Madeira forecasting systems

Operational & Research perspectives

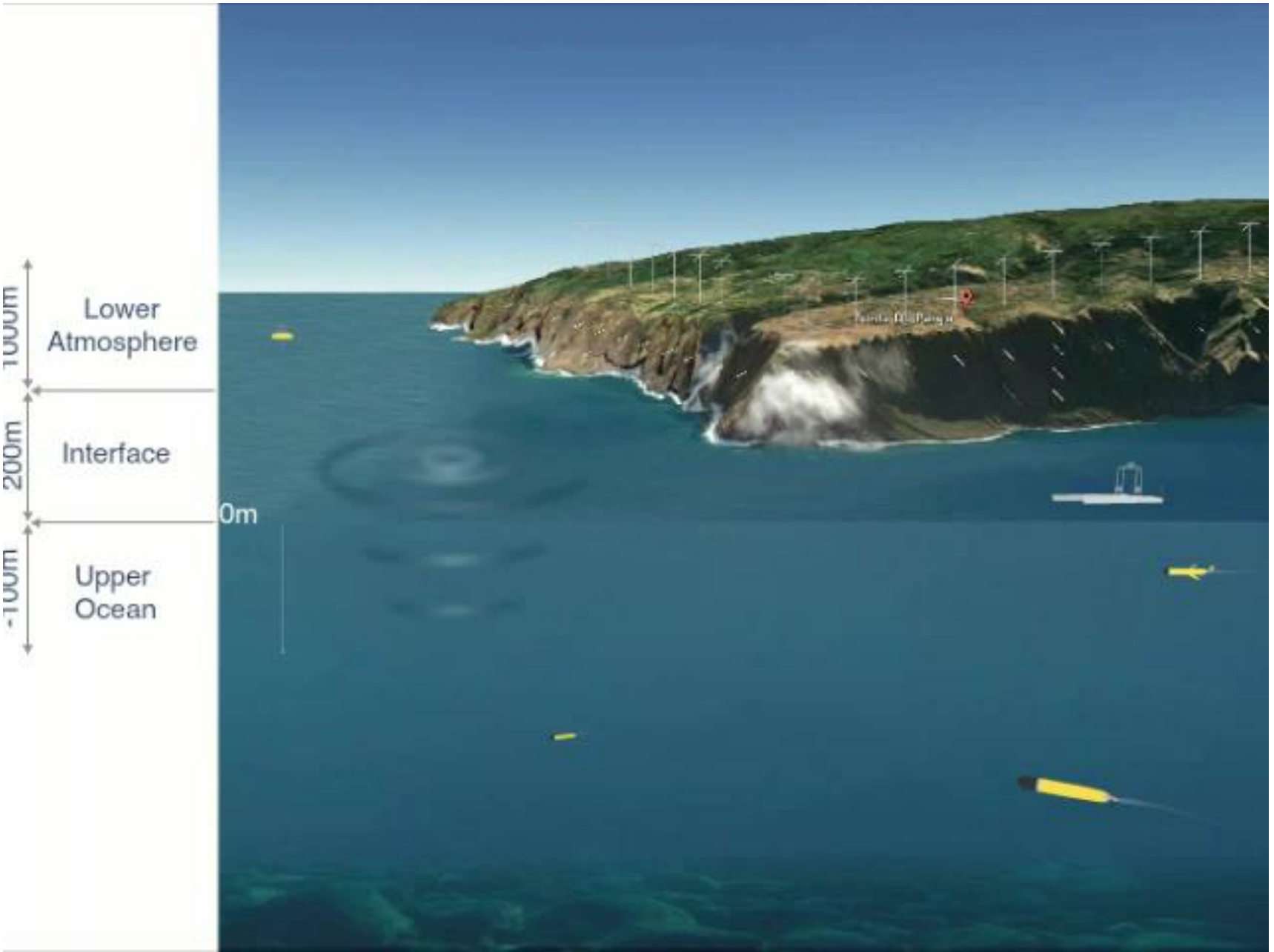
Rui Caldeira
Ocean Observatory of Madeira

Ricardo Tomé
IDL, FCUL, Portugal

Outline

- OOM / Project-OOM
- Forecasting Systems
  - Motivation
  - Forecasts & Products
- Research Agenda
- Future Prospects

The Vision…



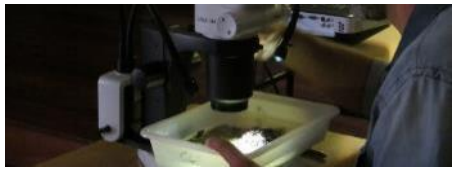
OCEANIC OBSERVATORY OF MADEIRA

OOM – OCEANIC OBSERVATORY OF MADEIRA

Regional Consortium

- Cooperation
- Optimization of resources
- Research & monitoring
- Data in a common platform: **oom.arditi.pt**

OOM – OCEANIC OBSERVATORY OF MADEIRA



TEAM MEMBERS

22

RESEARCHERS

26

CONTRACTED PROJECT-OOM

8 B.Sc.
13 M.Sc.
5 PhDs

8

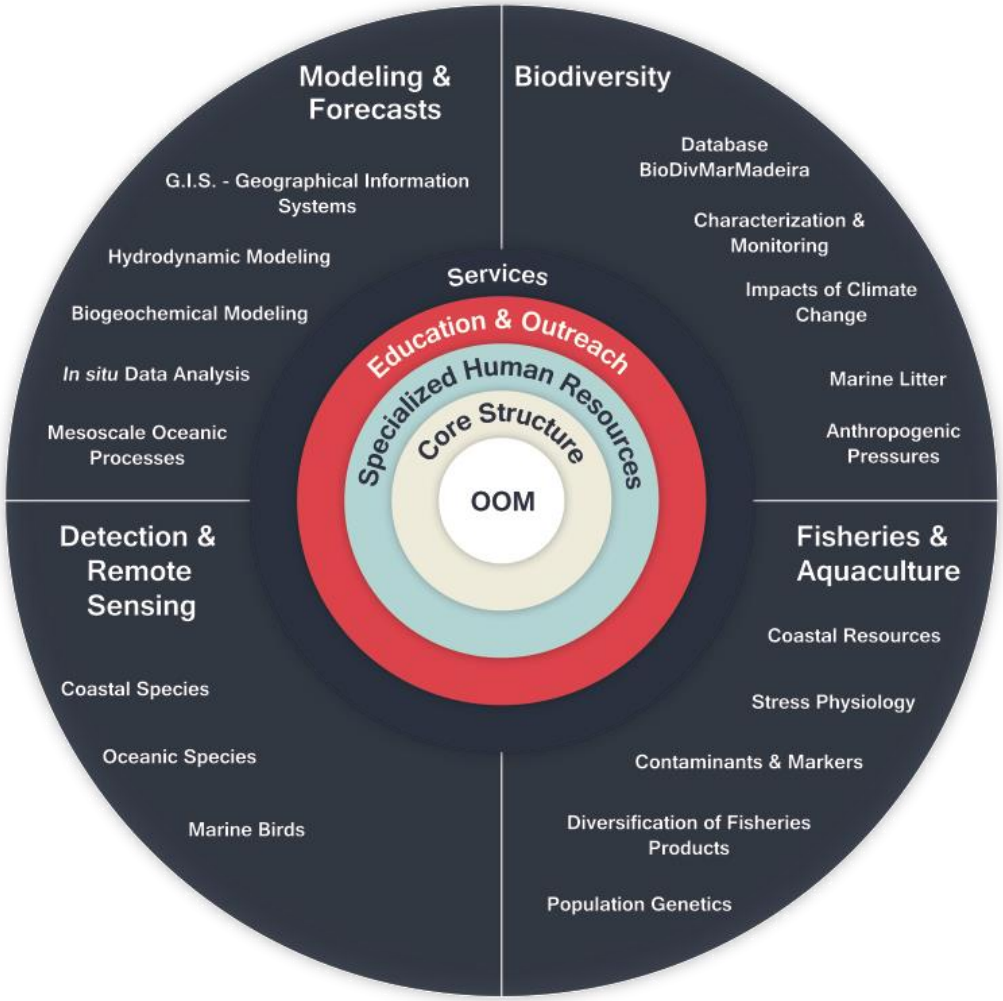
RESEARCHERS ARDITI

1 Phd student
7 PhDs

56 Researchers; 15 PhDs

PROJECT OOM: M1420-01-0145-FEDER-000001

The strategy…



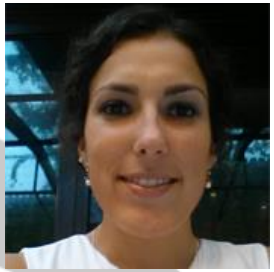
PROJECT COMPONENTS

- Core
  - Mangement
  - Information Technology
- Education & Outreach
  - Promote Ocean Literacy
- Research Themes (4)
  - Build critical mass and promote research excelency

The Team: Modeling & Forecasting

- Rui Caldeira
- Rui Vieira
- Cátia Azevedo
- Maria João Lima
- Gustavo Silva
- Ricardo Faria
- Jesus Reis
- José Alves
- Carlos Lucas









FORECASTING SYSTEMS

Motivation: Persistent tragic events…

- Heavy rains
- Mud slides
- Coastal floods

November 2012 => Claimed +1M €

February 2010 => Claimed +70 lives

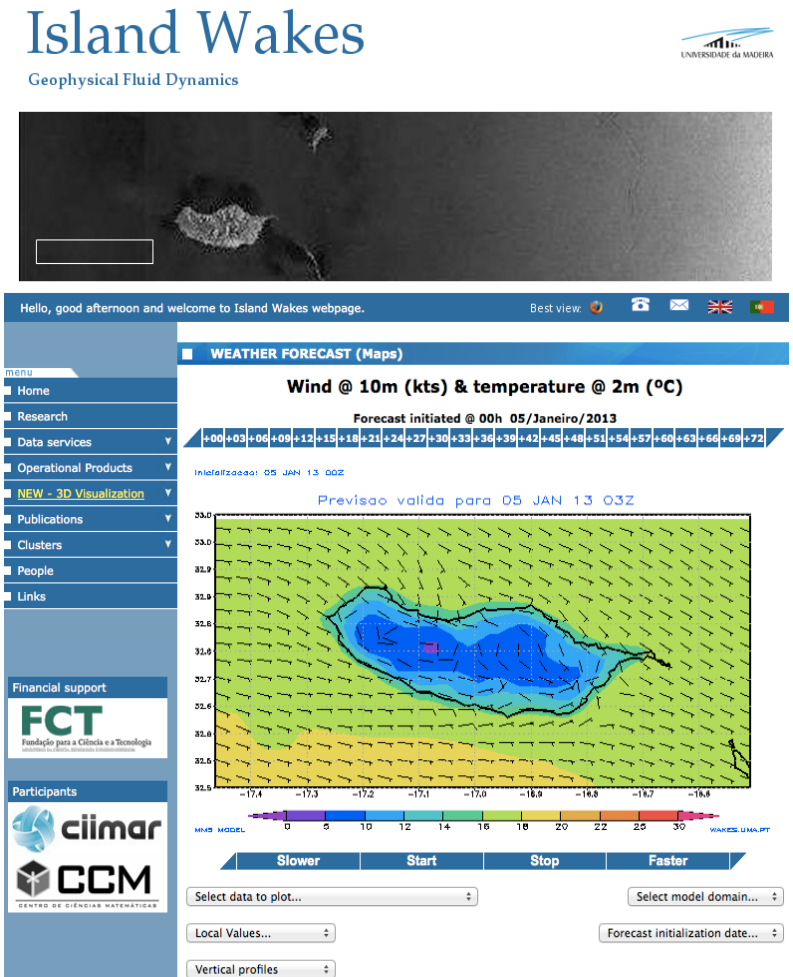
Winter 2009 2010=> Claimed +4M €

Accurate forecasts are essential !

