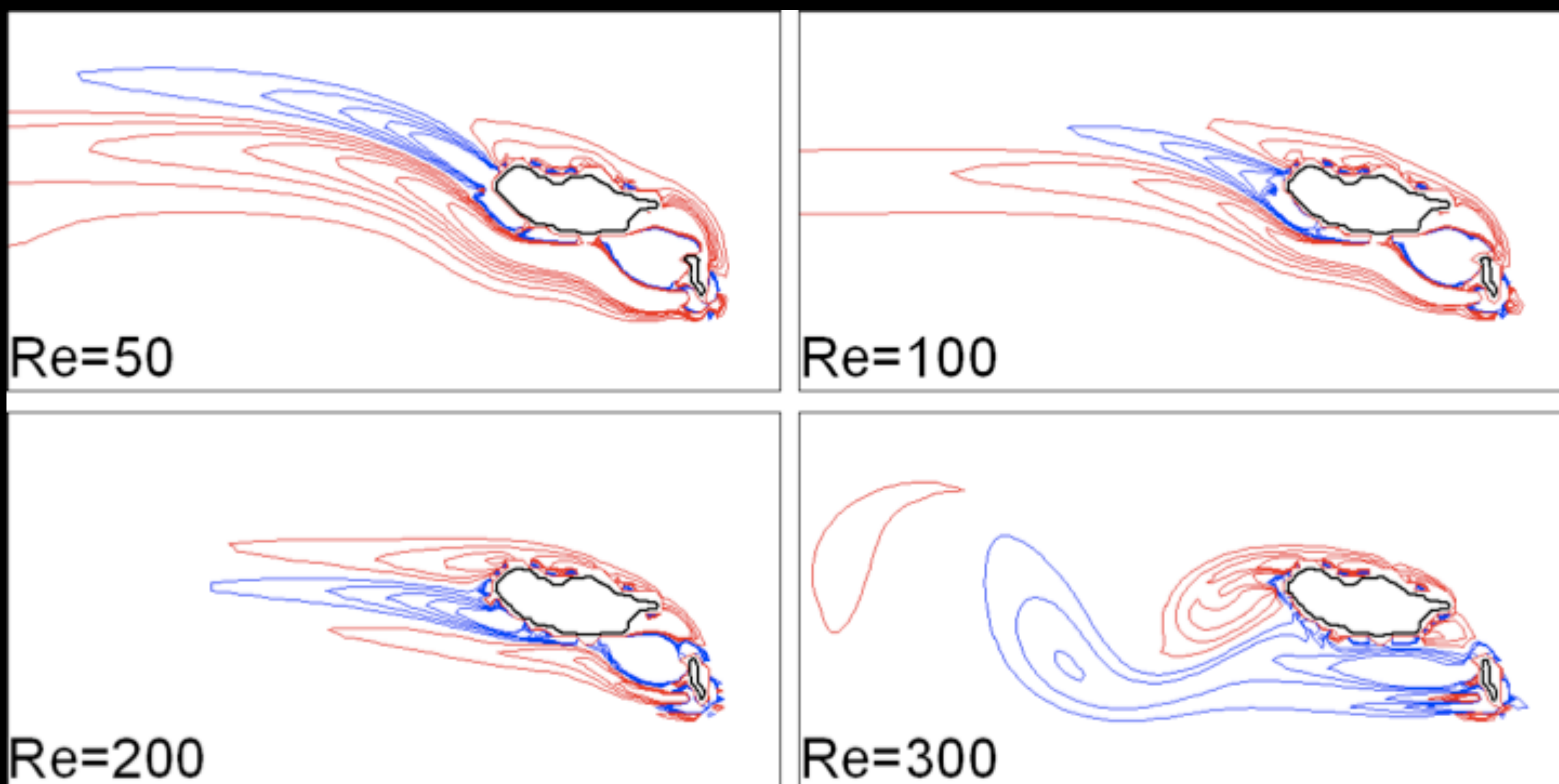
Nearby island effect



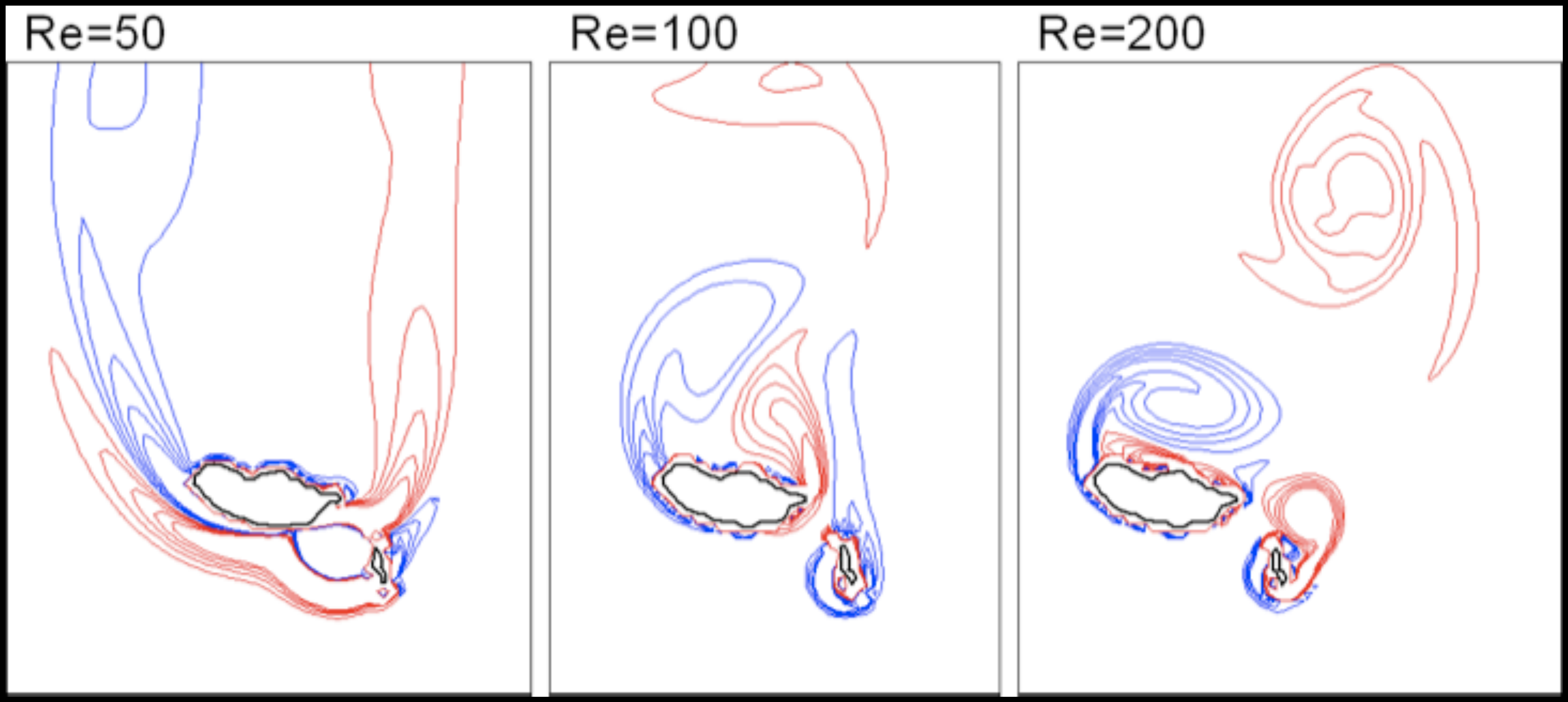
Flow direction



Flow direction



Flow direction

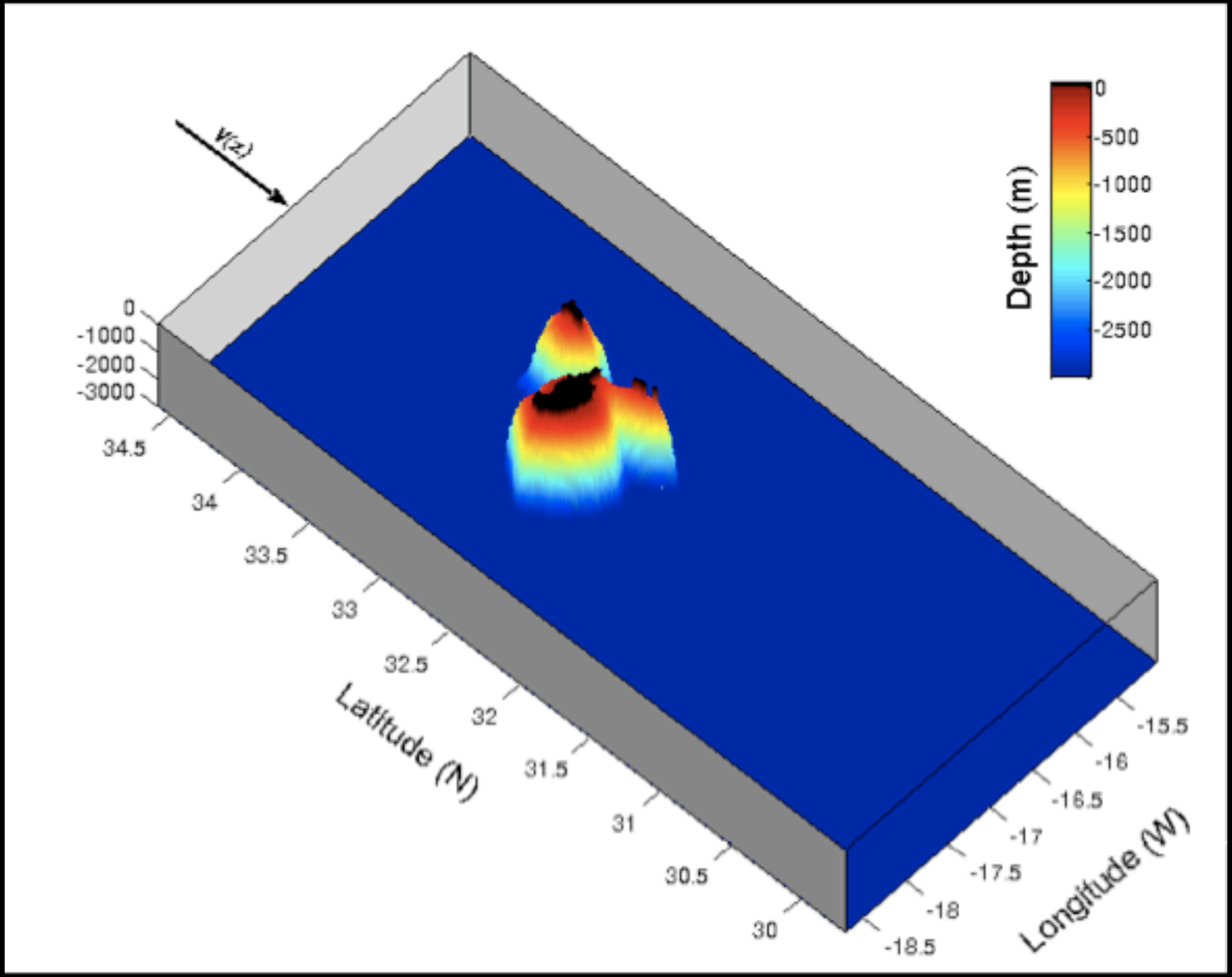


2D Case studies
Summary

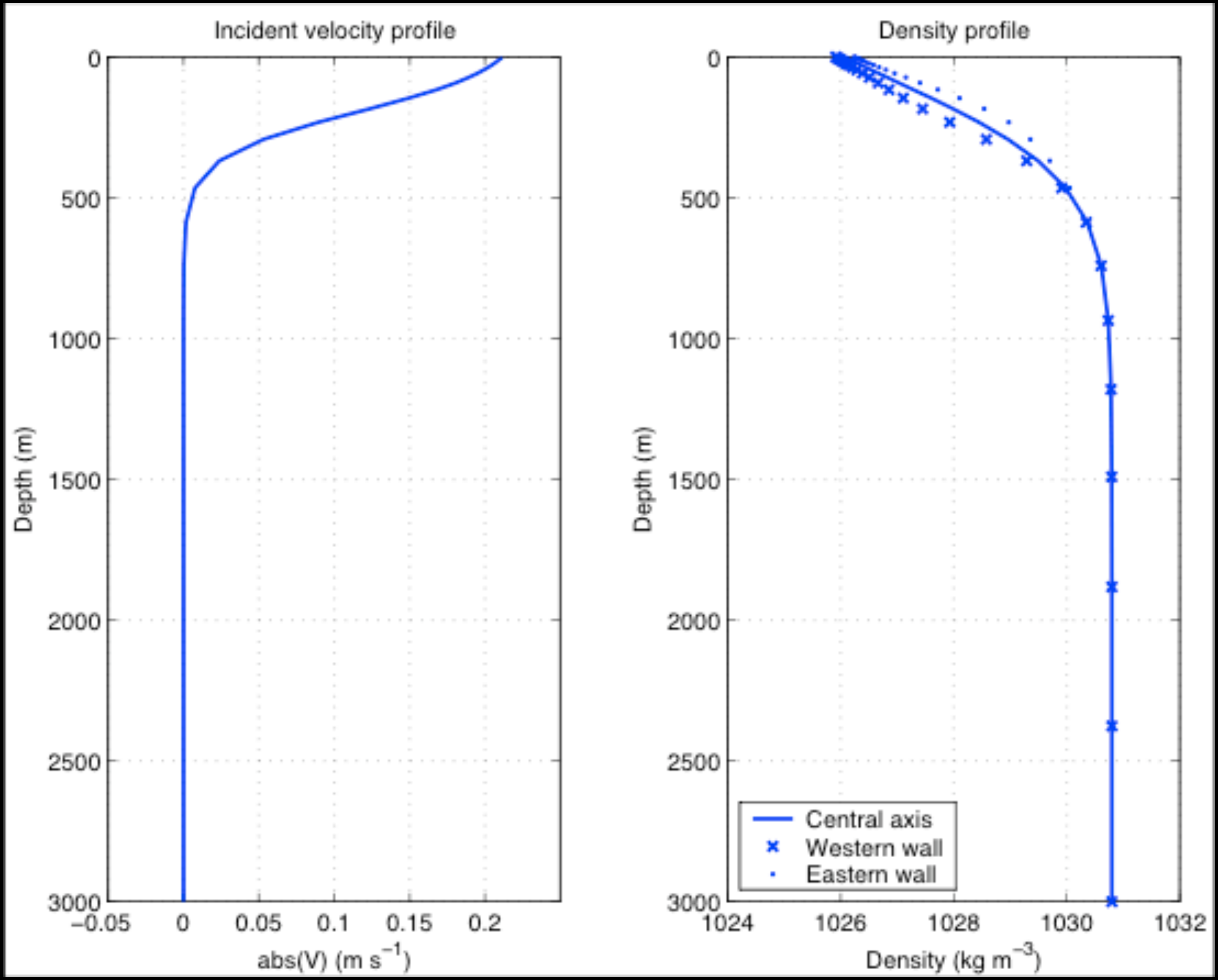
Case $(islands - inflow)$	Re	U $(m.s^{-1})$	ε	Eddy shedding period T_r
	50	0.088	0.02	30 days
Madeira-North	100	0.175	0.05	15 days
	200	0.351	0.09	7.5 days
	50	0.088	0.02	no shedding; steady state at 60 days
Madeira+Desertas-North	100	0.175	0.05	no shedding; steady state at 30.5 days
	200	0.351	0.09	6.3 days
	50	0.227	0.15	no shedding; steady state at 10 days
Madeira-West	100	0.455	0.3	no shedding; steady state at 4.6 days
	200	0.909	0.61	19 hours
	500	2.273	1.52	5.5 hours
	50	0.227	0.15	no shedding; steady state at 8 days
Madeira+Desertas-West	100	0.455	0.3	no shedding; steady state at 3.5 days
	200	0.909	0.61	8.3 hours
	500	2.273	1.52	?

Table 1: Simulation parameters; $A_H = 100m^2.s^{-1}$, $L = 57 \times 10^3 m$ for North inflow cases, and $L = 22 \times 10^3 m$ for West inflow cases.

3D setup


v(z)
Depth (m)
0
-500
-1000
-1500
-2000
-2500
0
-1000
-2000
-3000
34.5
34
33.5
33
32.5