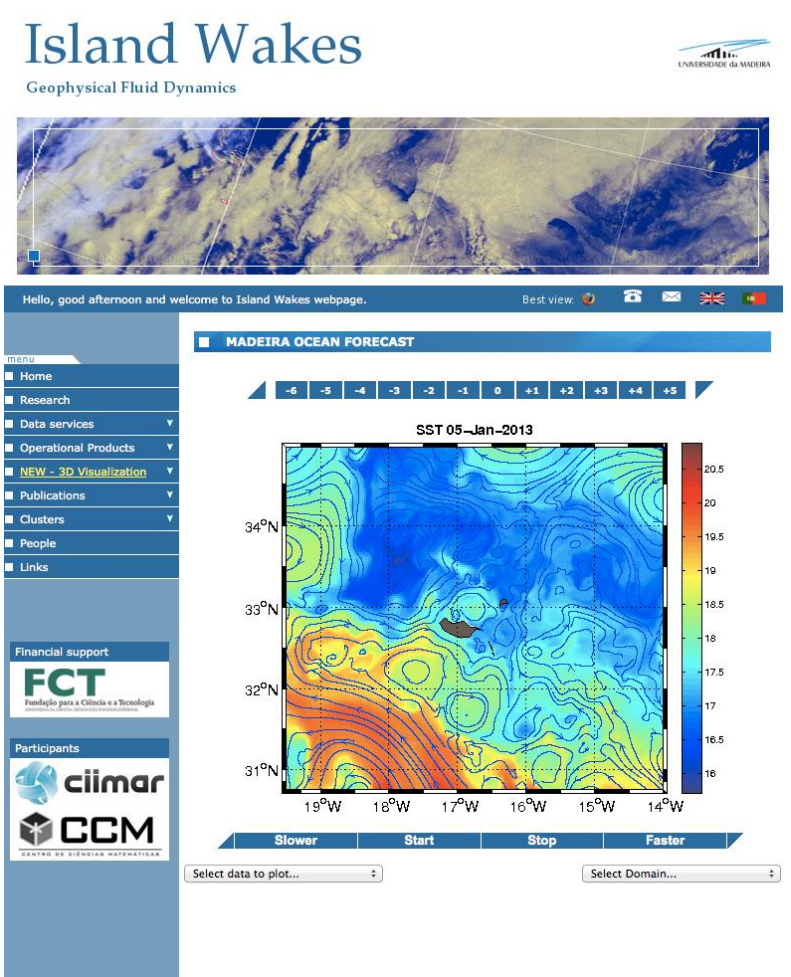
Forecasting started in 2008…

Uncoupled systems @ http://wakes.uma.pt

Meteo: GFS => MM5 (54,18,6,2 km)



Ocean: MERCATOR (NEMO) + GFS => ROMS



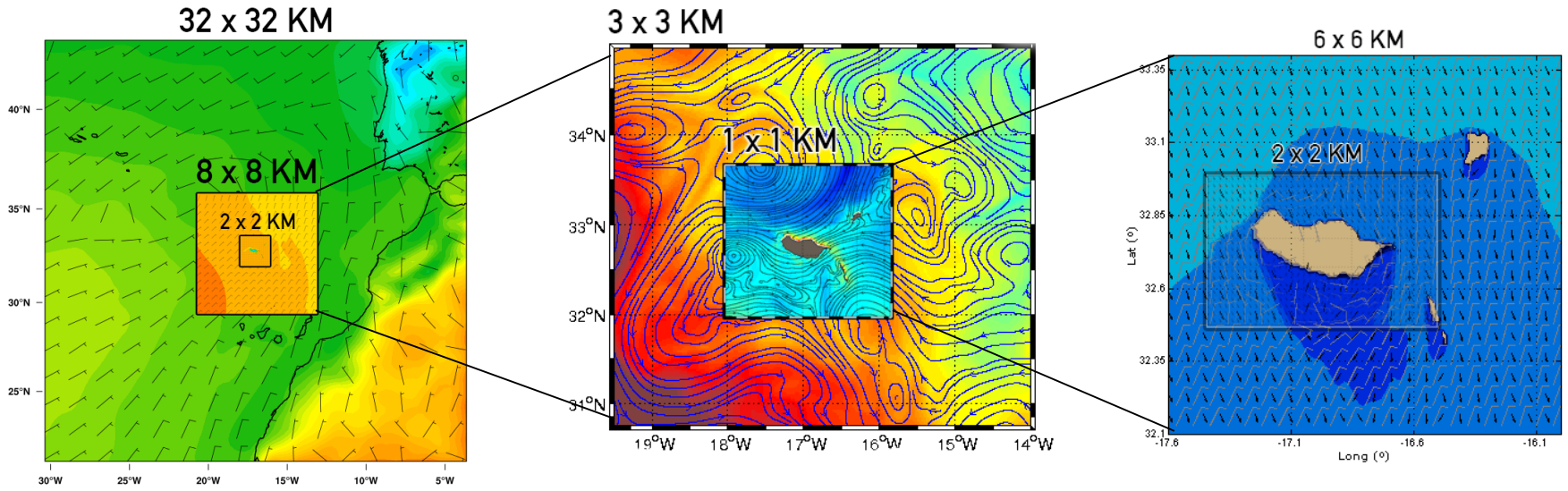
Operational Forecasting Systems

3 **separate** numerical components

WRF

ROMS

SWAN



PRODUCTS: MOBILE APP

FUNCTIONALITIES

- HR Forecasts (hourly)
- Satellite Images (3 days)
- Favorite Locations
- Webcams (hourly)

GET IT ON Google Play

Available on the App Store

Products: Printable weather forecasts

Santa Cruz									
23 / 09			24 / 09			25 / 09		
6 - 12	13 - 18	19 - 24	6 - 12	13 - 18	19 - 24	6 - 12	13 - 18	19 - 24
18º/20º	20º/21º	19º/20º	20º/22º	22º/23º	21º/22º	21º/22º	21º/22º	20º/21º
82 %	79 %	72 %	59 %	61 %	49 %	57 %	80 %	79 %

Available on the App Store

Madeira

GET IT ON Google play

ciimar madeira

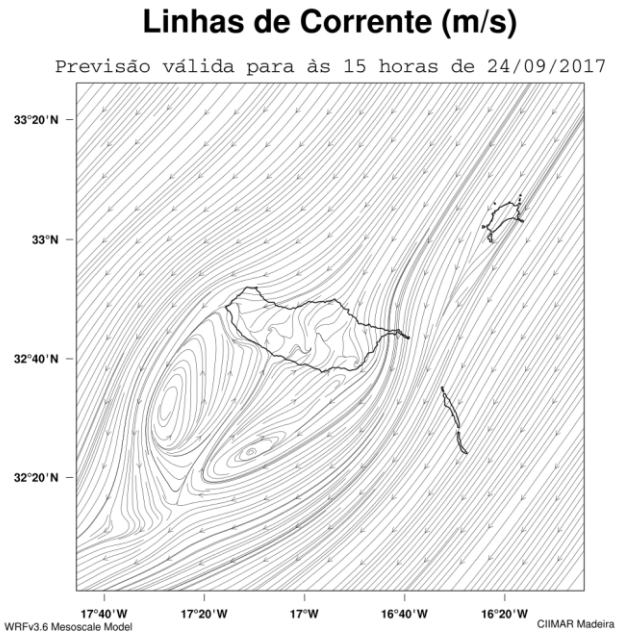
ciimarmadeira.org

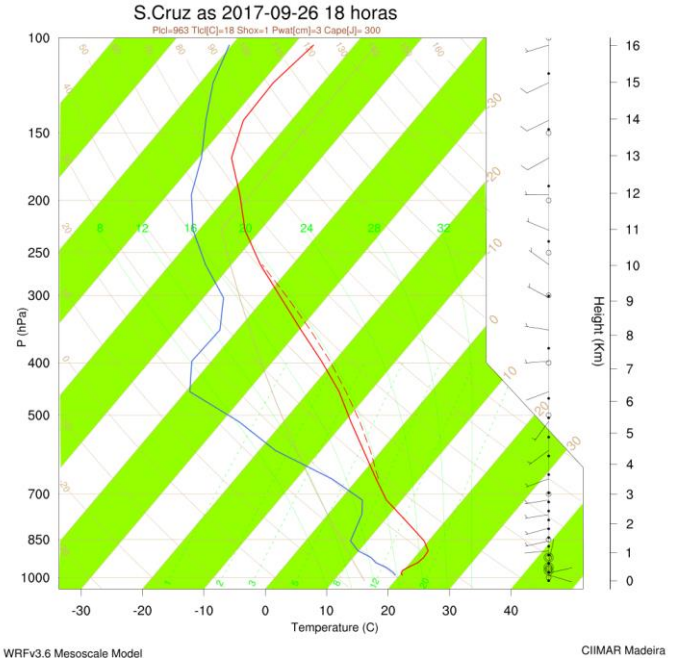
CIIMAR-Madeira

Funchal			Câmara de Lobos			Ribeira Brava			Ponta do Sol			Calheta		
23 / 09		24 / 09	23 / 09		24 / 09	23 / 09		24 / 09	23 / 09		24 / 09	23 / 09		24 / 09
1 - 12	13 - 24	>24	1 - 12	13 - 24	>24	1 - 12	13 - 24	>24	1 - 12	13 - 24	>24	1 - 12	13 - 24	>24
20º/21º	21º/22º	20º/22º	18º/21º	20º/21º	19º/22º	18º/21º	19º/21º	19º/22º	20º/21º	21º/22º	21º/22º	18º/20º	19º/21º	19º/21º
77 %	83 %	77 %	74 %	72 %	67 %	81 %	82 %	81 %	89 %	88 %	87 %	82 %	76 %	73 %

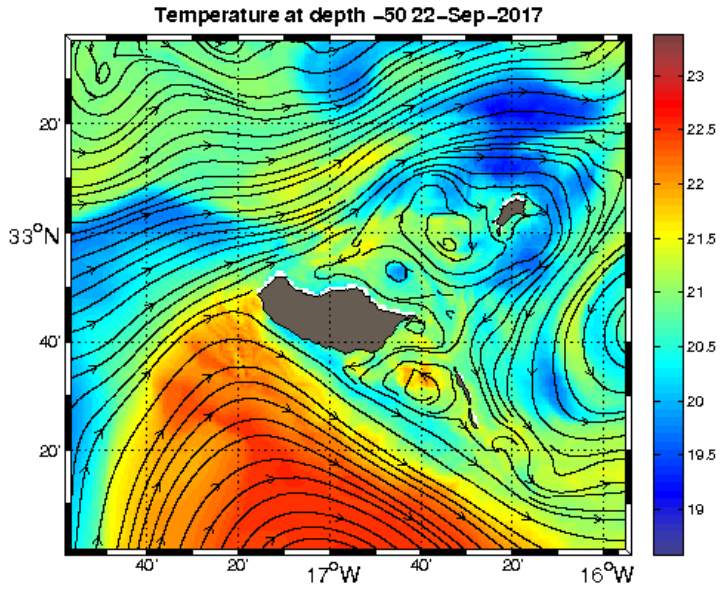
Porto Moniz			São Vicente			Santana			Machico			Porto Santo		
23 / 09		24 / 09	23 / 09		24 / 09	23 / 09		24 / 09	23 / 09		24 / 09	23 / 09		24 / 09
1 - 12	13 - 24	>24	1 - 12	13 - 24	>24	1 - 12	13 - 24	>24	2 - 12	13 - 24	>24	2 - 12	13 - 24	>24
17º/21º	18º/21º	18º/22º	16º/20º	17º/21º	17º/22º	14º/18º	15º/18º	14º/20º	16º/19º	16º/20º	16º/21º	17º/21º	17º/22º	16º/22º
80 %	76 %	71 %	76 %	70 %	59 %	89 %	82 %	67 %	87 %	82 %	68 %	80 %	77 %	82 %