32
31.5
31
30.5
30
Latitude (N)
-15.5
-16
-16.5
-17
-17.5
-18
-18.5
Longitude (W)

3D setup



Incident velocity profile
Depth (m)
abs(V) (m s^{-1})
0
500
1000
1500
2000
2500
3000
−0.05
0
0.05
0.1
0.15
0.2
Density profile
Depth (m)
Density (kg m^{-3})
1024
1026
1028
1030
1032
Central axis
Western wall
Eastern wall

ROMS setup

- **Horizontal boundary conditions**

✓ *North*
Meridional inflow, i.e. $u = 0$, $v(z) = \frac{c_1}{2}\left[1 + \tanh\left(\frac{z+h_s}{h_d}\right)\right]$, w=0

✓ *South*
Numerical sponge (viscosity and diffusivity incremented linearly to southern edge of domain)

✓ *East and West*
Slip conditions, i.e. $u = 0$;

✓ *Boundaries around the island*
No-slip conditions, i.e. $\mathbf{v} = (0, 0, 0)$

- **Vertical boundary conditions**

✓ *Bottom (z=-H, flat)*
No-slip conditions

✓ *Top* Free surface
$w = \frac{d\eta}{dt}$

ROMS setup

- ✓ Velocity:

$$u(x,y,z,t_0) = 0, \;\; v(x,y,z,t_0) = v(z), \;\; w(x,y,z,t_0) = 0$$

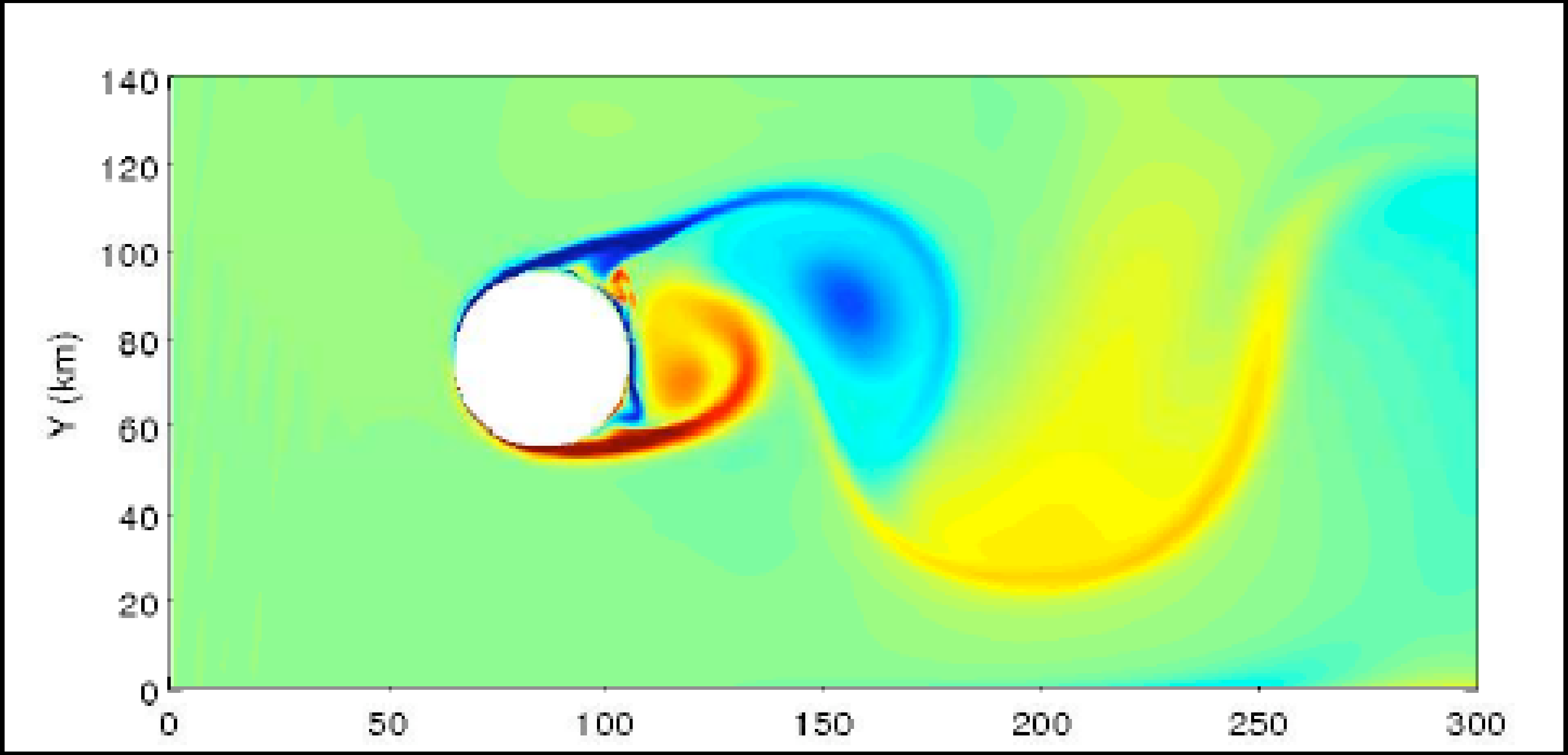
- ✓ Free surface elevation:

$$\eta_0(x,y,z,t) = \frac{c_1 f}{g}(x - 2x_m)$$

- ✓ Temperature: thermal wind balance with the initial velocity field
- ✓ Salinity: constant

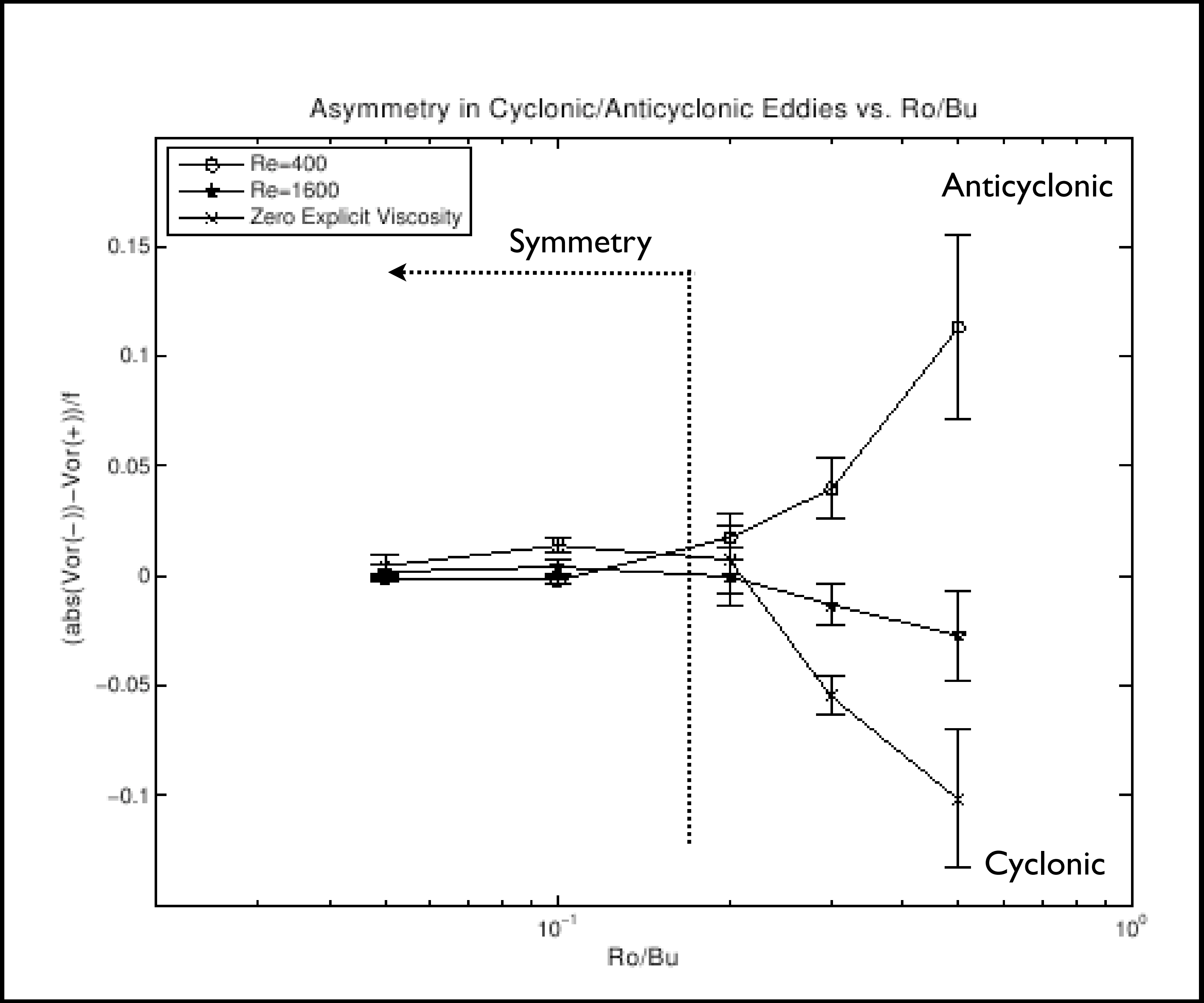
Working hypothesis

Dong et al., 2007

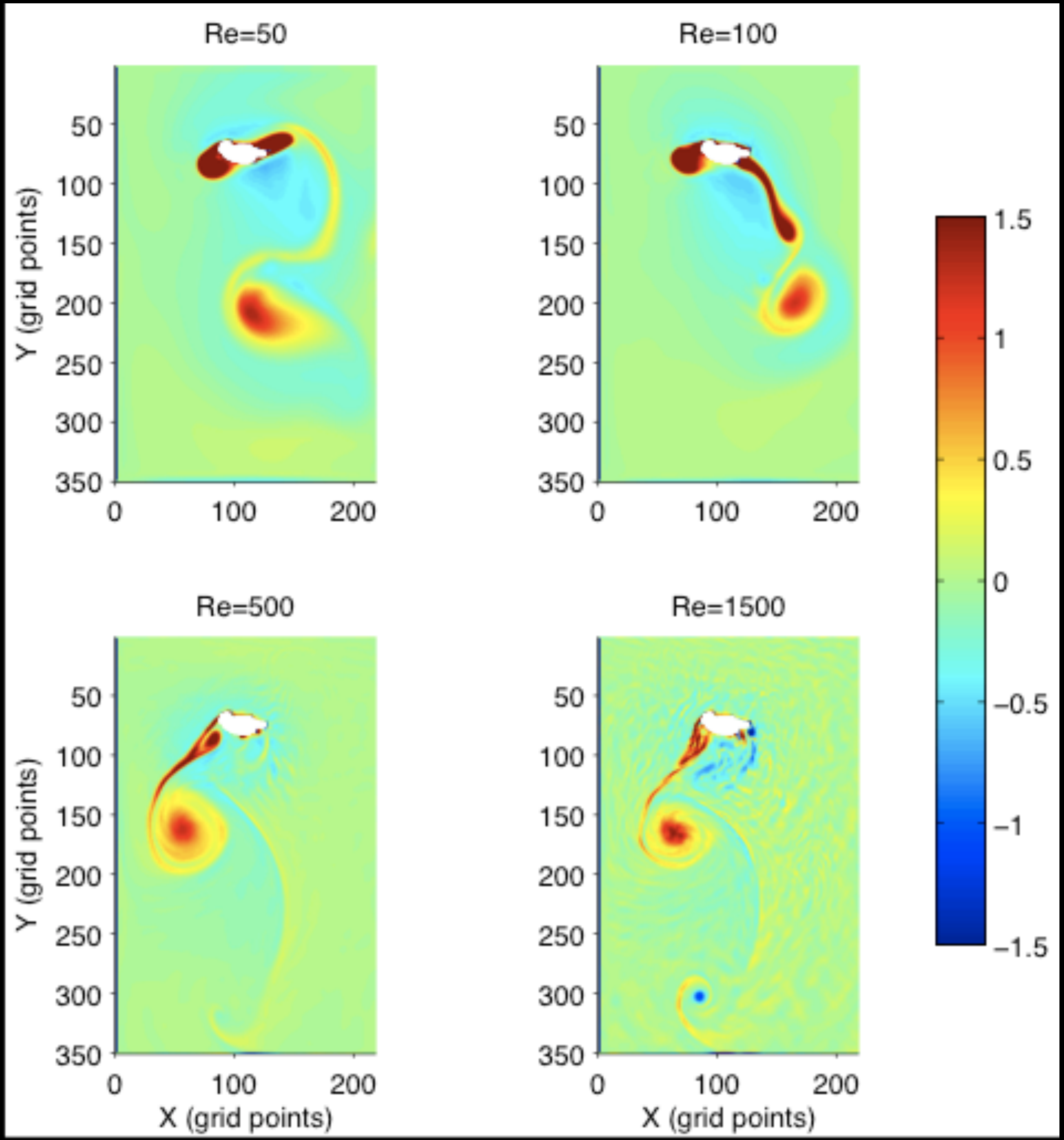


Working hypothesis

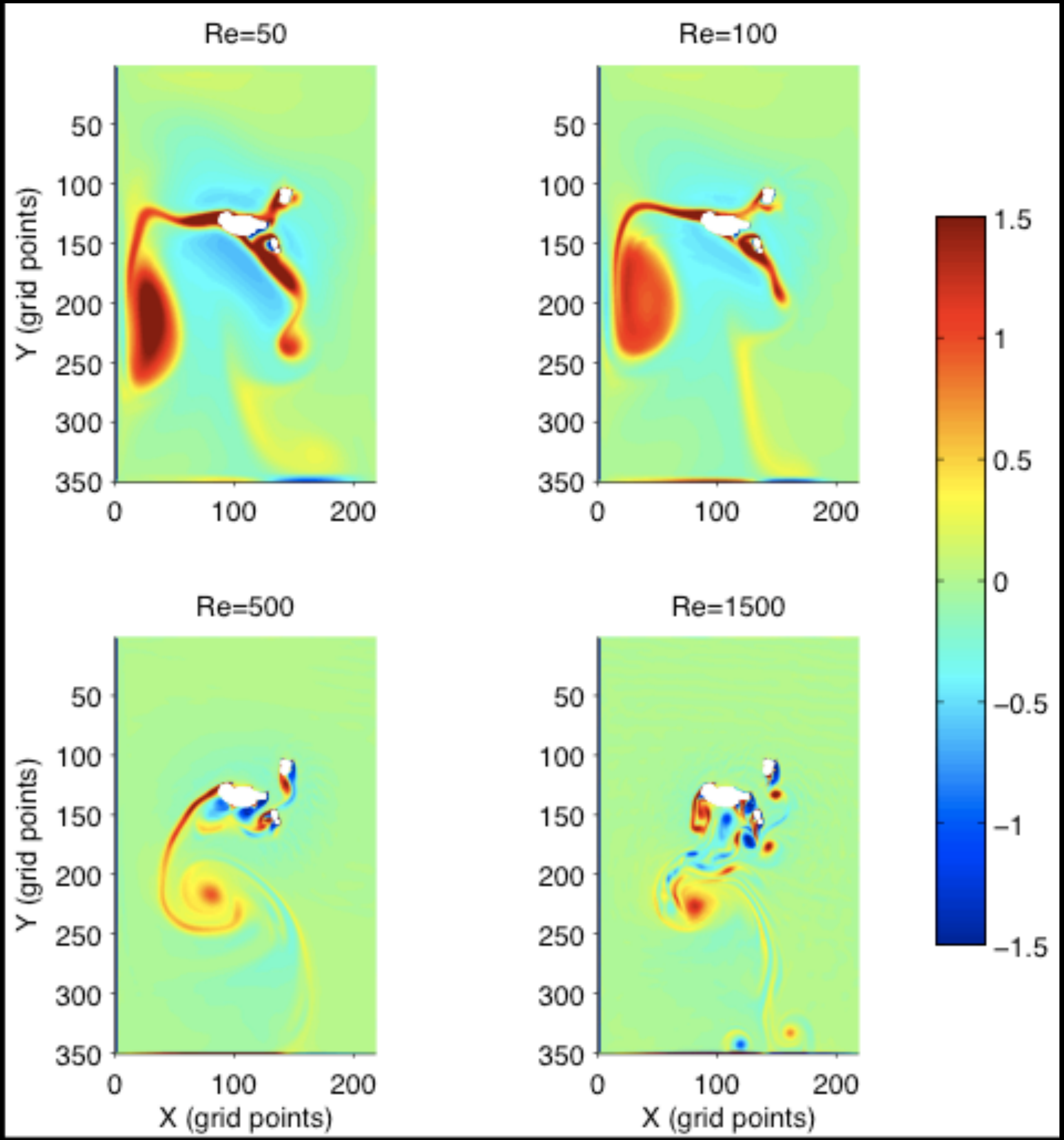
Dong et al., 2007

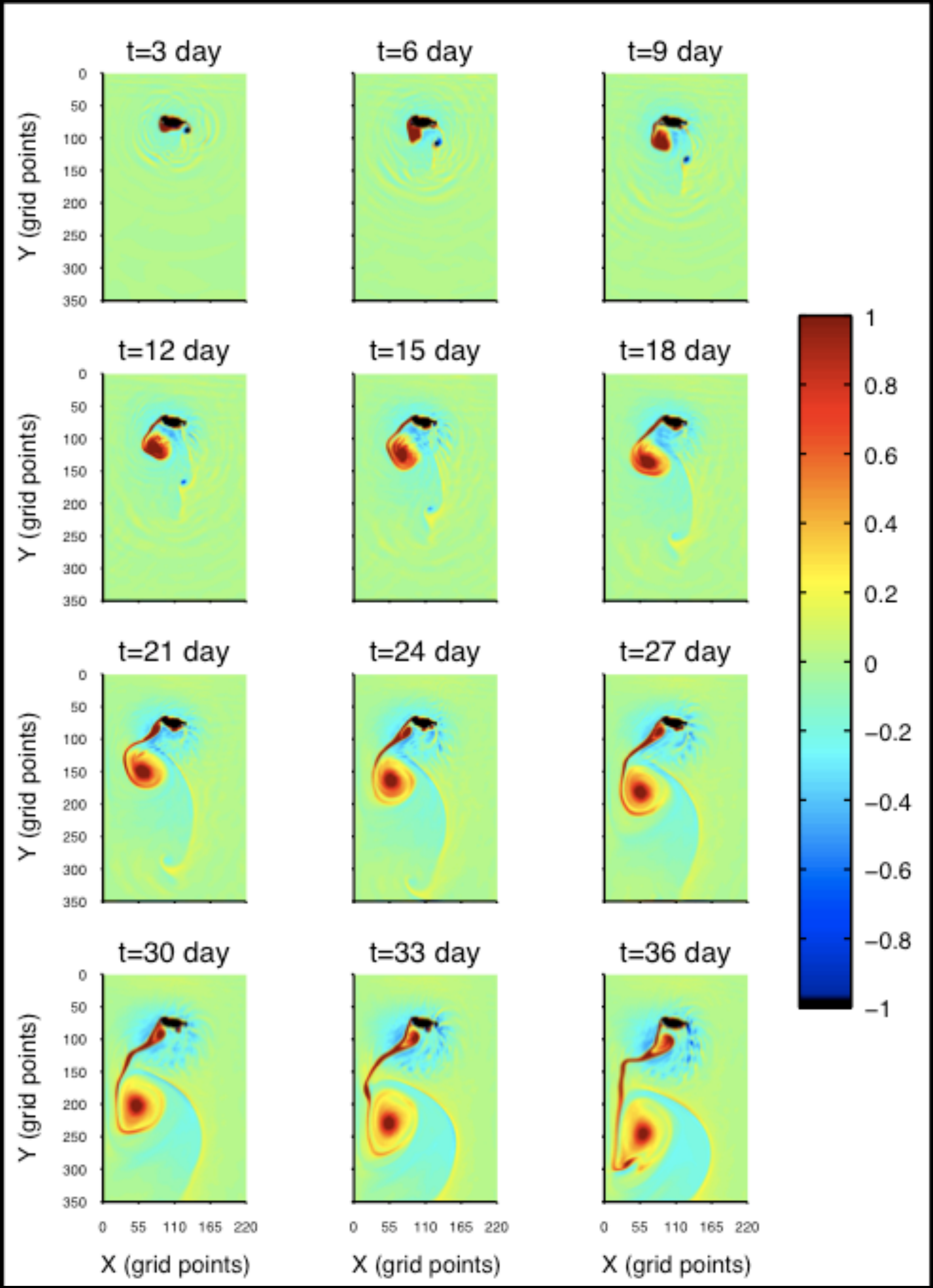


Re sensitivity study

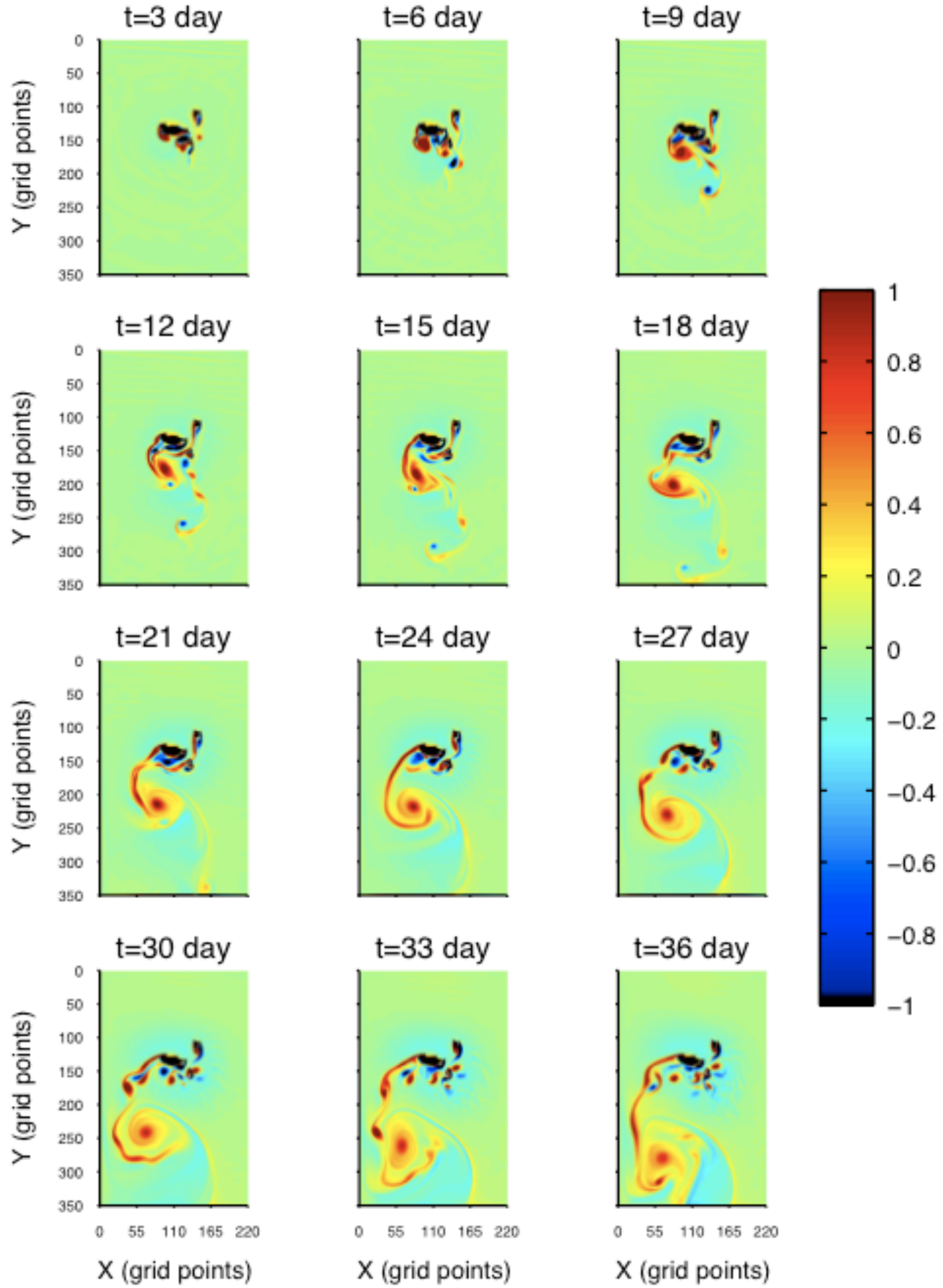


Re sensitivity study





t=3 day
t=6 day
t=9 day
t=12 day
t=15 day
t=18 day
t=21 day
t=24 day
t=27 day
t=30 day
t=33 day
t=36 day
Y (grid points)
X (grid points)