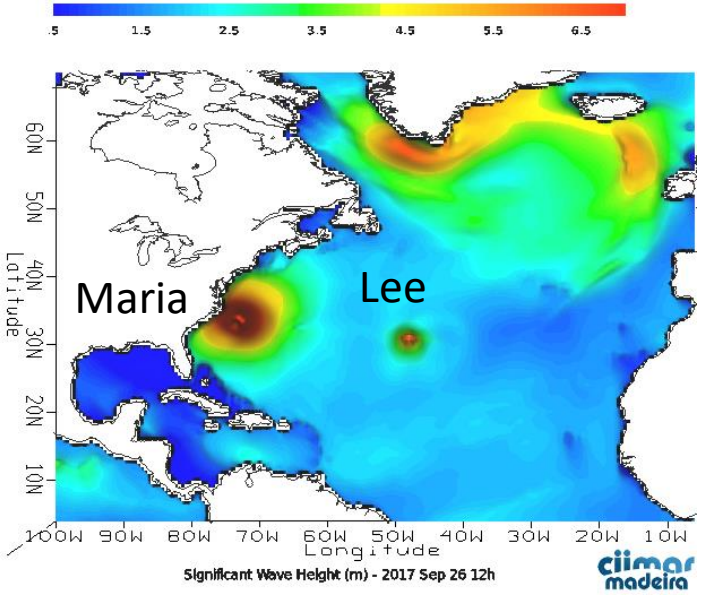
Atmosphere

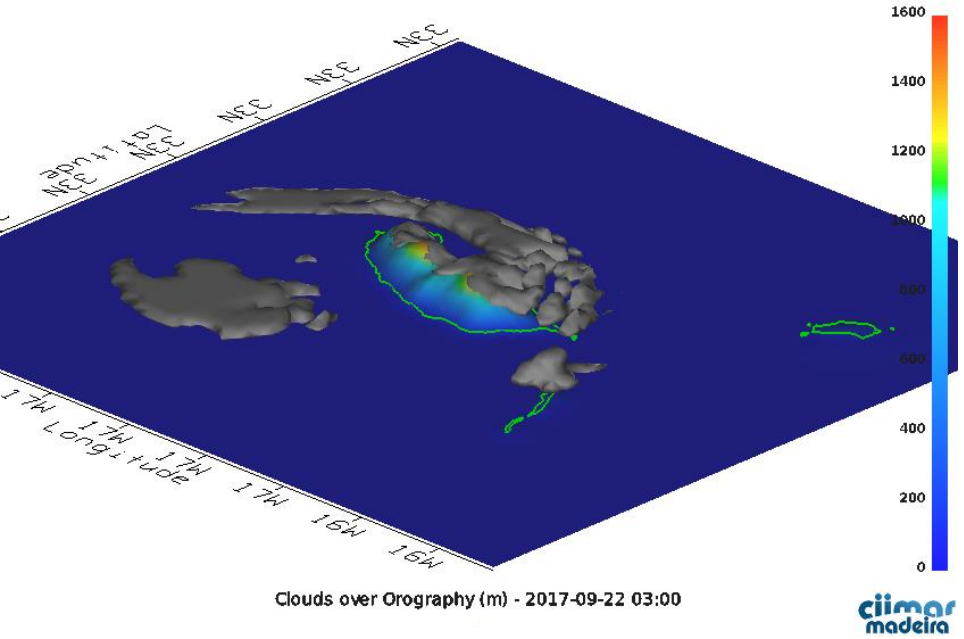




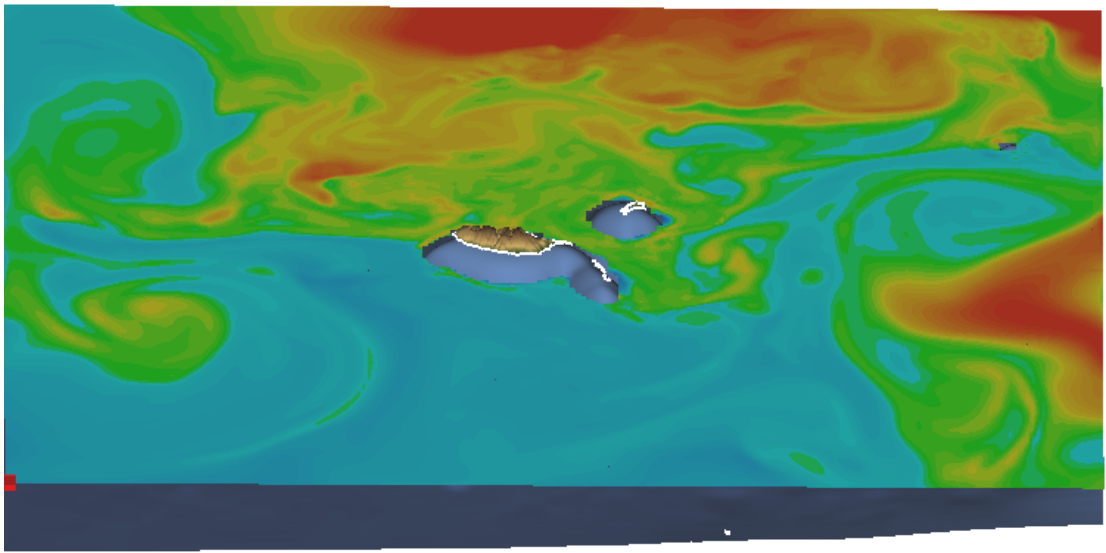
Ocean







3D Visualizations



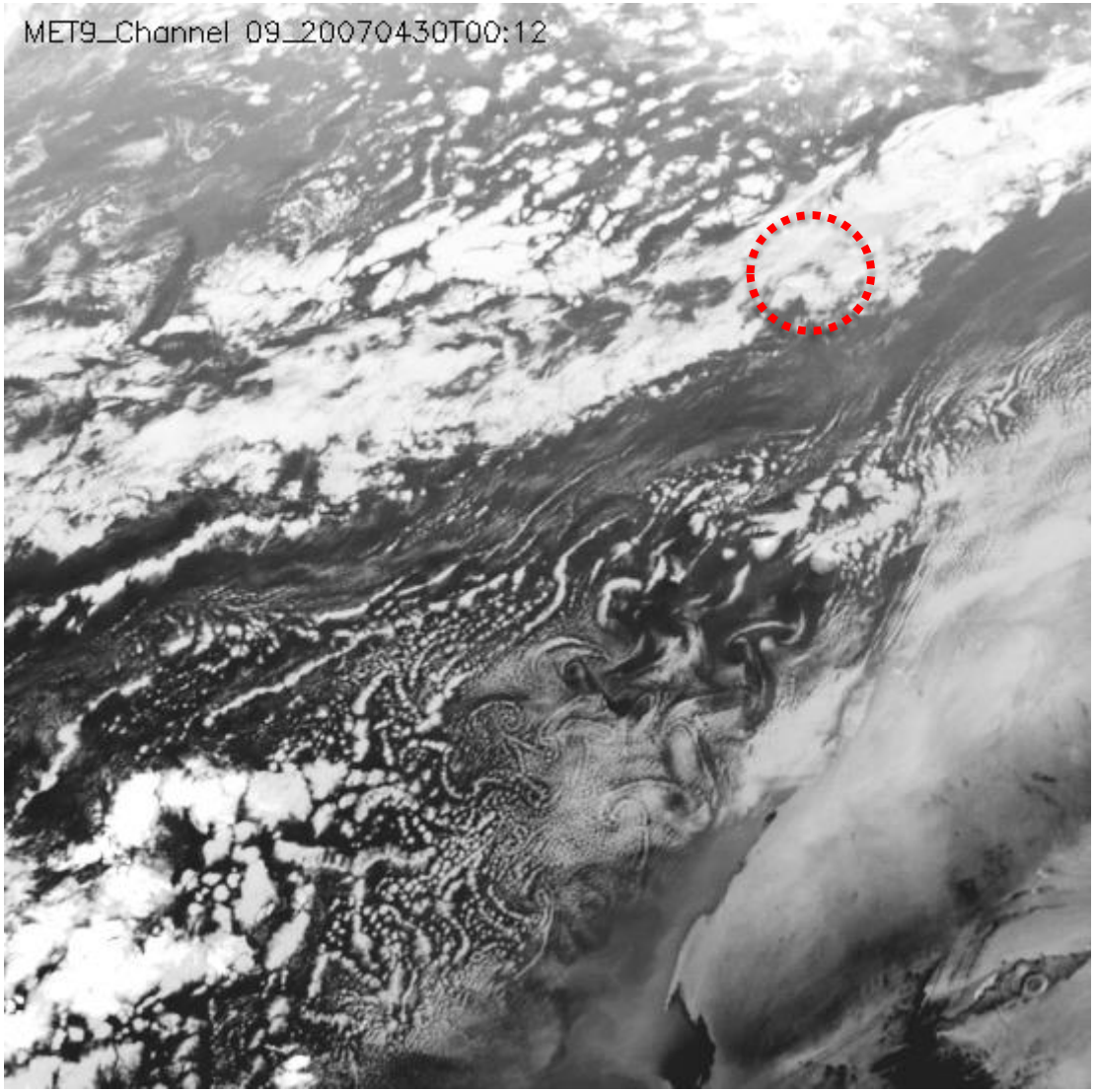
Madeira 9 July 2010

Courtesy of Ákos Horváth

Meteosat-9, IR108 channel

vortex shedding frequency: 4-5 hrs

Madeira 30 Abril 2007



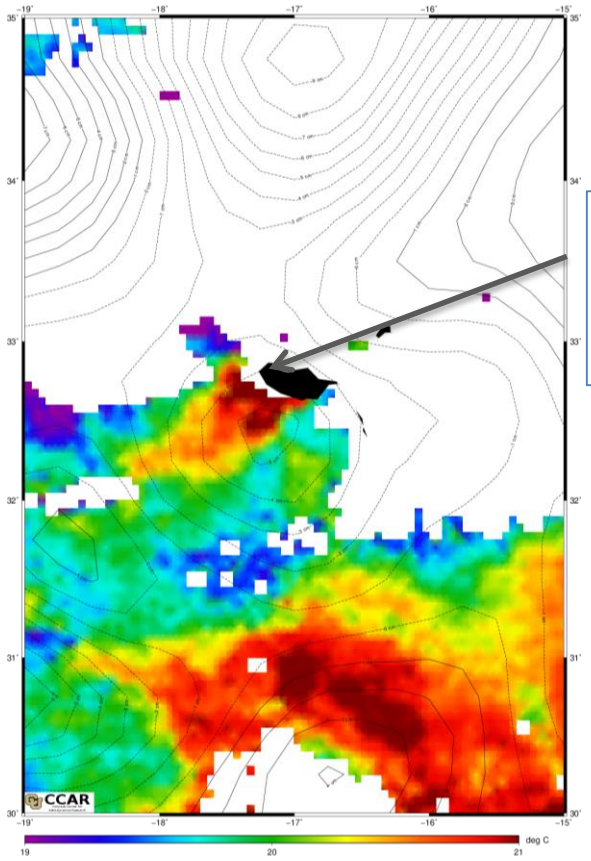
Courtesy of Ákos Horváth

Meteosat-9, IR108 channel

vortex shedding frequency: 4-5 hrs

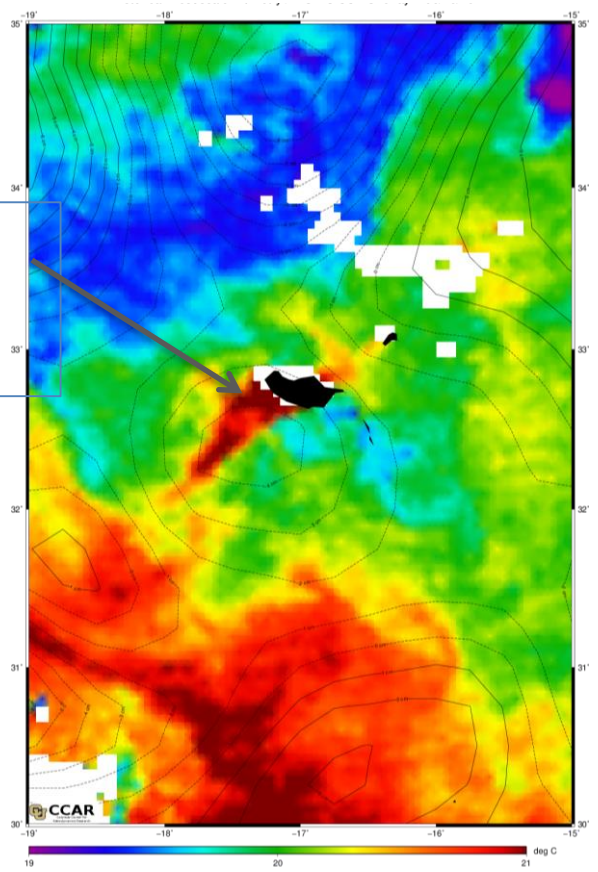
Observed Impact on Ocean SST

15 June 2011



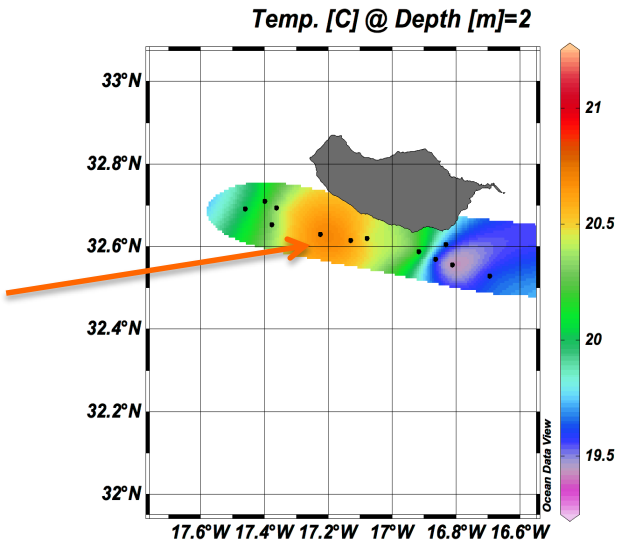
+2º C in wake region cyclonic circulation

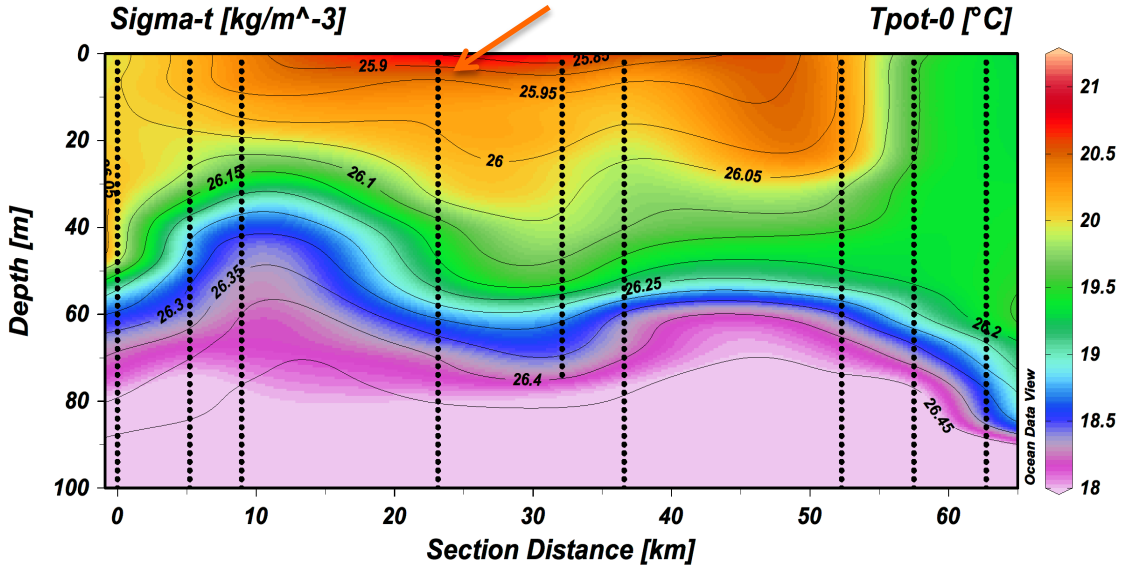
20 June 2011



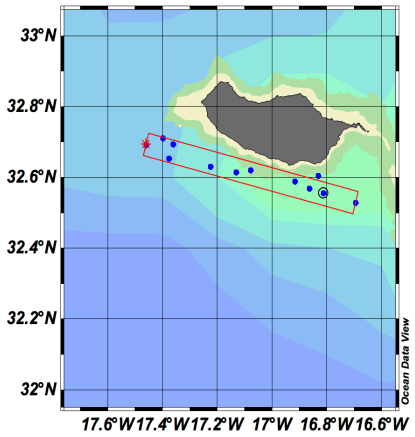
MODIS SST daily average

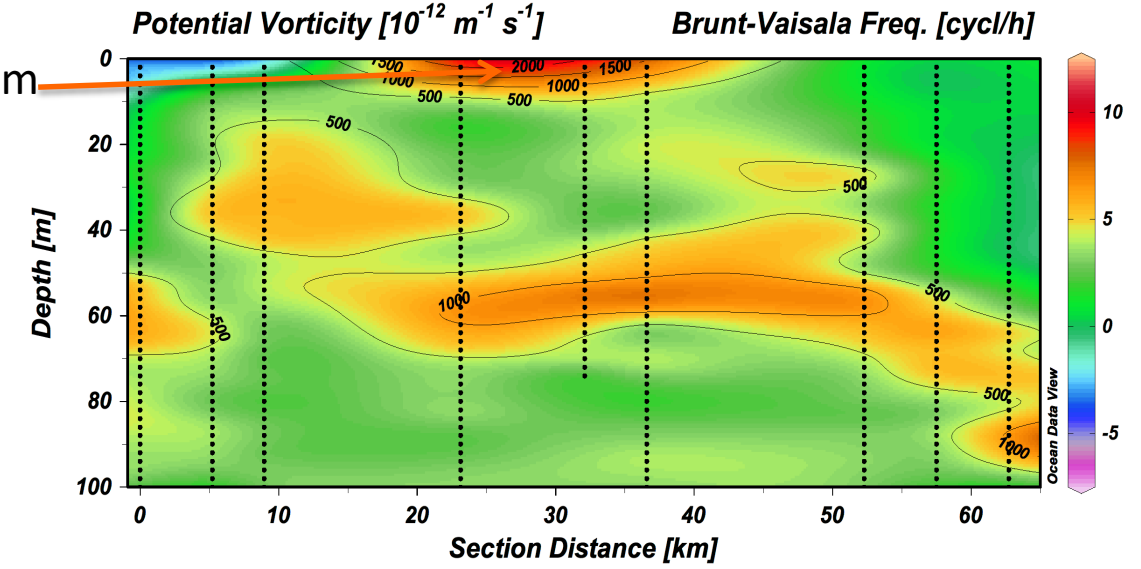
In situ measurements of warm (SST) wake

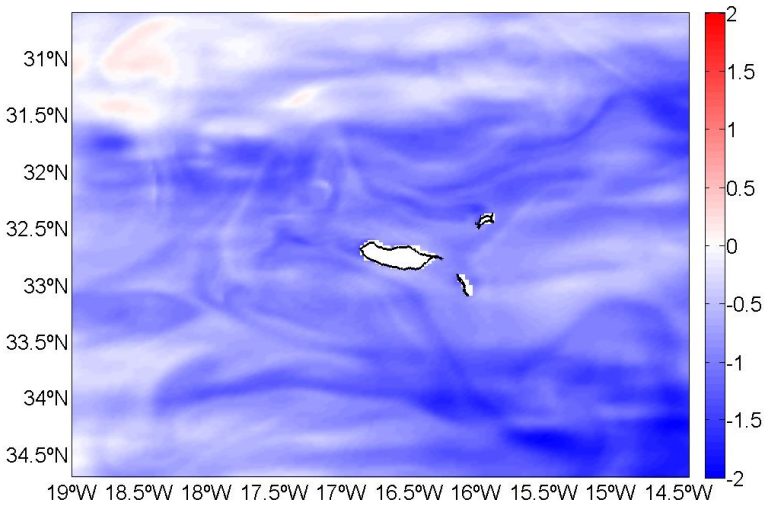




5-10m







JOURNAL OF OPERATIONAL OCEANOGRAPHY, 2016
http://dx.doi.org/10.1080/1755876X.2016.1205304

Taylor & Francis
Taylor & Francis Group

Challenges of building an operational ocean forecasting system for small island regions: regional to local

Rui Caldeira[a,b,c], Xavier Couvelard[b,d], Rui Vieira[c], Carlos Lucas[c], Iria Sala[a] and Ignasi Vallès Casanova[c]

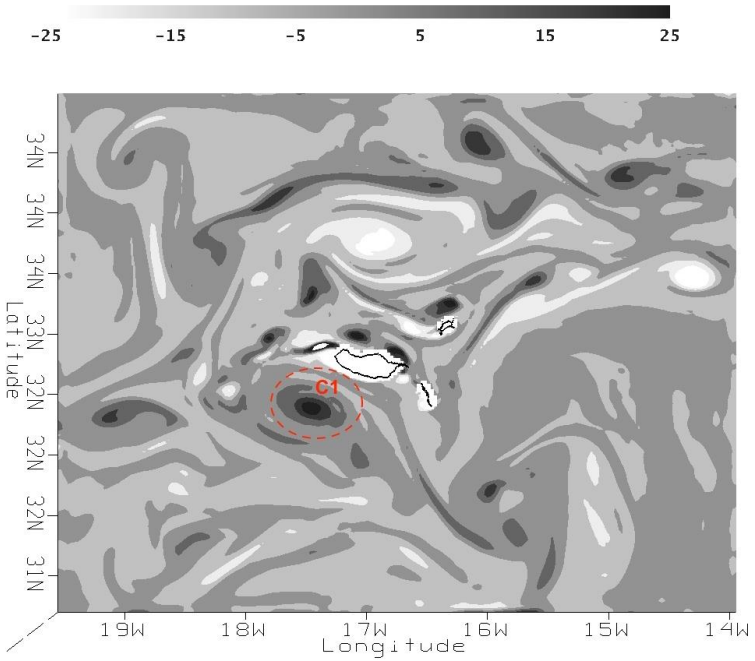
[a]CIIMAR - Interdisciplinary Centre of Marine and Environmental Research, Porto, Portugal; [b]CCM – Centro de Ciências Matemáticas, Universidade da Madeira, Funchal, Portugal; [c]CIIMAR-Madeira – Centro Interdisciplinar de Investigação Marinha e Ambiental da Madeira, Funchal, Portugal; [d]LOPS – Laboratoire d'Océanographie Physique et Spatiale, UMR 6523, CNRS-IFREMER-IRD-UBO, Centre Ifremer de Brest, Plouzané, France

ABSTRACT

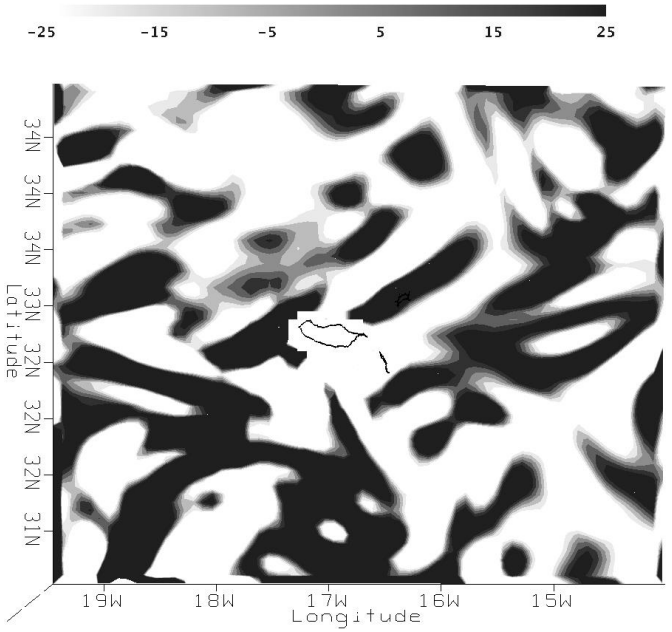
An ocean circulation forecasting model for the Madeira Archipelago is operational since May 2010. Developing a forecasting system for a small island oceanic region, deprived from *in-situ* observations, is a challenging task since there are limited ways to validate predictions. Furthermore, model resolution concurrent with insufficient computational power, locally available, are other limiting factors to consider. Regional models combined with the possibility to downscale solutions onto a higher resolution island-scale model is a way to overcome some of such limitations. Nevertheless, generalised regional models must be able to accurately represent the far-field and transport important features such as meddies onto the local systems; while island-scale models must have sufficient grid resolution as well as adequate physics and accurate atmospheric forcing to resolve the near-field phenomena. An island-induced cyclonic eddy event was successfully observed and forecasted with the current approach (regional-local). Generalised single (regional) model initiatives will prove to be insufficient to deal with mesoscale dynamic systems, islands and seamounts are important generators of mesoscale features in the NE Atlantic, with basin scale implications. The forecasting systems of the future should also consider upscaling valid local (island-scale) solutions onto Regional and/or Global models.