0 50 100 150 200 250 300 350
0 55 110 165 220
1 0.8 0.6 0.4 0.2 0 −0.2 −0.4 −0.6 −0.8 −1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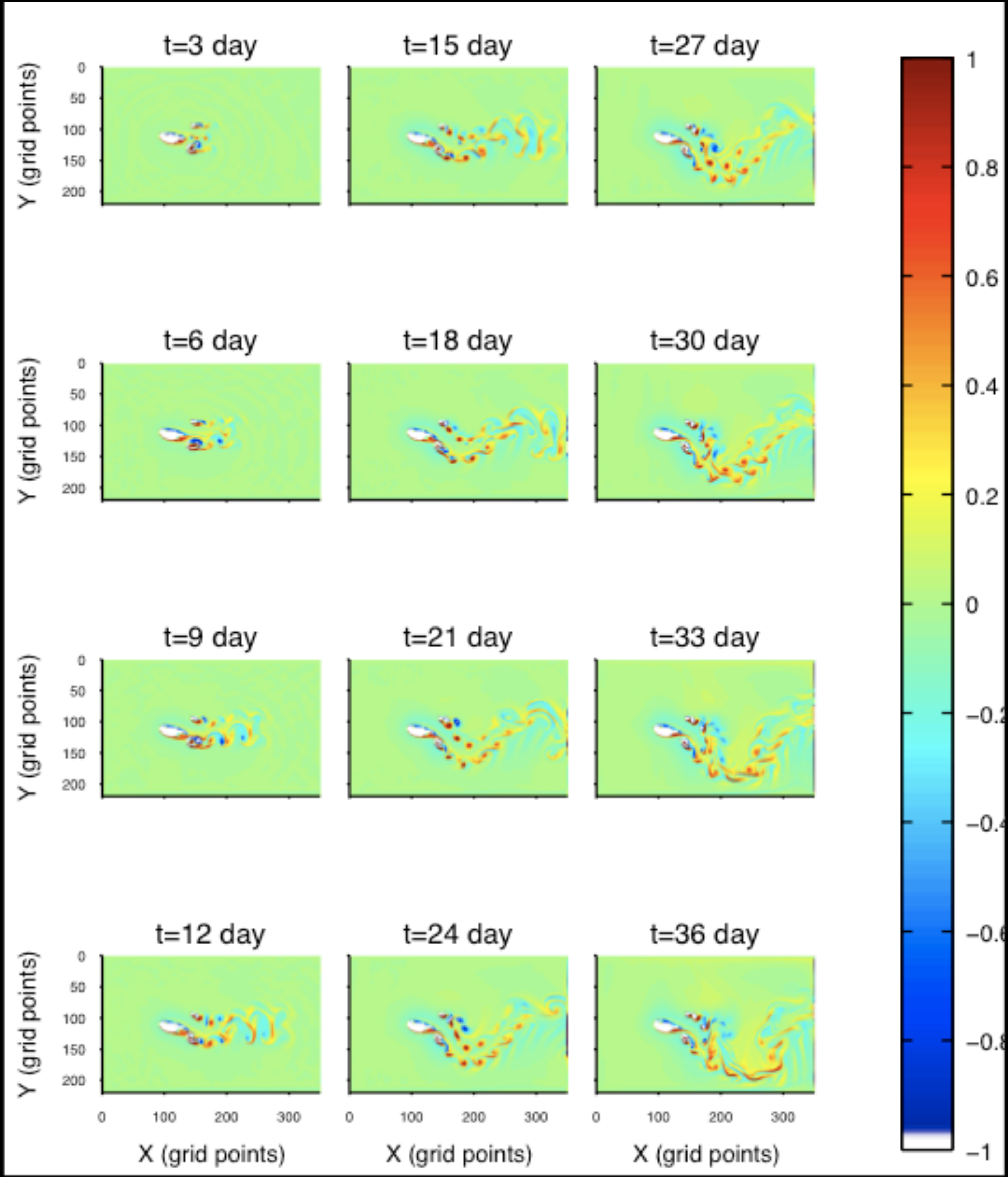
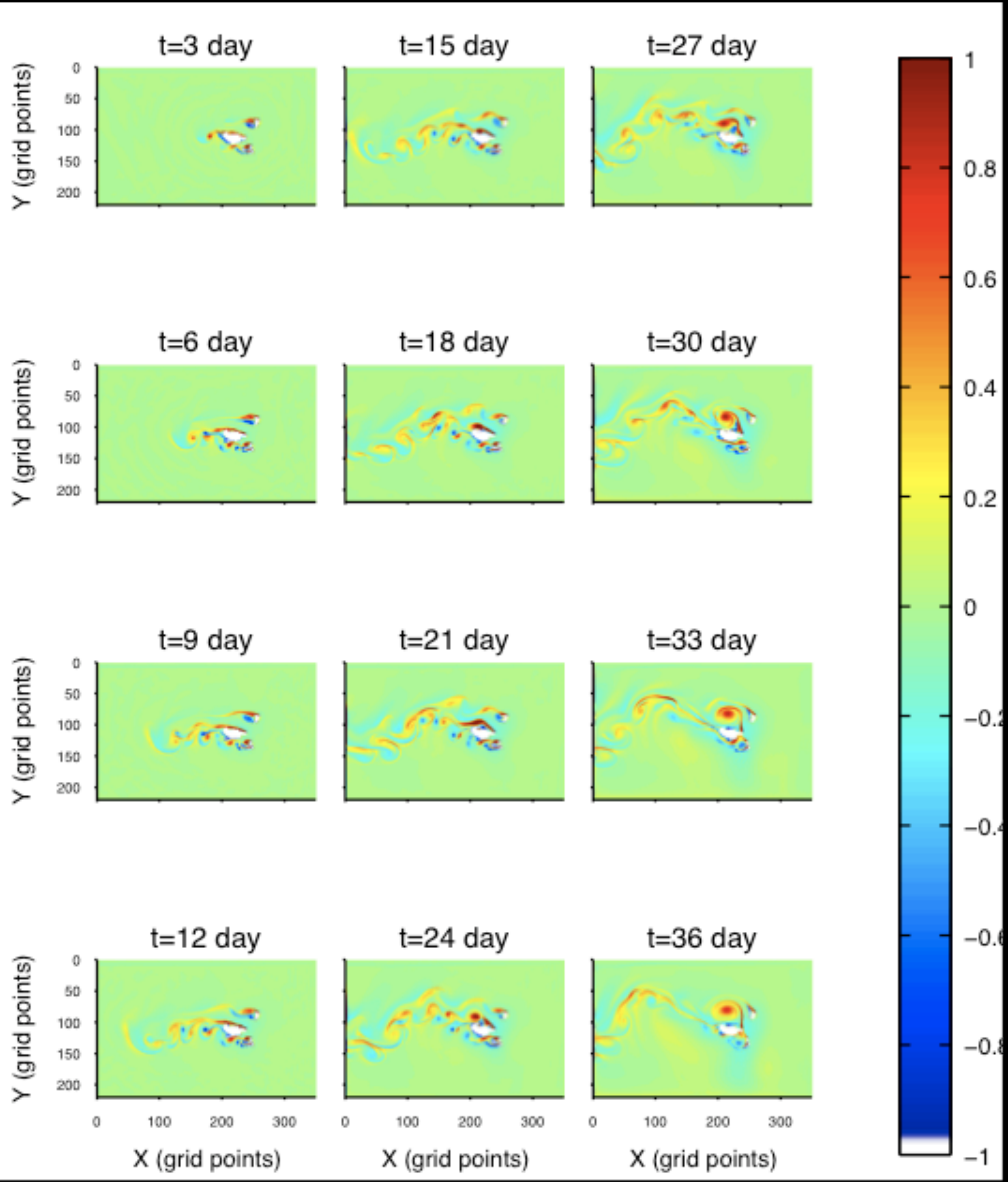
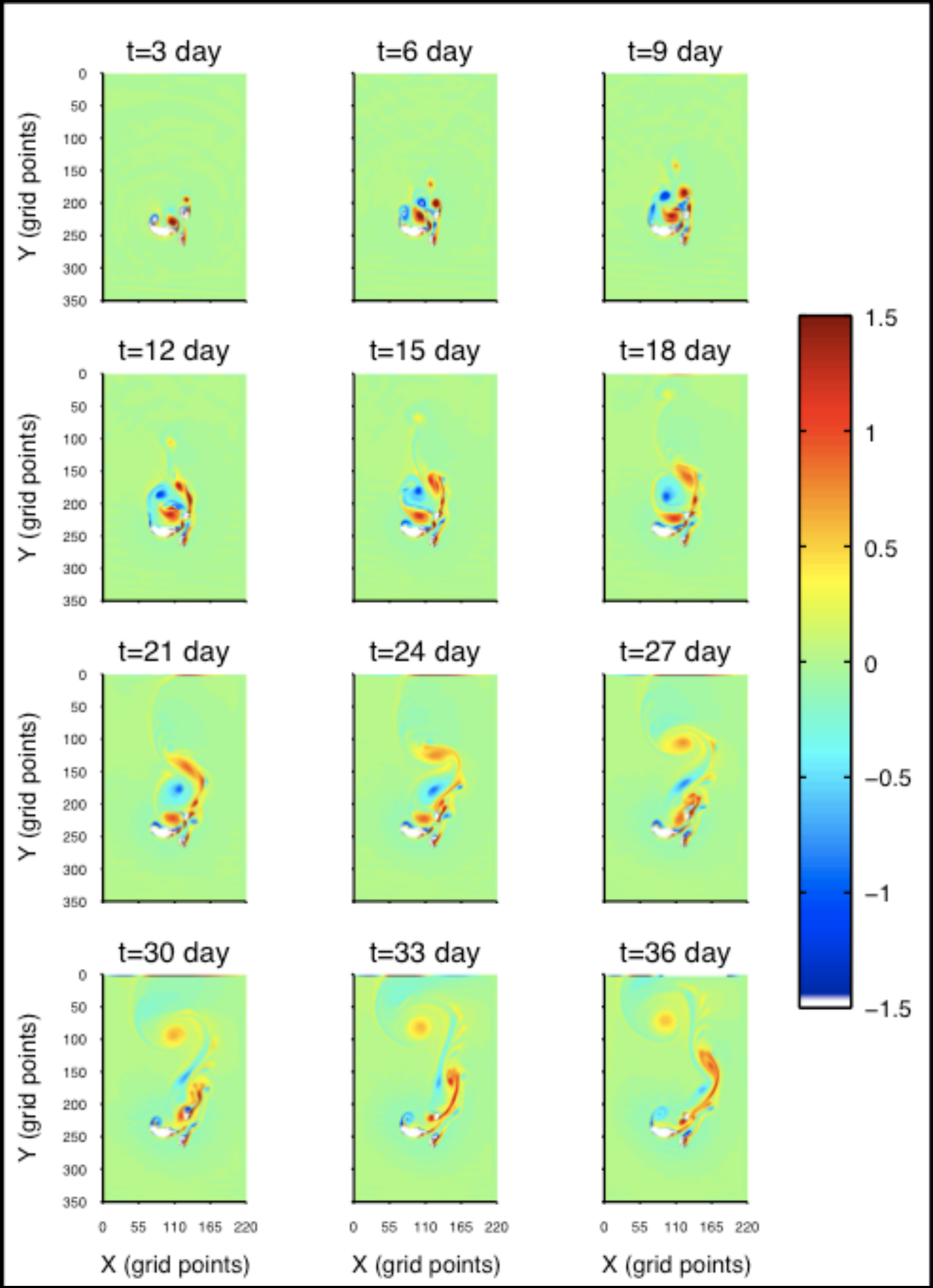
t=6 day
t=9 day
t=12 day
t=15 day
t=18 day
t=21 day
t=24 day
t=27 day
t=30 day
t=33 day
t=36 day
Y (grid points)
X (grid points)
0
50
100
150
200
250
300
350
0
55
110
165
220
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1

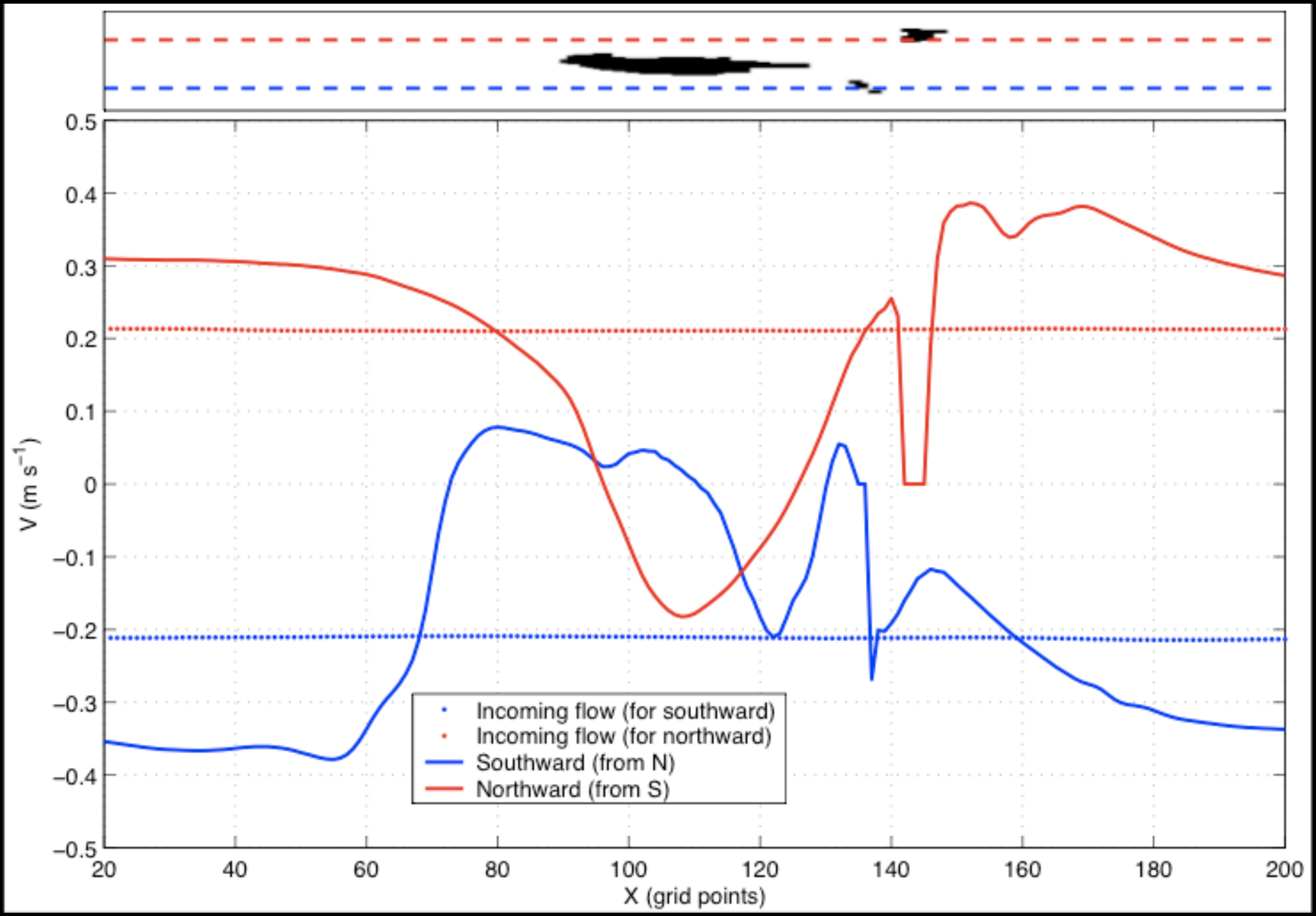

t=3 day
t=15 day
t=27 day
t=6 day
t=18 day
t=30 day
t=9 day
t=21 day
t=33 day
t=12 day
t=24 day
t=36 day
Y (grid points)
X (grid points)
0
50
100
150
200
300
1
0.8
0.6
0.4
0.2
−1


t=3 day
t=15 day
t=27 day
t=6 day
t=18 day
t=30 day
t=9 day
t=21 day
t=33 day
t=12 day
t=24 day
t=36 day
Y (grid points)
X (grid points)
0
50
100
150
200
300
1
0.8
0.6
0.4
0.2
−1

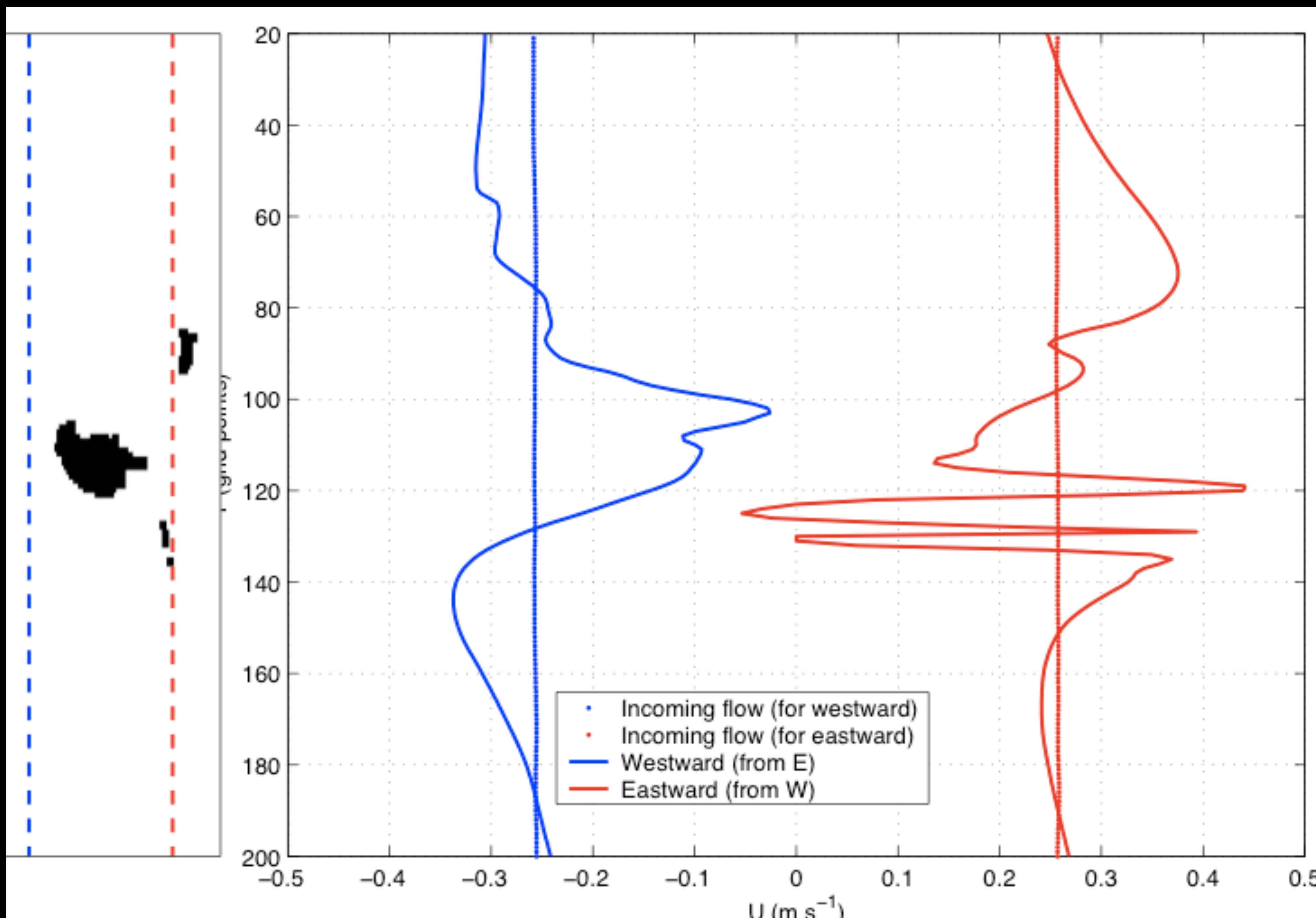


t=3 day
t=6 day
t=9 day
t=12 day
t=15 day
t=18 day
t=21 day
t=24 day
t=27 day
t=30 day
t=33 day
t=36 day
Y (grid points)
X (grid points)
0
50
100
150
200
250
300
350
0
55
110
165
220
1.5
1
0.5
0
−0.5
−1
−1.5