ARTICLE HISTORY
Received 24 March 2015
Accepted 17 June 2016

ROMS (1/32º <=> 1/118º)



MERCATOR (1/32º)

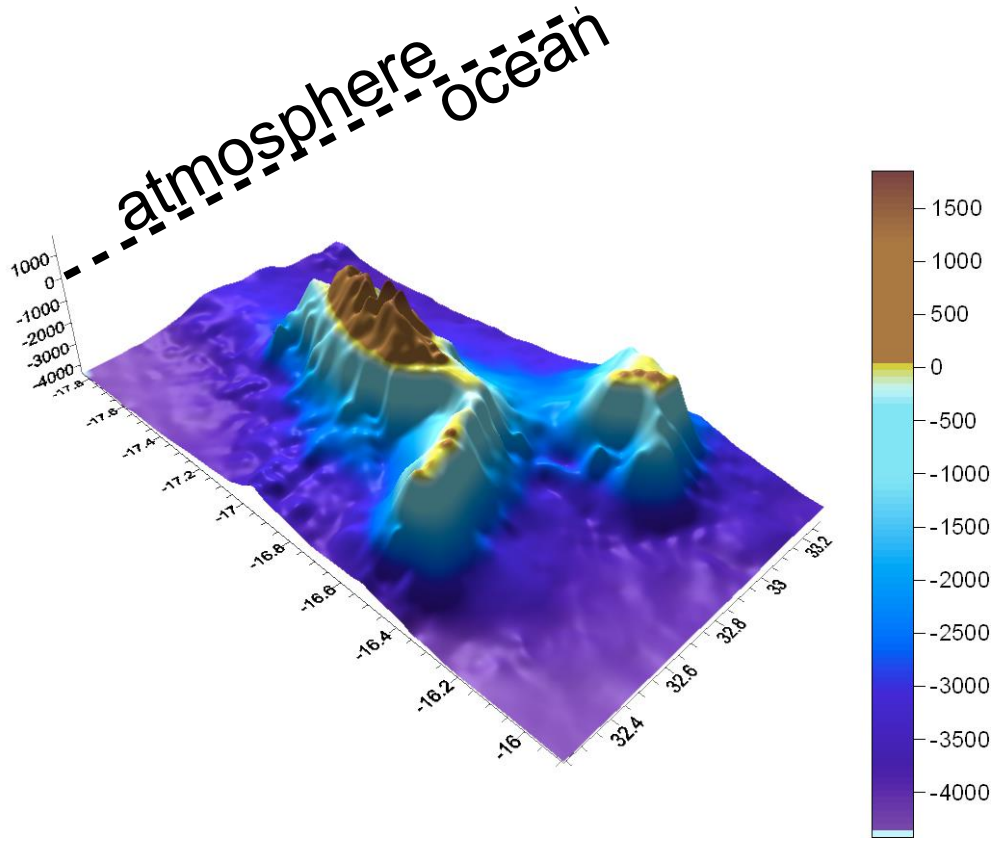


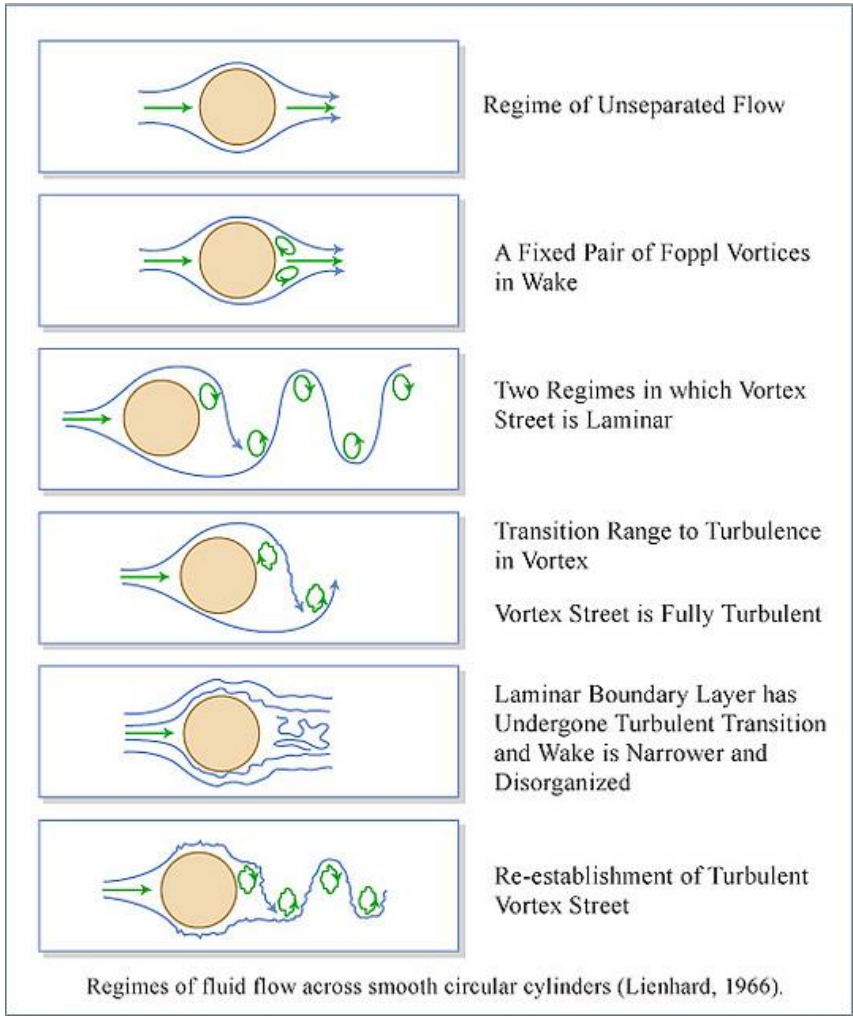
RESEARCH

Research Agenda

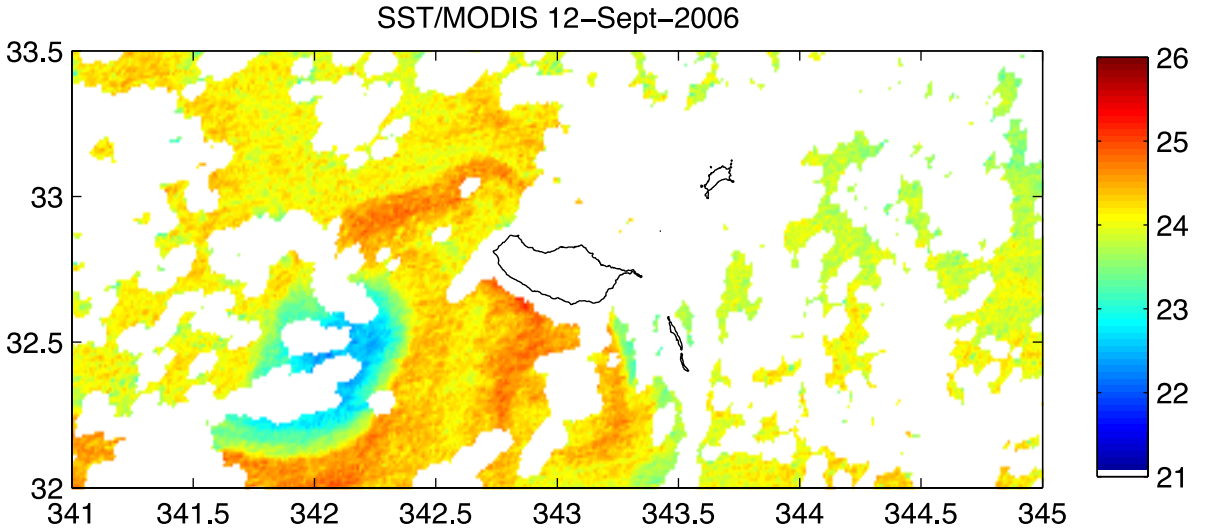
- Understand different wake regimes i.e. vortex shedding / lee waves;
- Impacts of the atmospheric wakes on ocean wakes i.e. momentum & thermodynamics;
- Evolution of lee oceanic eddies;
- Ongoing / future work …