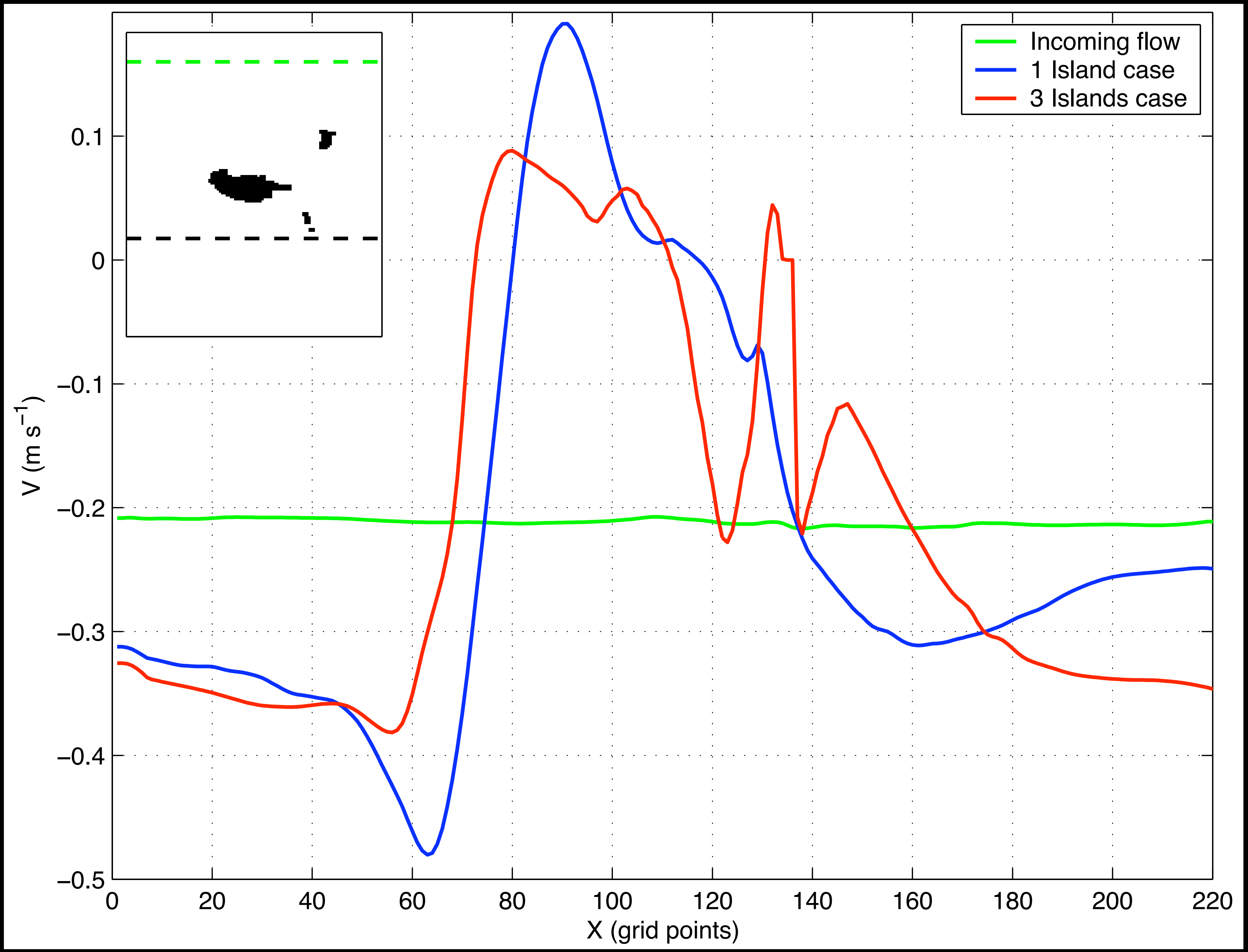
Flow direction



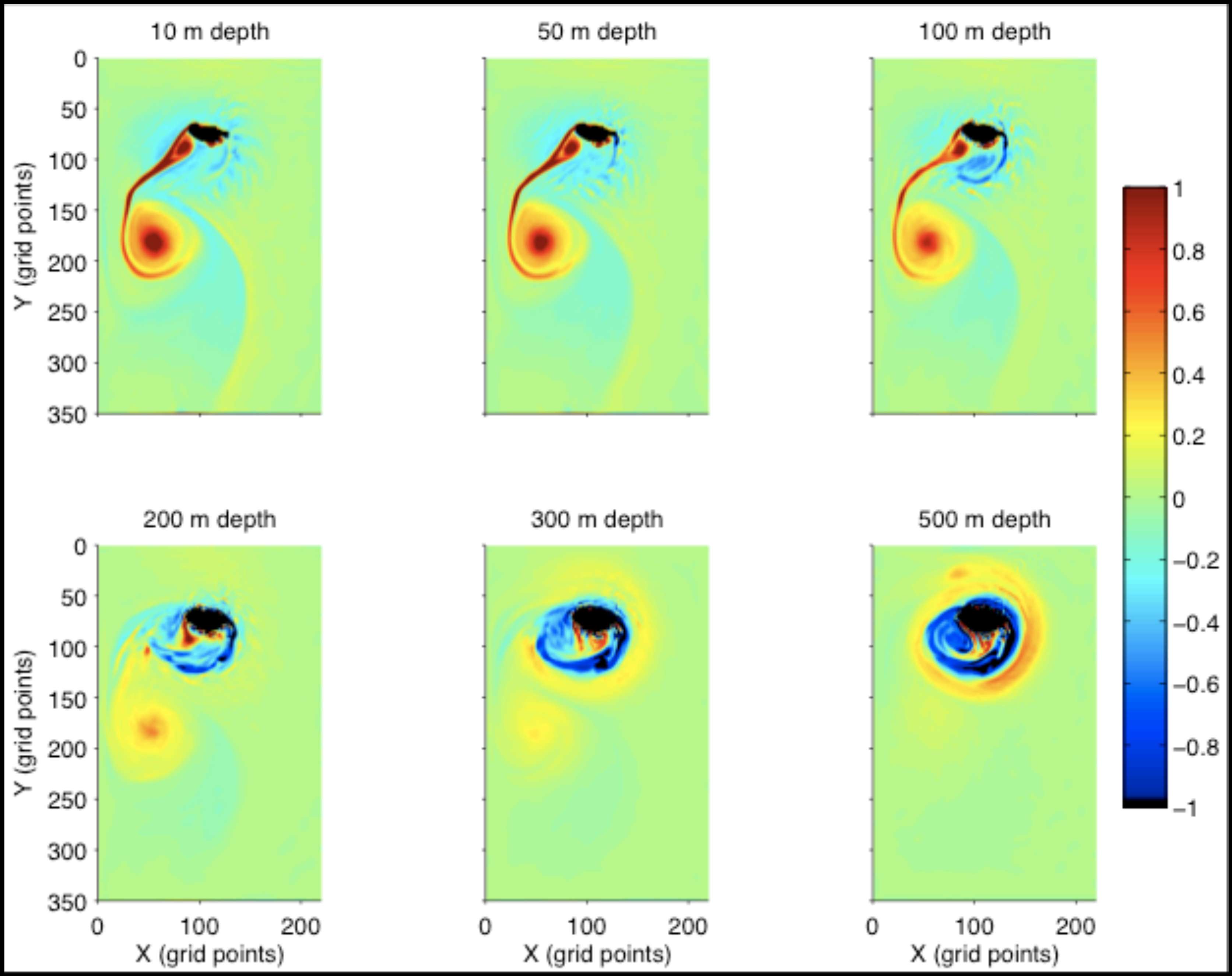
Flow direction



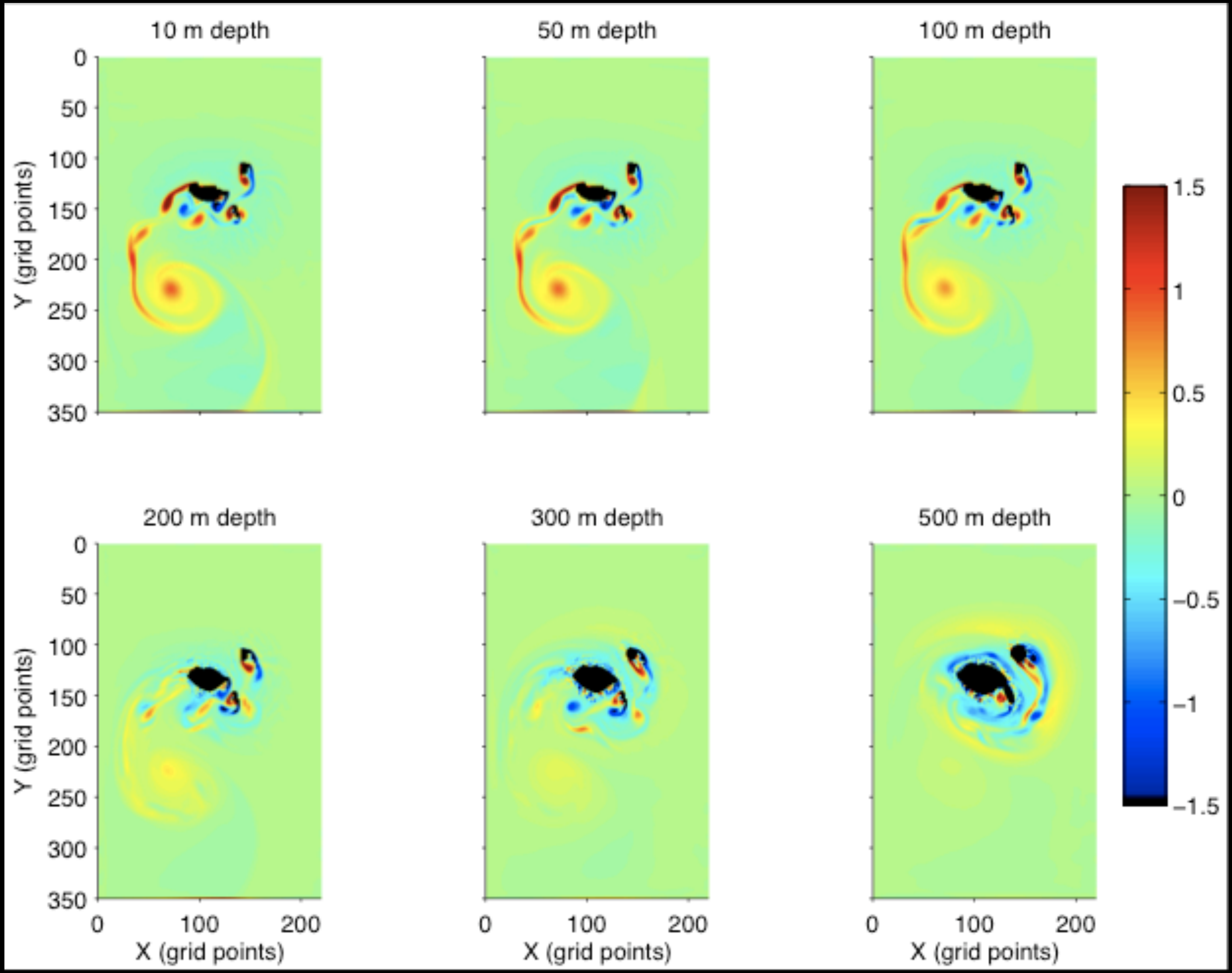
Nearby island effect



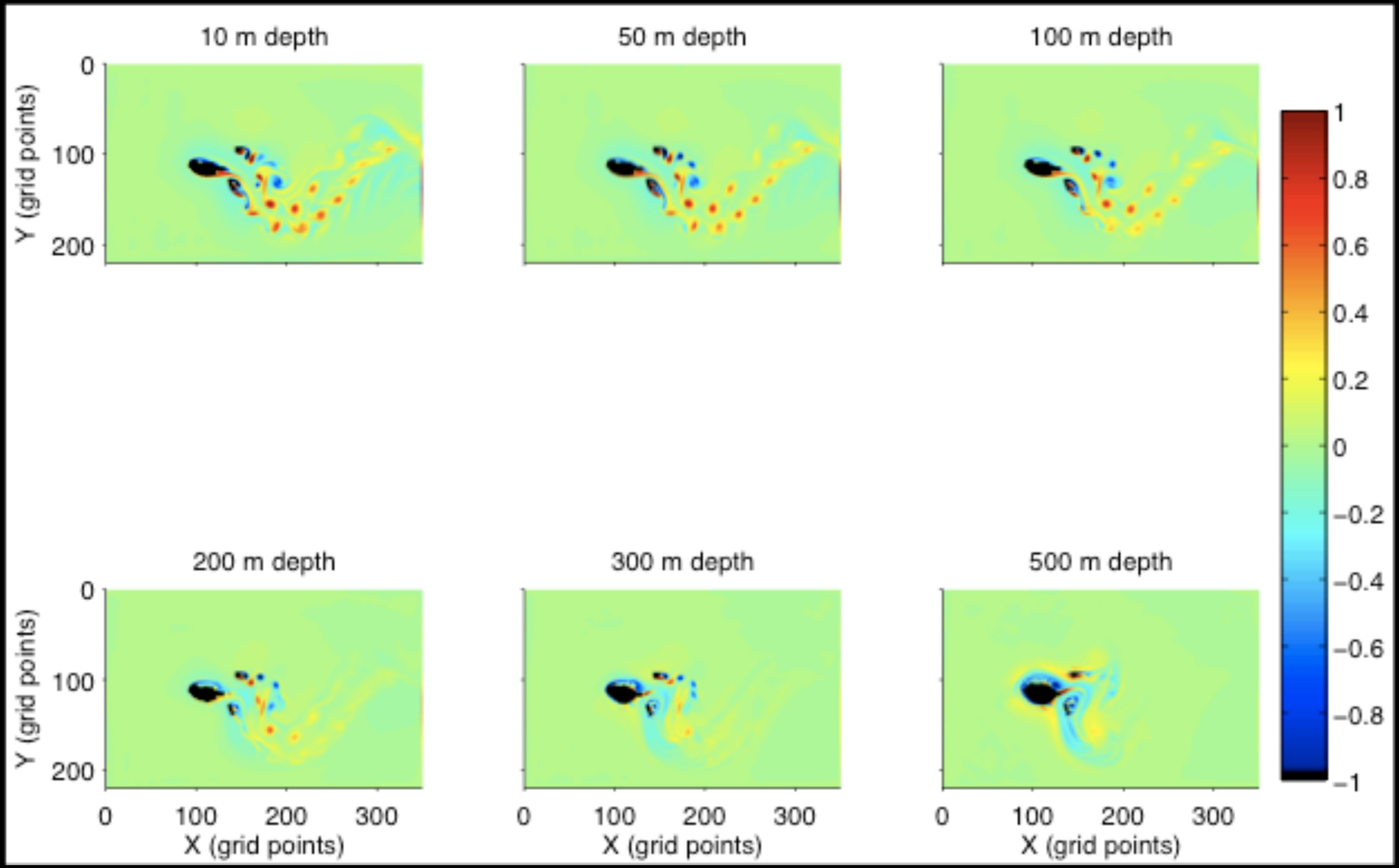
Depth varying vorticity



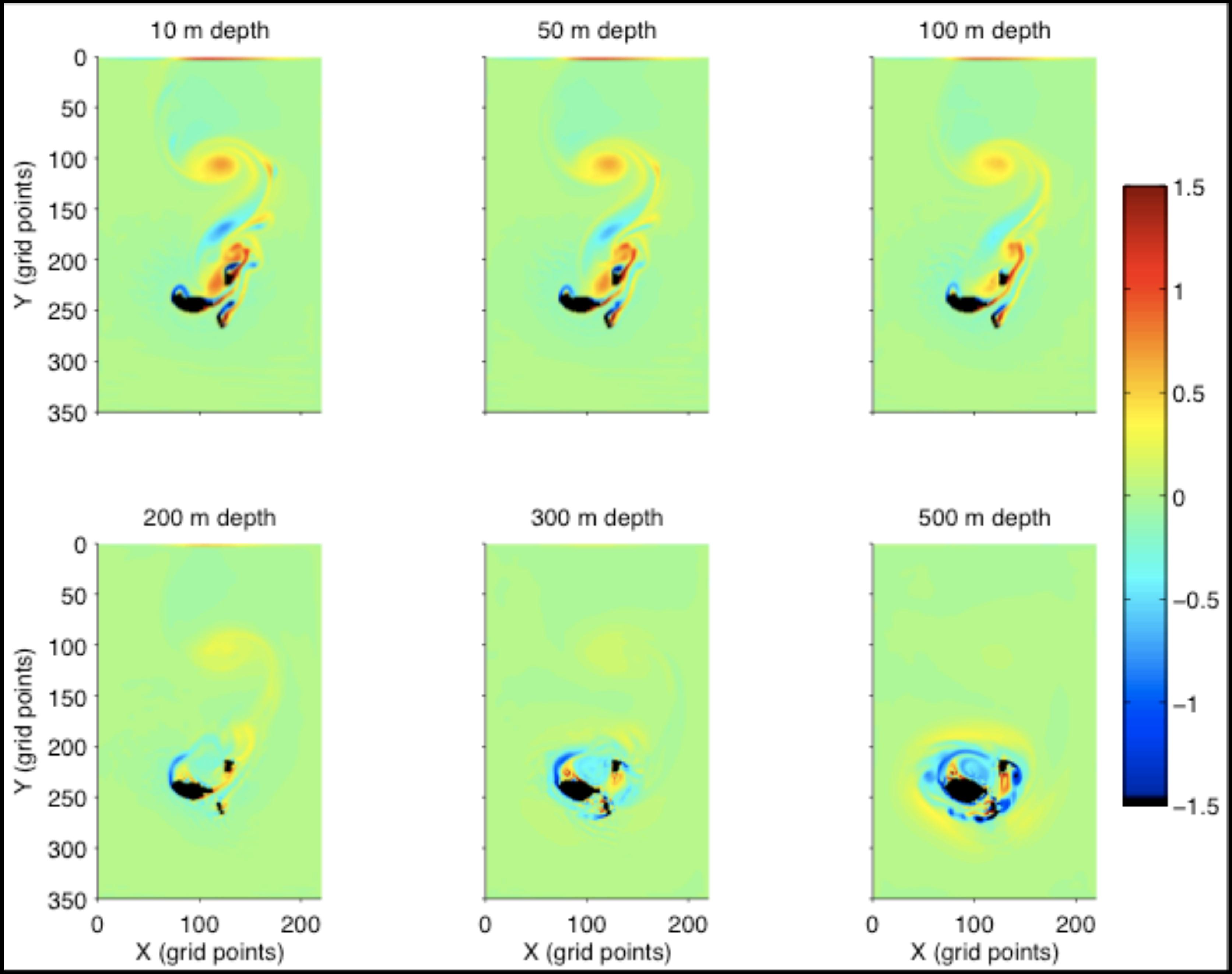
Depth varying vorticity



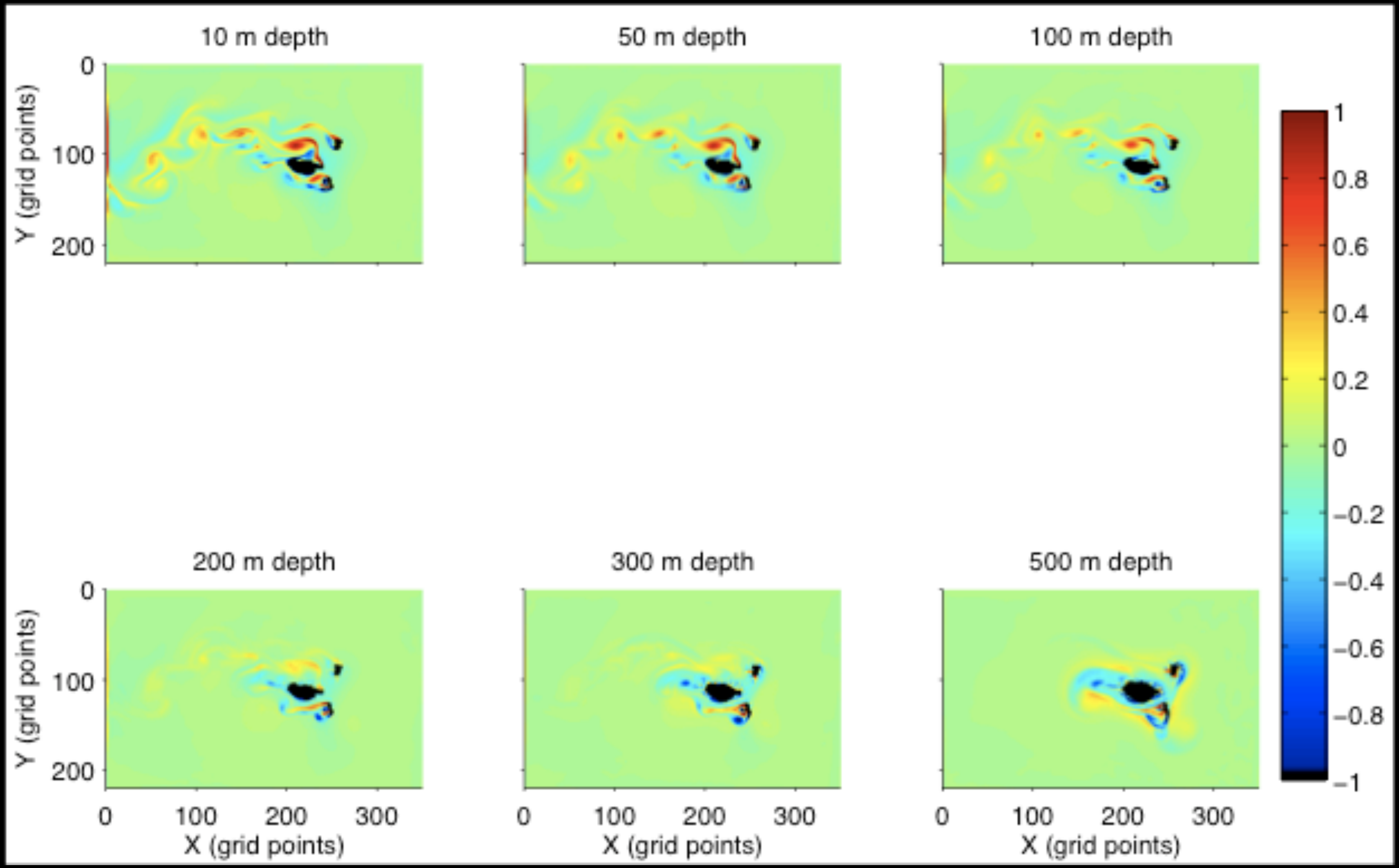
Depth varying vorticity



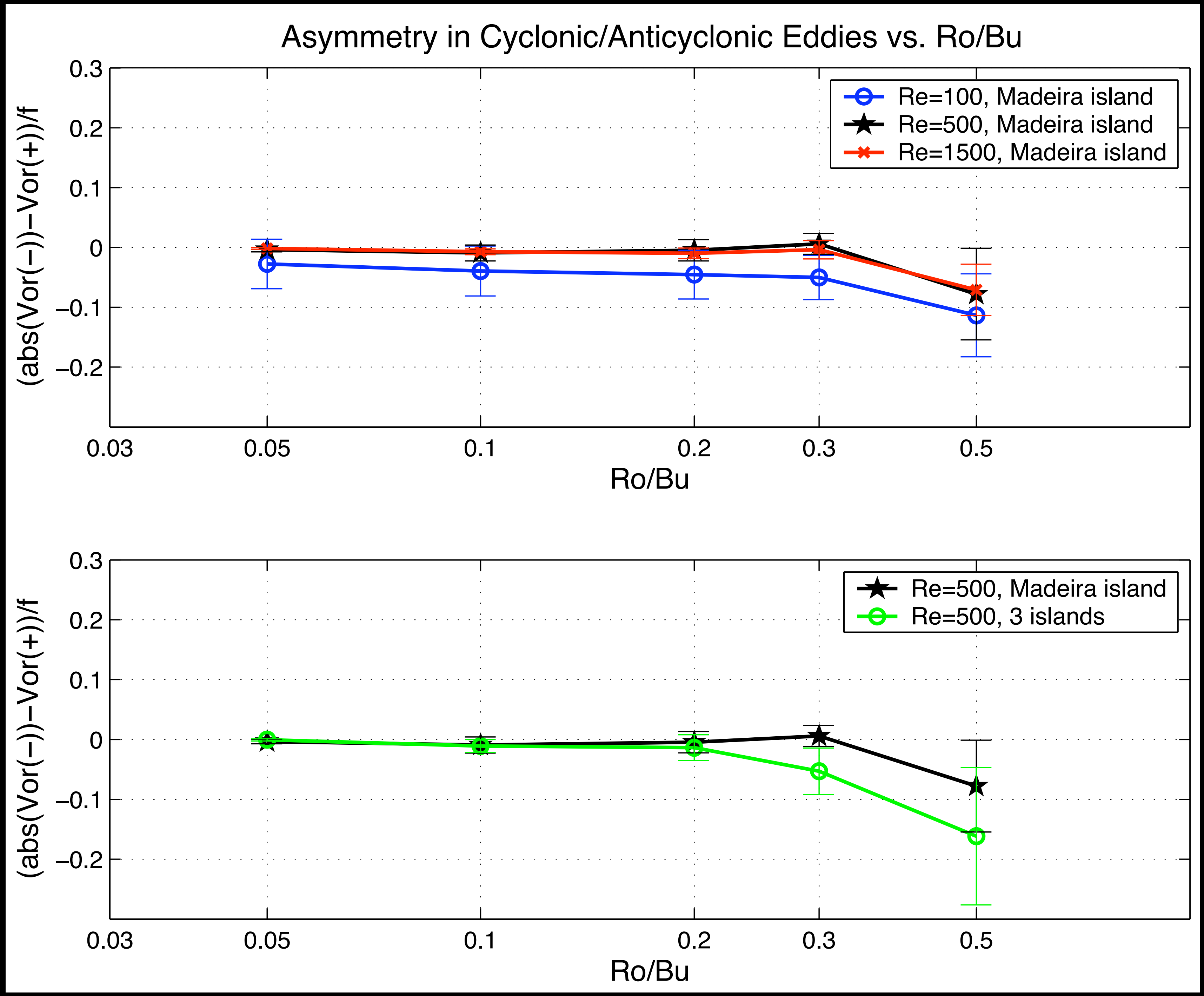
Depth varying vorticity



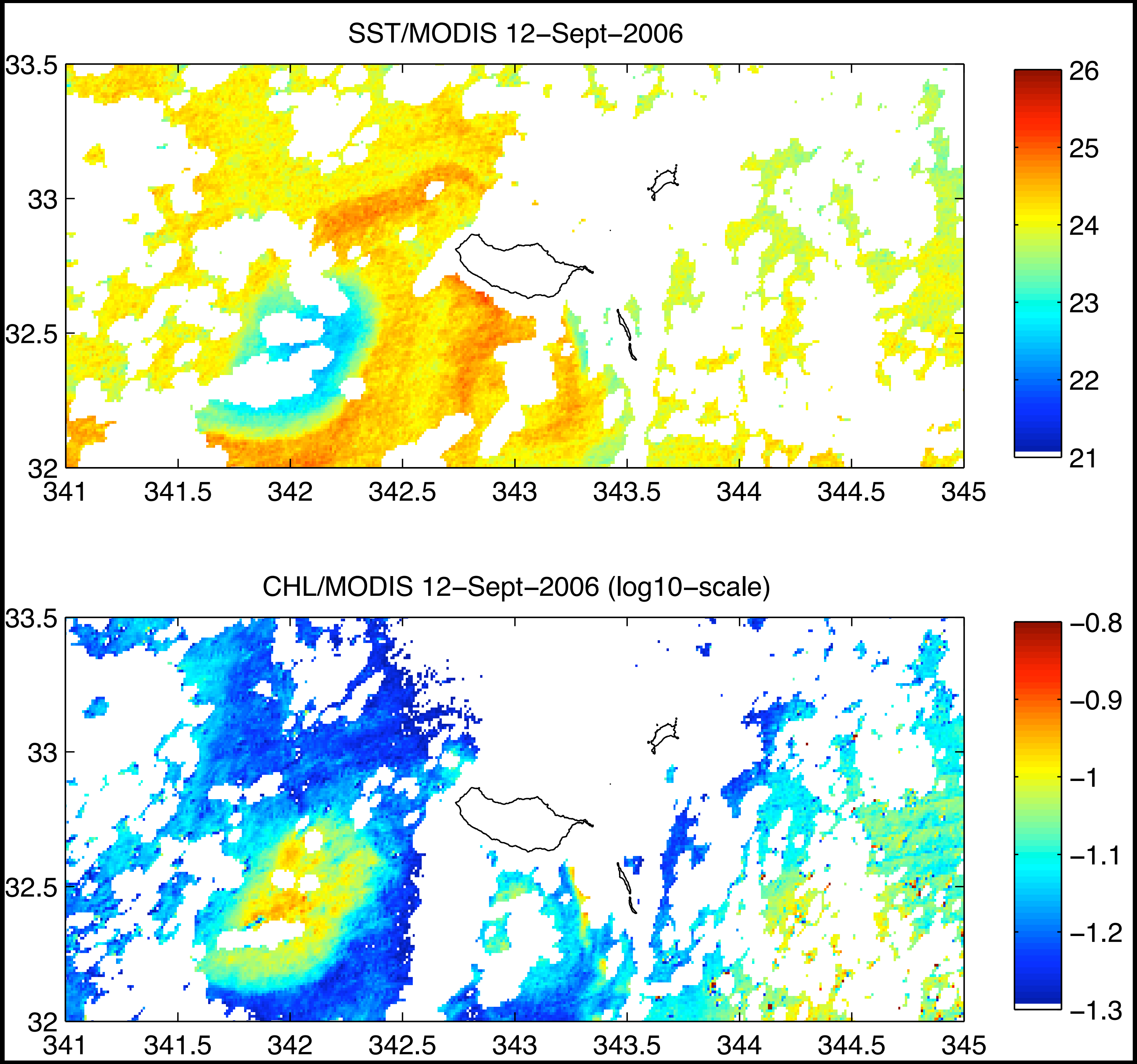
Depth varying vorticity



New hypothesis
(Madeira asymmetric case)



Theory vs observations



General conclusions

- Madeira island wake differs from the classical symmetric case
- Cyclonic eddy formation dominates
  => enhanced by stratification (3D)
- Small nearby islands (Desertas) suppress eddy shedding
- Madeira mesoscale eddy activity mixes 200-300m of surface water => DCM

Future work...

TIRIS - Three dimensional vortex Instability at high Reynolds number around IslandS

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CNRS-Hydralab

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- Hydralab III
- Access conditions and support for users
- User selection rules:
- Eligibility for access

Grenoble Coriolis platform
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- Contact/documents
- Presentation
- Projects
- Publications

Toulouse Hydraulic flume
- Presentation
- Projects

RUI MIGUEL A. CALDEIRA

Island wakes

3 NOV - 28 NOV 2008

In order to expand our understanding of the Geophysical Fluid Dynamic aspects of island wakes, members of this project, in collaboration with international colleagues from France , Spain, Germany and the UK, were awarded financial support to participated in an european integrated infrastructure initiative: HYDRALAB III, in order to study a 'continuum of wake regimes' in a laboratory setting. The experiments will take place during November 2008 in the rotating tank for geophysical studies, located in Grenoble, France.

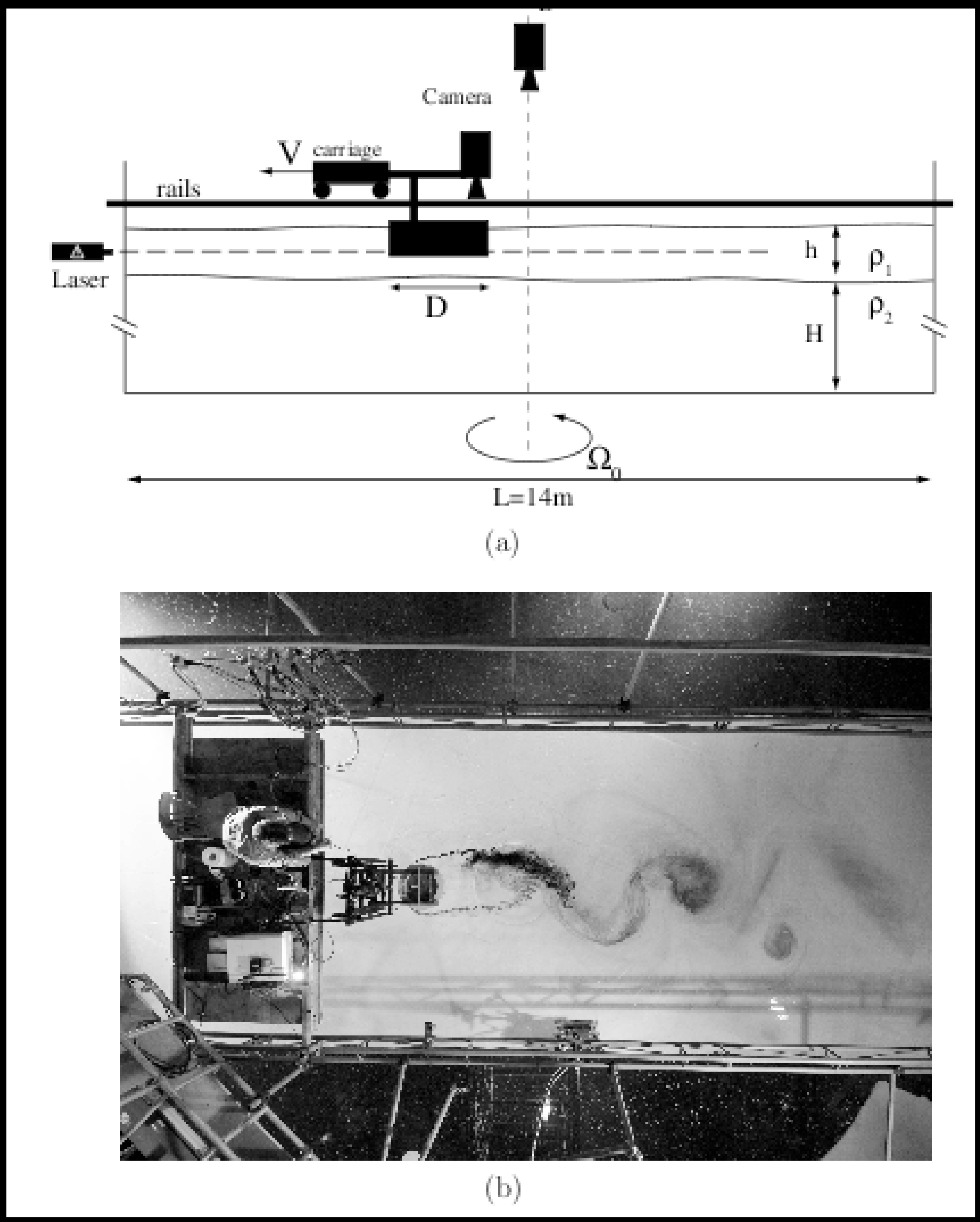
Participants

Name	Position	Country
R. Caldeira	Researcher	Portugal