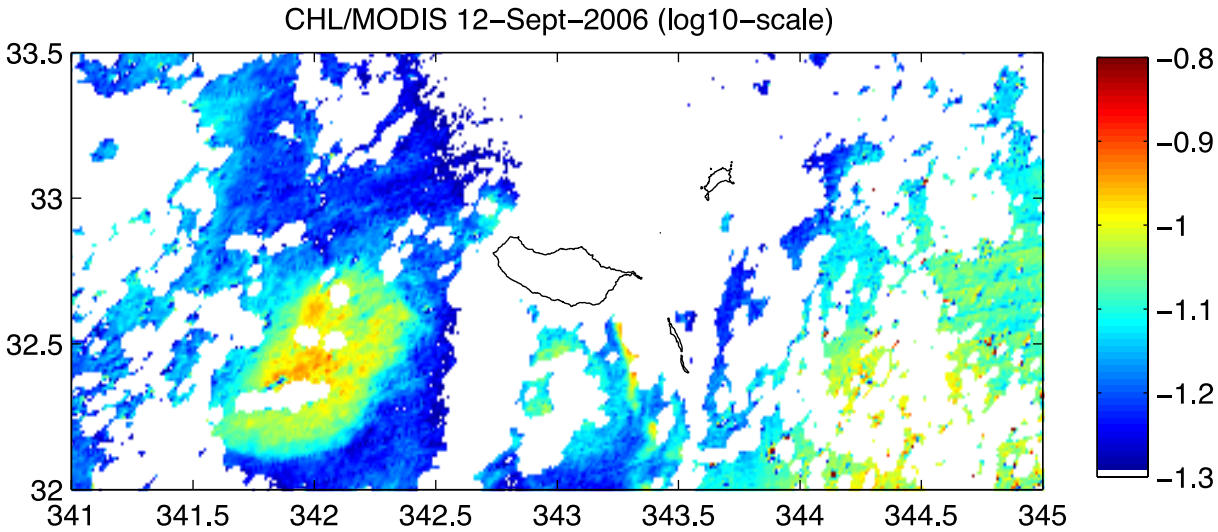
Perturbing geophysical fluids

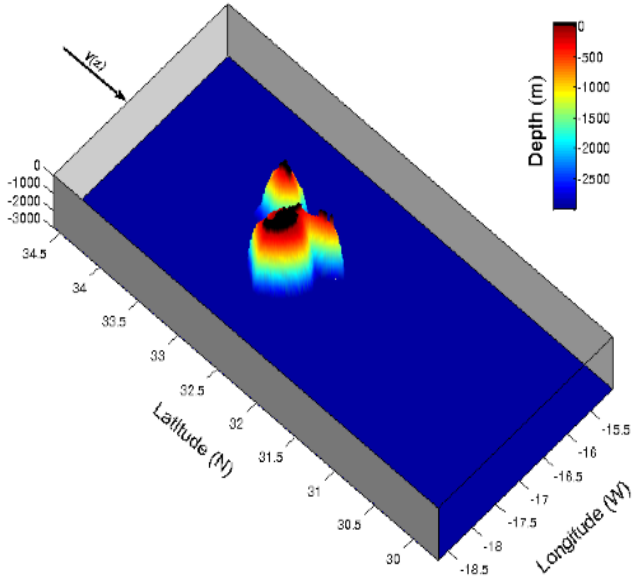


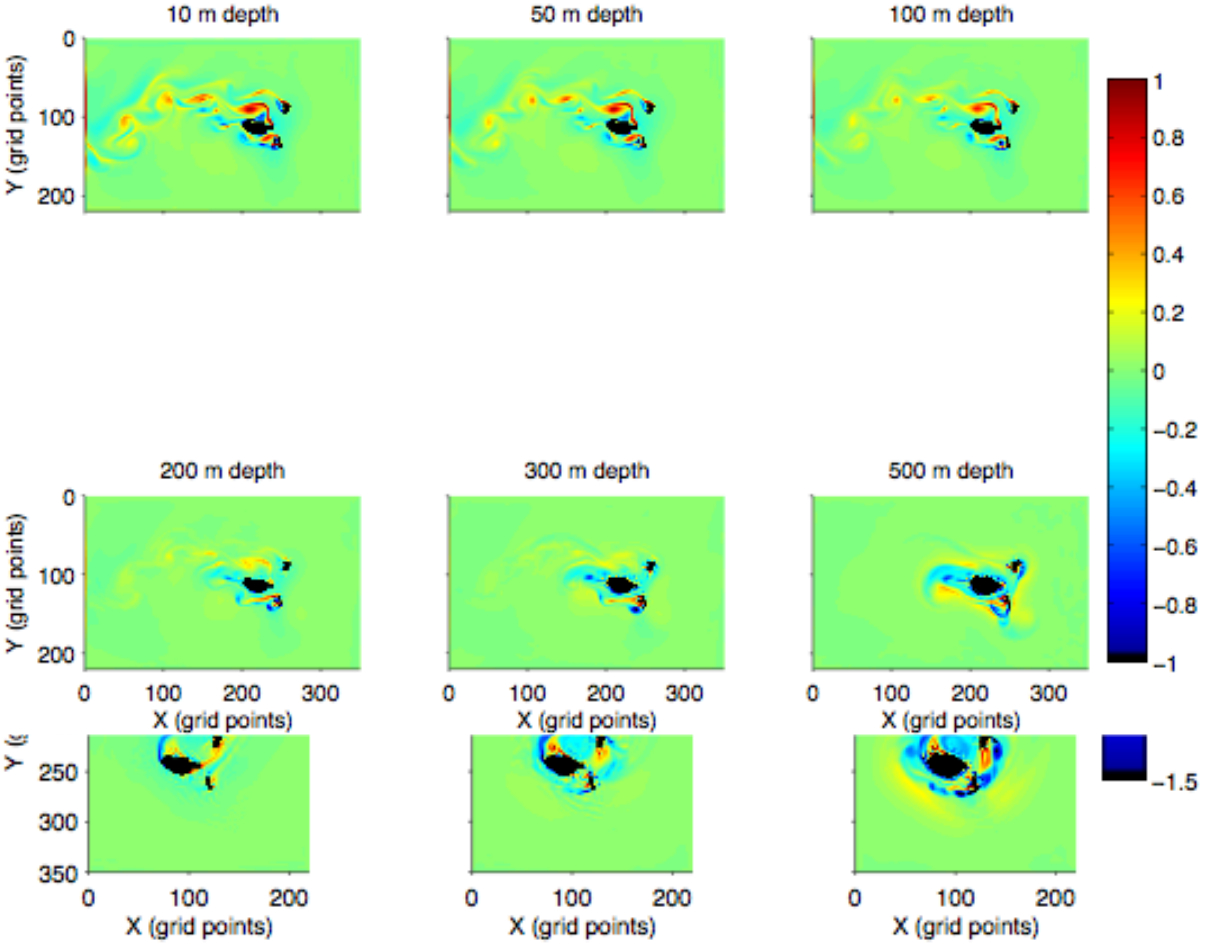


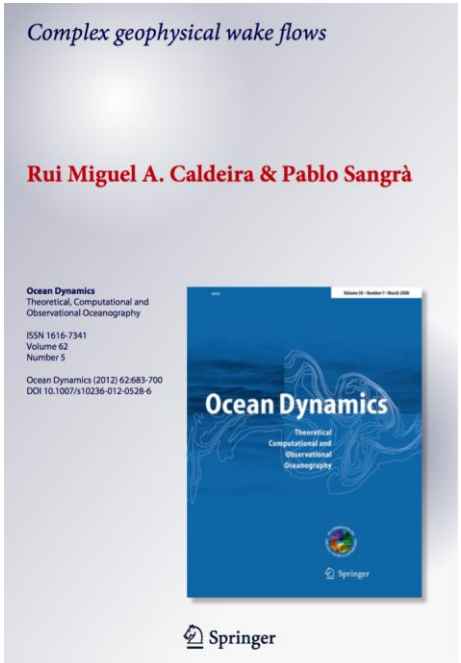
Regimes of fluid flow across smooth circular cylinders (Lienhard, 1966).


SST/MODIS 12–Sept–2006
33.5
33
32.5
32
341
341.5
342
342.5
343
343.5
344
344.5
345
26
25
24
23
22
21


CHL/MODIS 12–Sept–2006 (log10–scale)
33.5
33
32.5
32
341
341.5
342
342.5
343
343.5
344
344.5
345
−0.8
−0.9
−1
−1.1
−1.2
−1.3

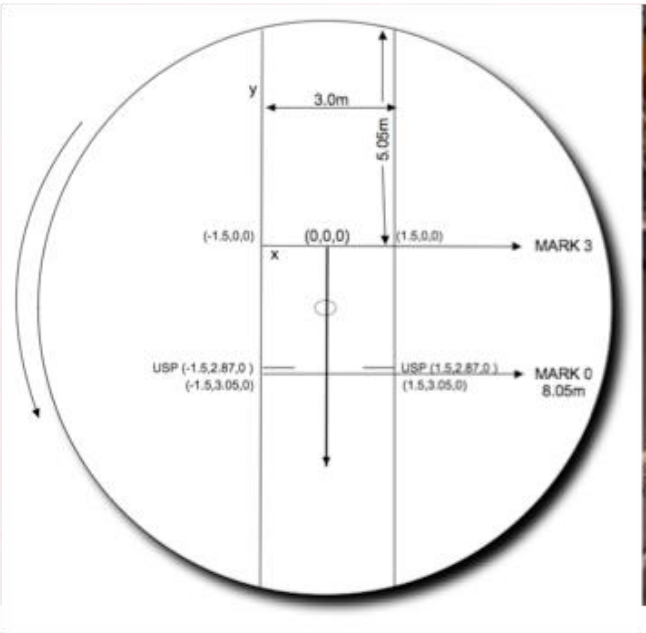

V(z)
Depth (m)
0
-500
-1000
-1500
-2000
-2500
0
-1000
-2000
-3000
34.5
34
33.5
33
32.5
32
31.5
31
30.5
30
Latitude (N)
-15.5
-16
-16.5
-17
-17.5
-18
-18.5
Longitude (W)

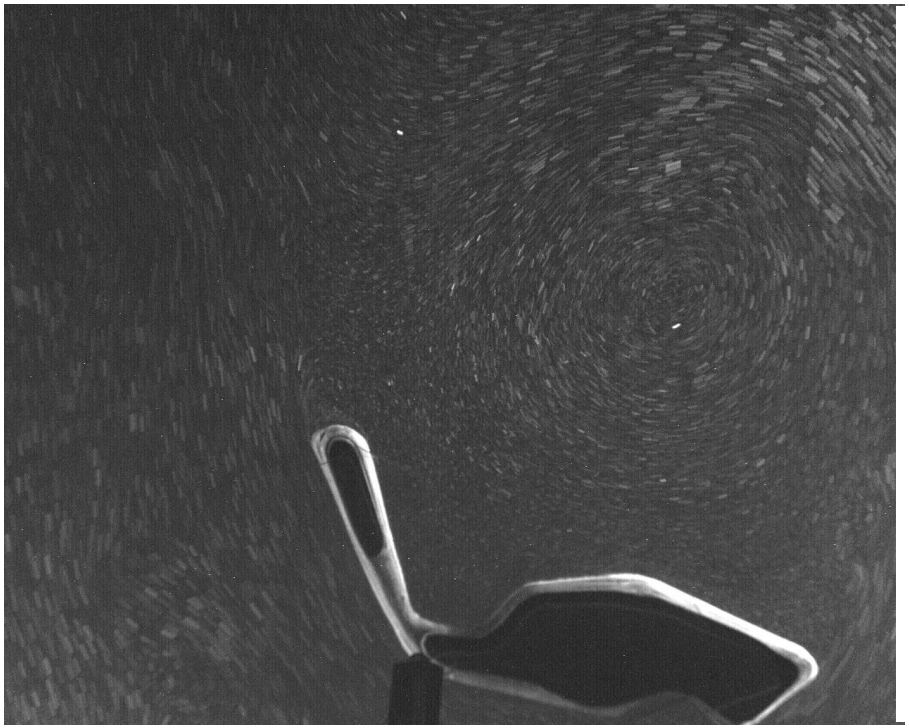

10 m depth
50 m depth
100 m depth
200 m depth
300 m depth
500 m depth
Y (grid points)
X (grid points)
0
100
200
300
250
350
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.5

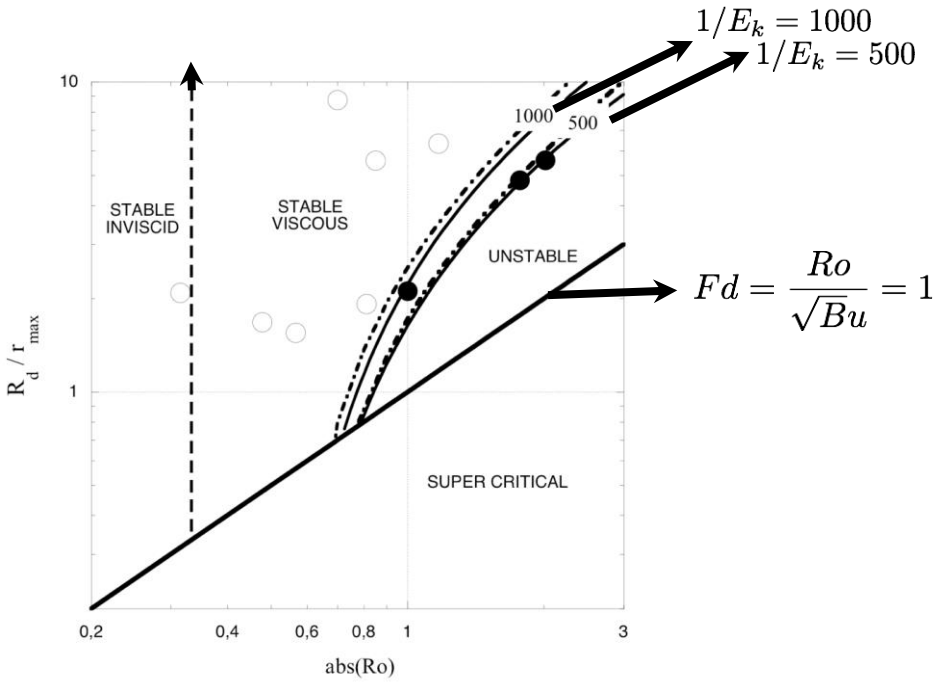

Complex geophysical wake flows
Rui Miguel A. Caldeira & Pablo Sangrà
Ocean Dynamics
Theoretical, Computational and Observational Oceanography
ISSN 1616-7341
Volume 62
Number 5
Ocean Dynamics (2012) 62:683-700
DOI 10.1007/s10236-012-0528-6
Ocean Dynamics
Theoretical
Computational and
Observational
Oceanography
Springer
Springer

Laboratory Studies

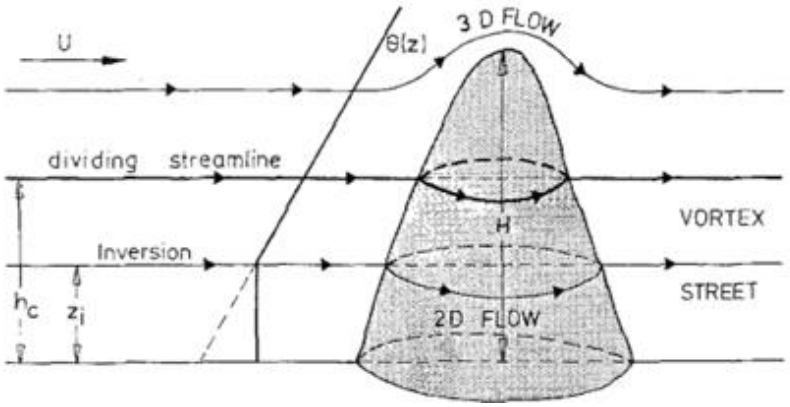
HYDRALAB III, FP6



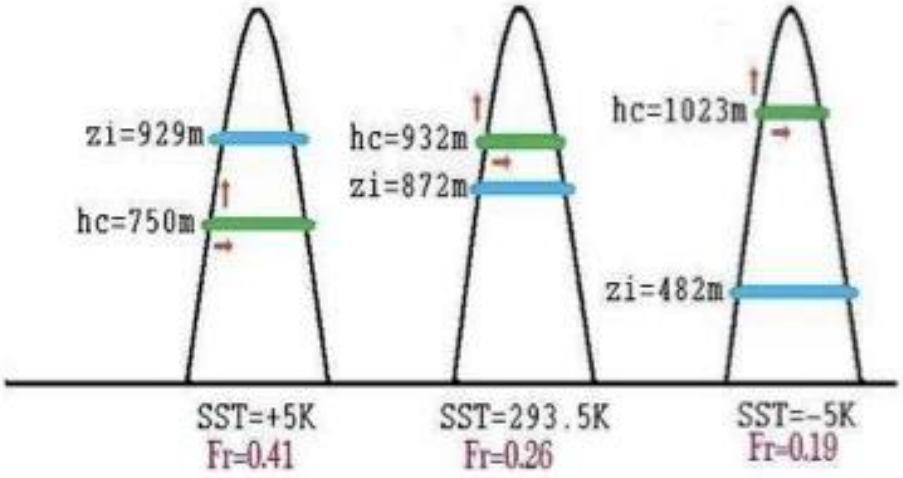




Etling, 1989



$$h_c = H(1 - Fr) \qquad Fr = \frac{U}{NH}$$



Wake Response to an Ocean-Feedback Mechanism: Madeira Island Case Study

Rui M. A. Caldeira & Ricardo Tomé

Boundary-Layer Meteorology
An International Journal of Physical, Chemical and Biological Processes in the Atmospheric Boundary Layer

ISSN 0006-8314
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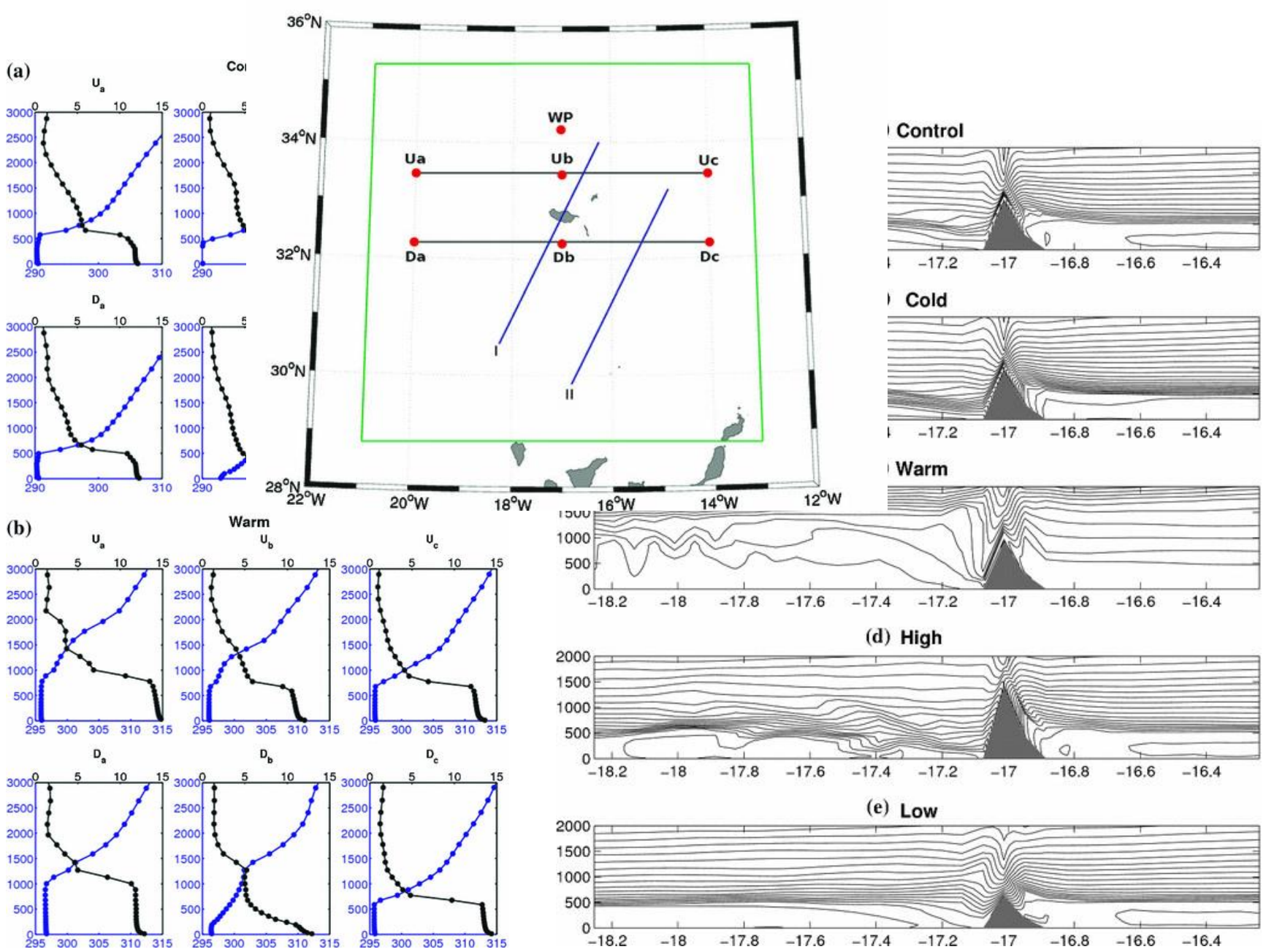
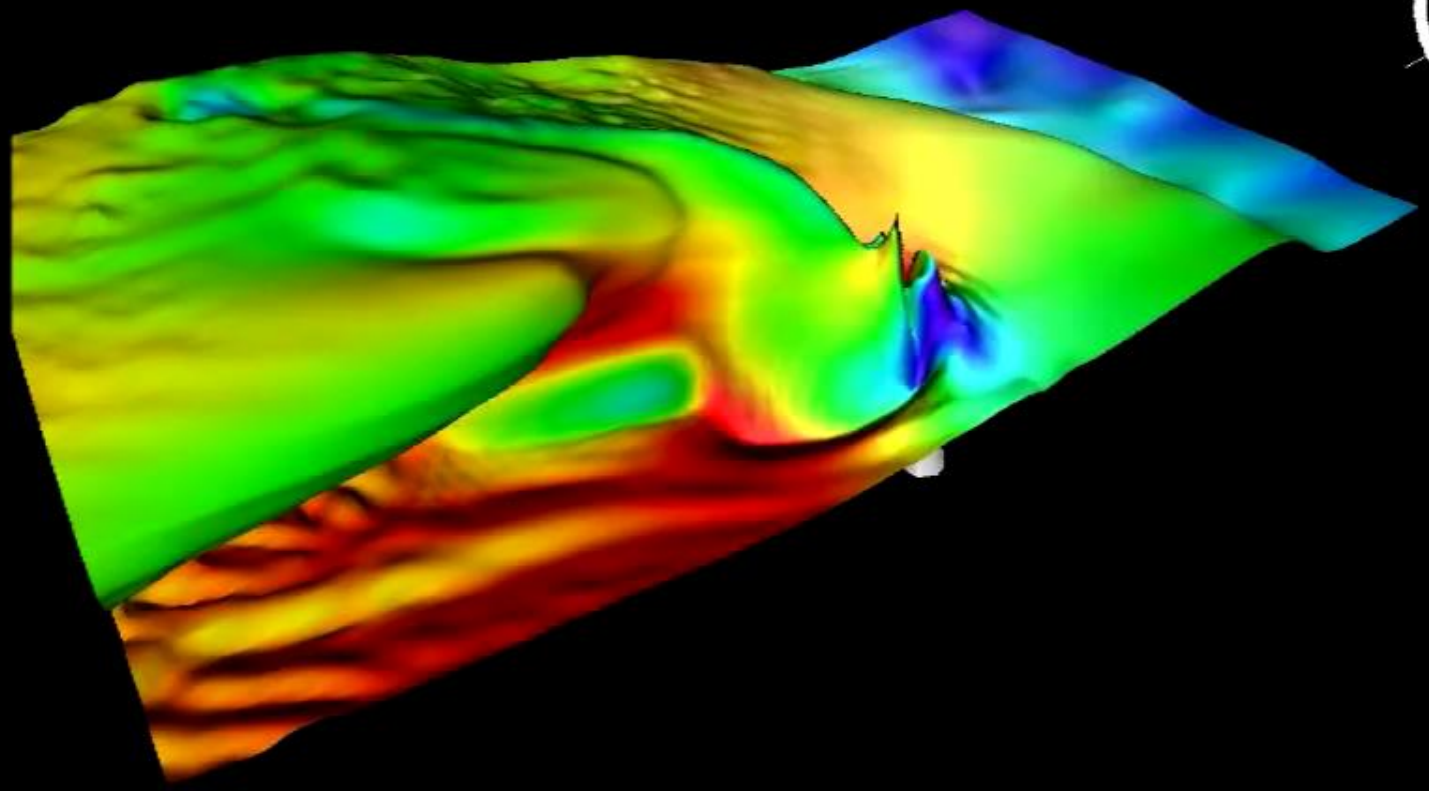
Number 2

Boundary-Layer Meteorol (2013)
148:419-436
DOI 10.1007/s10546-013-9817-y

Springer


(a)
Co
U_a
D_a
(b)
Warm
U_a
U_b
U_c
D_a
D_b
D_c
36°N
34°N
32°N
30°N
28°N
22°W
20°W
18°W
16°W
14°W
12°W
WP
Ua
Ub
Uc
Da
Db
Dc
I
II
Control
Cold
Warm
(d) High
(e) Low



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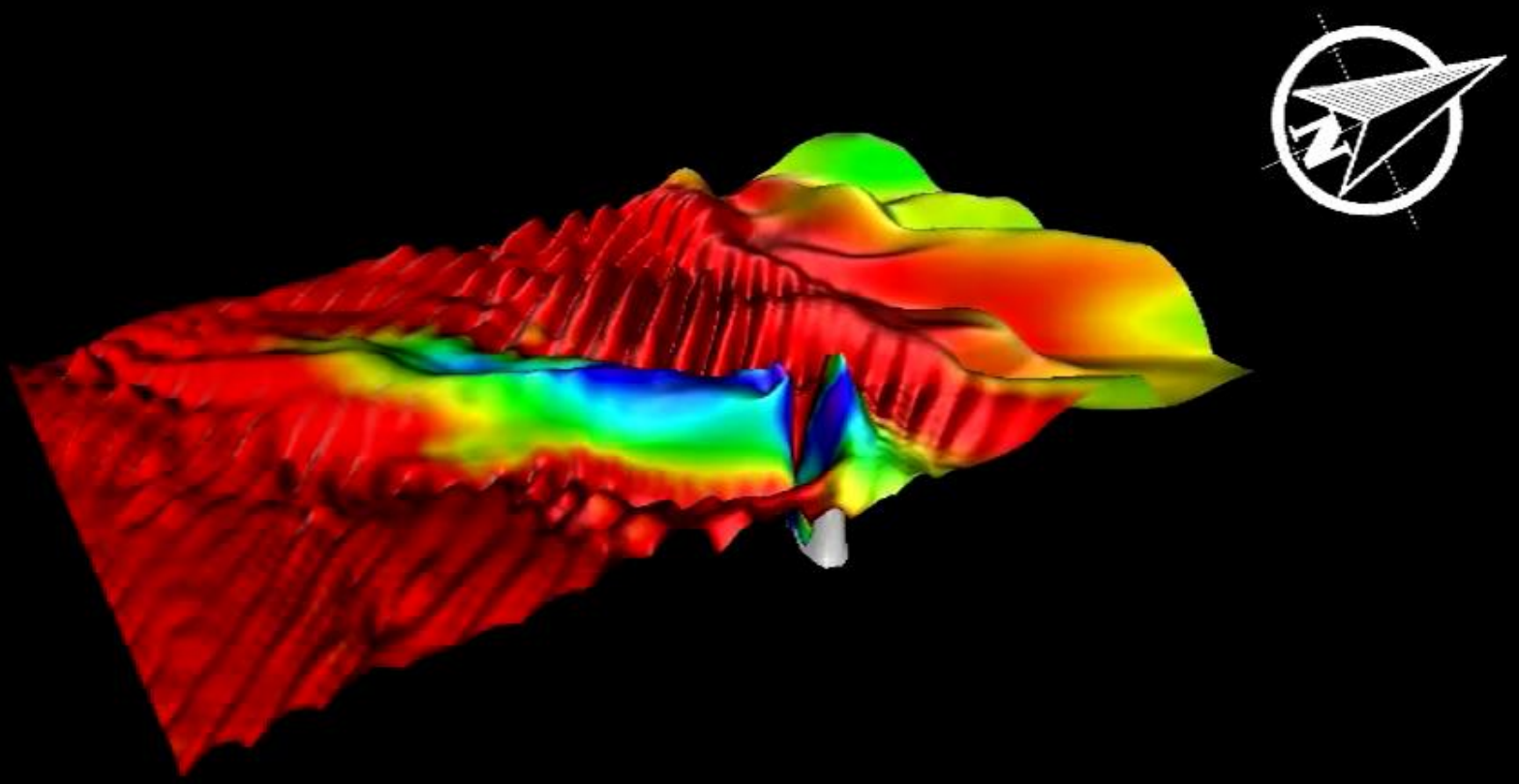
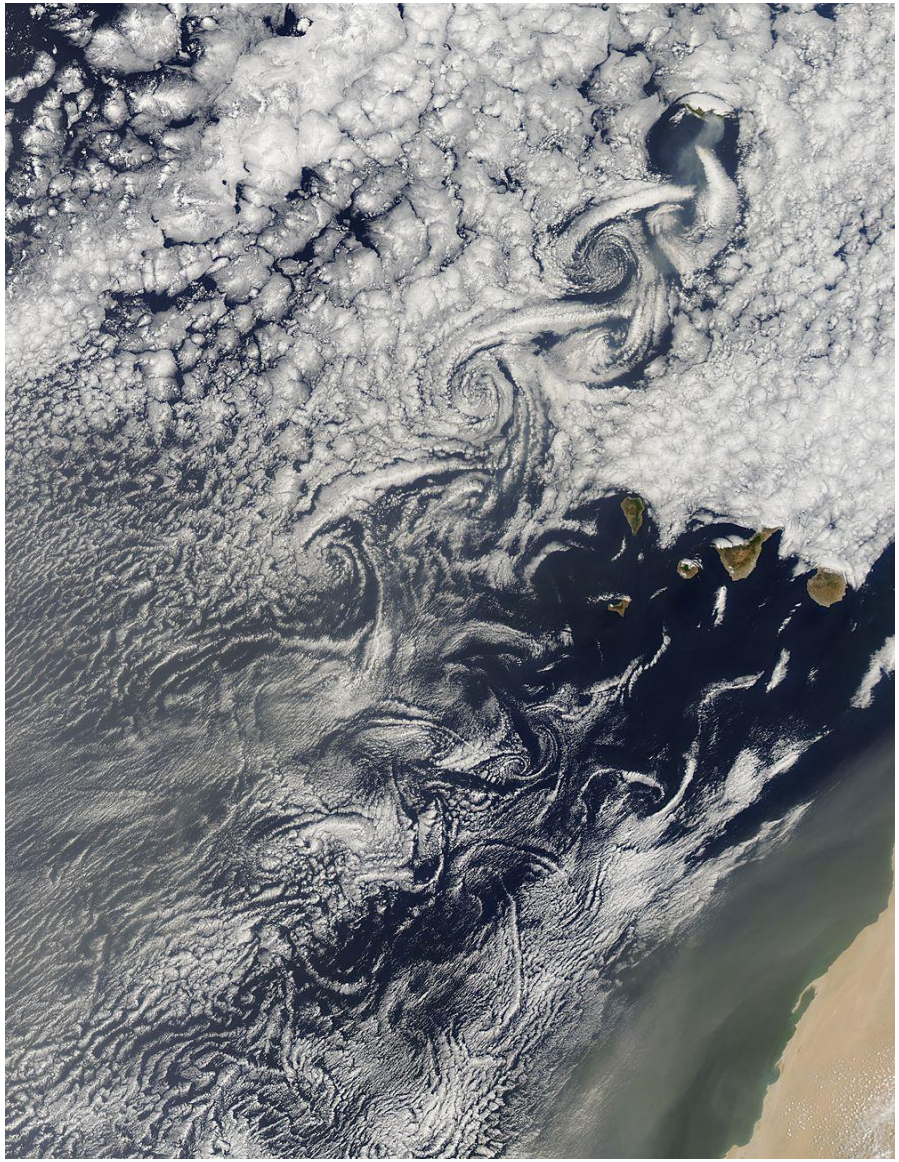