A. Stegner	Researcher	France
C. Dong	Researcher	USA
G. King	Researcher	UK
R. Penel	PhD student	France
A. Valente	PhD student	Portugal
A. Lazar		France

In the same section
- Generation of interfacial solitons by internal-wave beams
- Characterising 'Zonostrophic flow' in b-plane Geostrophic Turbulence
- Effect of rotation on massively separated turbulent flows
- Modelling Antarctic Flows
- Nonlinear transfer of internal-tide energy and the effect of rotation: an experimental study on bottom reflection, subharmonic resonance, and scattering at a thermocline.
- Coriolis effects in flows around and over isolated topographies
- Rotating stratified flow over rough topography
- The effect of rotation on axisymmetric gravity currents with stratified fluids and inclined

Future work...

TIRIS - Three dimensional vortex Instability at high Reynolds number around IslandS

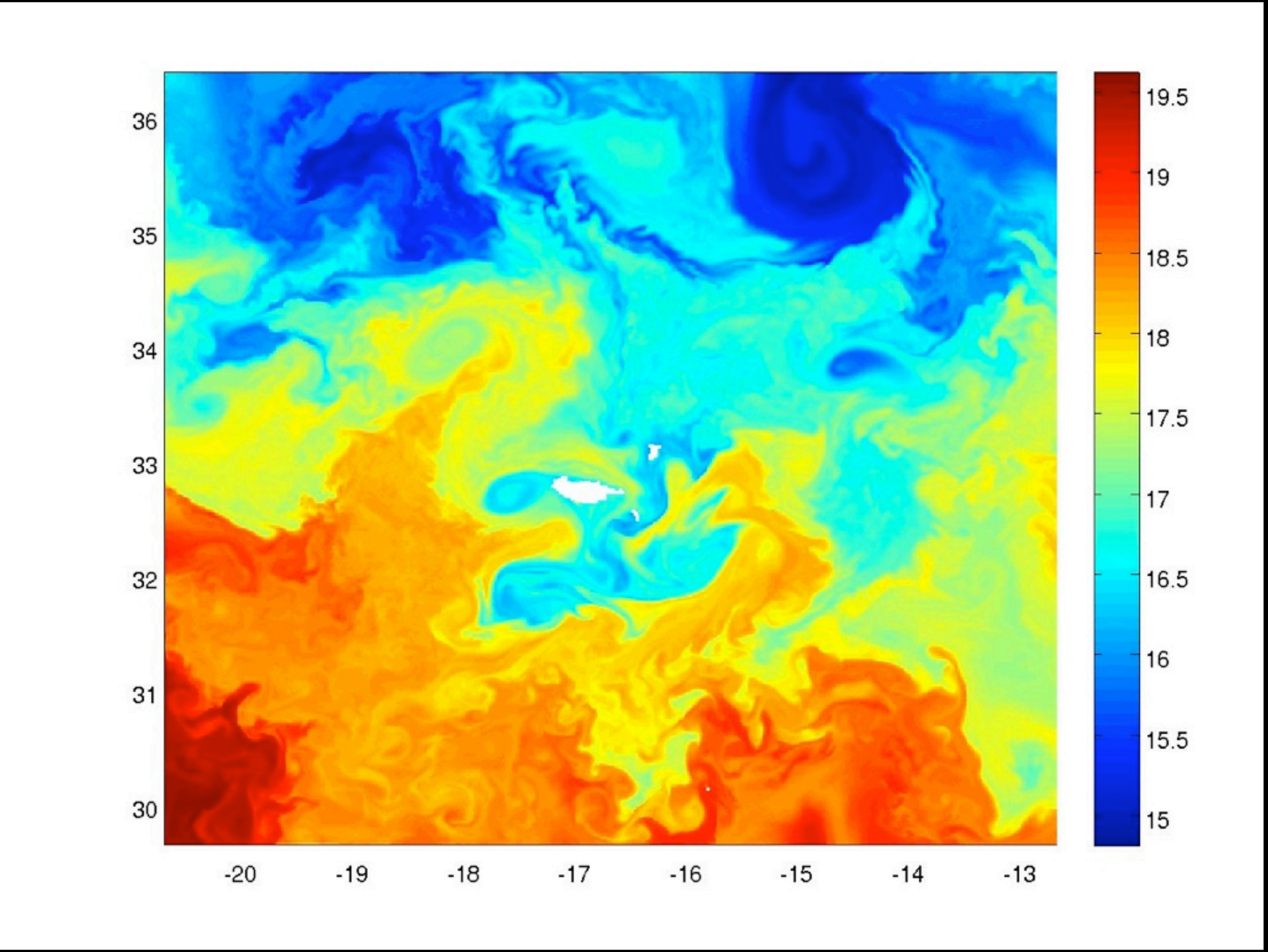


(a)

(b)

Future work...

High resolution (realistic) numerical modeling



Future...

CIMAR - High Performance Computing (HPC) facility