Date/Time: 2002-07-04_23:00:00

EUFAR: i-WAKE

European Facility for Airborne Research



Atmospheric Wake of Madeira: First Aerial Observations and Numerical Simulations

VANDA GRUBIŠIĆ*

National Center for Atmospheric Research,+ Boulder, Colorado

JOHANNES SACHSPERGER

Department of Meteorology and Geophysics, University of Vienna, Vienna, Austria

RUI M. A. CALDEIRA

Interdisciplinary Center of Marine and Environmental Research (CIIMAR), and Center for Mathematical Sciences (CCM), University of Madeira, Funchal, Madeira, Portugal

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ABSTRACT

The island of Madeira is well known for giving rise to atmospheric wakes. Strong and unsteady atmospheric wakes, resembling a von Kármán vortex street, are frequently observed in satellite images leeward of Madeira, especially during summer months, when conditions favoring the formation of atmospheric wakes occur frequently under the influence of the Azores high.

Reported here is the analysis of the first airborne measurements of Madeira's wake collected during the 2010 Island-induced Wake (I-WAKE) campaign. High-resolution in situ and remote sensing data were collected in the I-WAKE by a research aircraft. The measurements reveal distinctive wake signatures, including strong lateral wind shear zones and warm and dry eddies downwind of the island. A strong anticorrelation of the horizontal wind speed and sea surface temperature (SST) was found within the wake.

High-resolution numerical simulations with the Weather Research and Forecasting (WRF) Model were used to study the dynamics of the wake generation and its temporal evolution. The comparison of the model results and observations reveals a remarkable fidelity of the simulated wake features within the marine boundary layer (MBL). Strong potential vorticity (PV) anomalies were found in the simulated MBL wake, emanating from the flanks of the island. The response of the wake formation within the MBL to surface friction and enhanced thermal forcing is explored through the model sensitivity analyses.

1. Introduction

Atmospheric wakes leeward of isolated mountainous islands represent a zone of momentum deficit in stratified flow past isolated obstacles. The wakes are expected to be most distinctive in regions of sustained unidirectional winds in the presence of a strong marine boundary layer (MBL) inversion, lying at or below the mountain-top height. Such conditions prevail during summer months in the subtropical eastern Atlantic and provide key ingredients for the formation of atmospheric wakes generated by both the island of Madeira and the Canary Islands (Chopra and Hubert 1965; Zimmermann 1969). Madeira's wake was among the first to be identified in satellite imagery and documented in scientific literature (e.g., Hubert and Krueger 1962; Scorer 1986) owing to cloud formations within the subtropical stratus cover making the mesoscale flow structures within the wake easily identifiable (Fig. 1).

The first in situ observations within an atmospheric wake were collected during an airborne field campaign

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* Additional affiliation: Department of Meteorology and Geophysics, University of Vienna, Vienna, Austria.

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Corresponding author address: Vanda Grubišić, EOL, NCAR, P.O. Box 3000, Boulder, CO 80307.
E-mail: grubisic@ucar.edu

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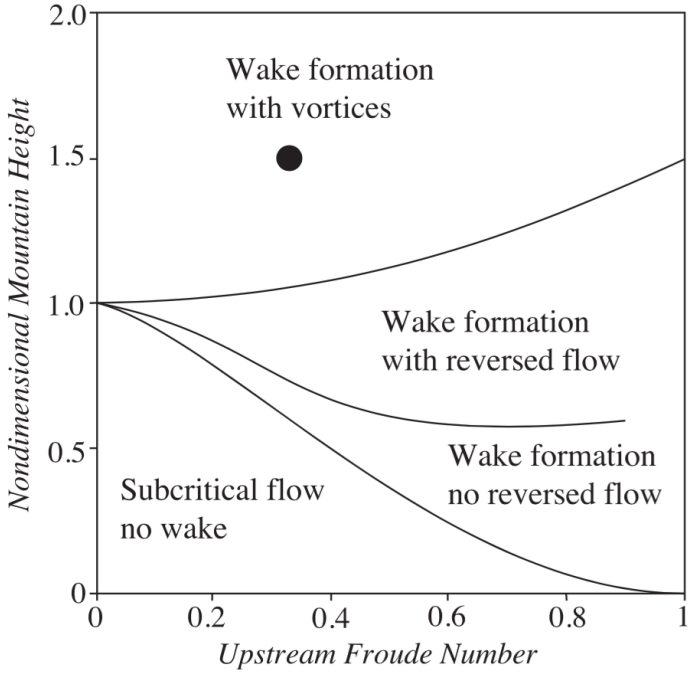
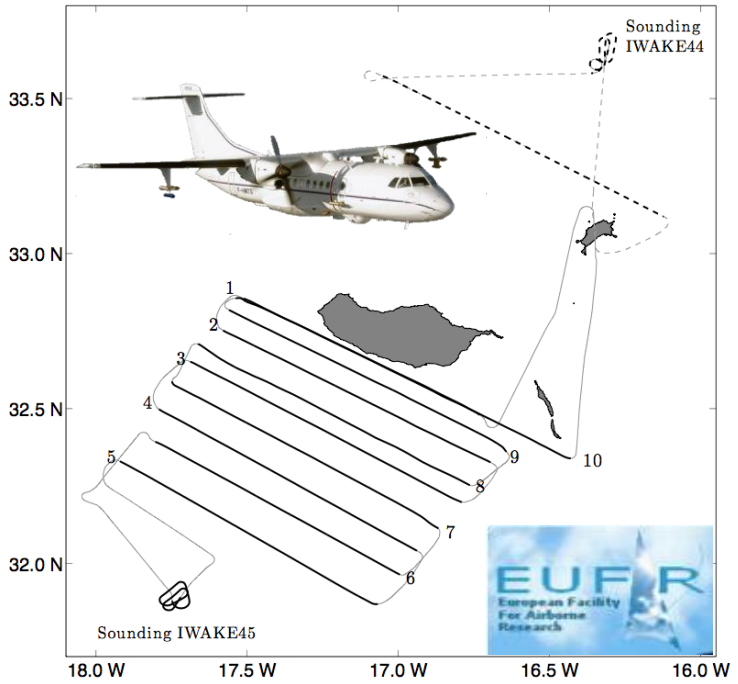
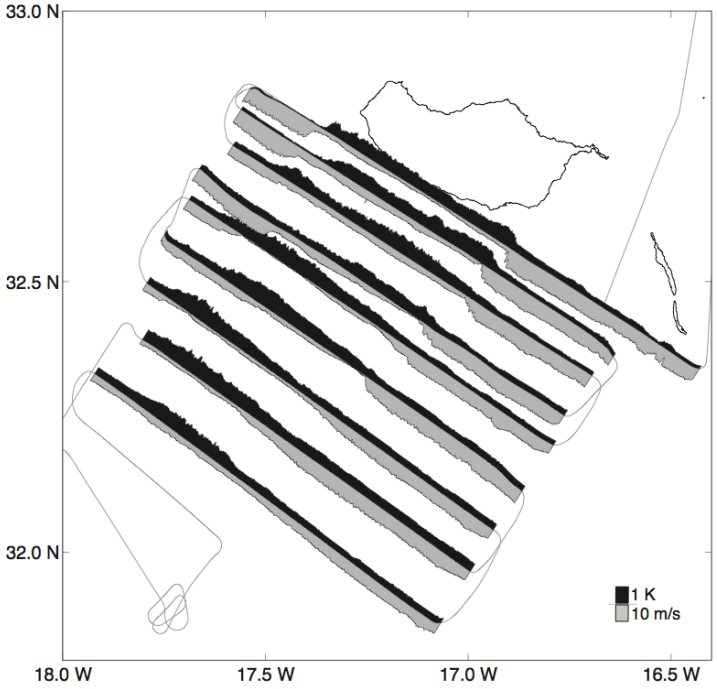
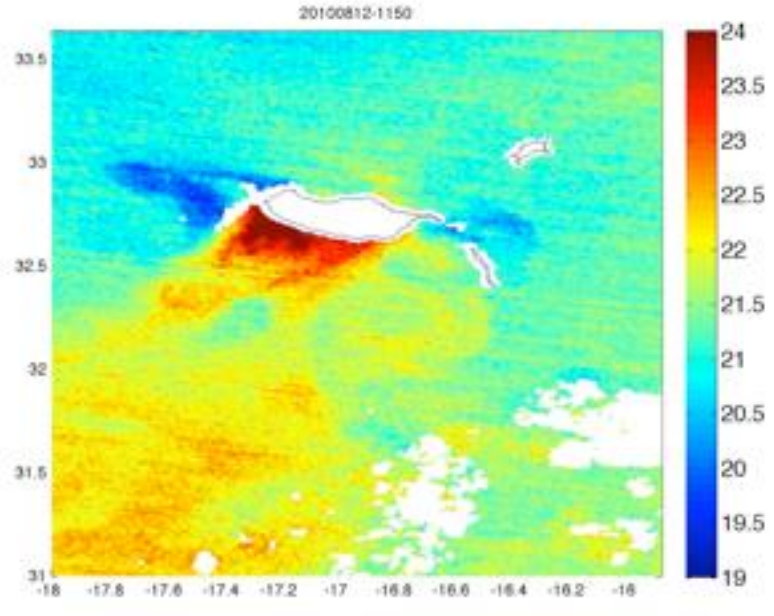
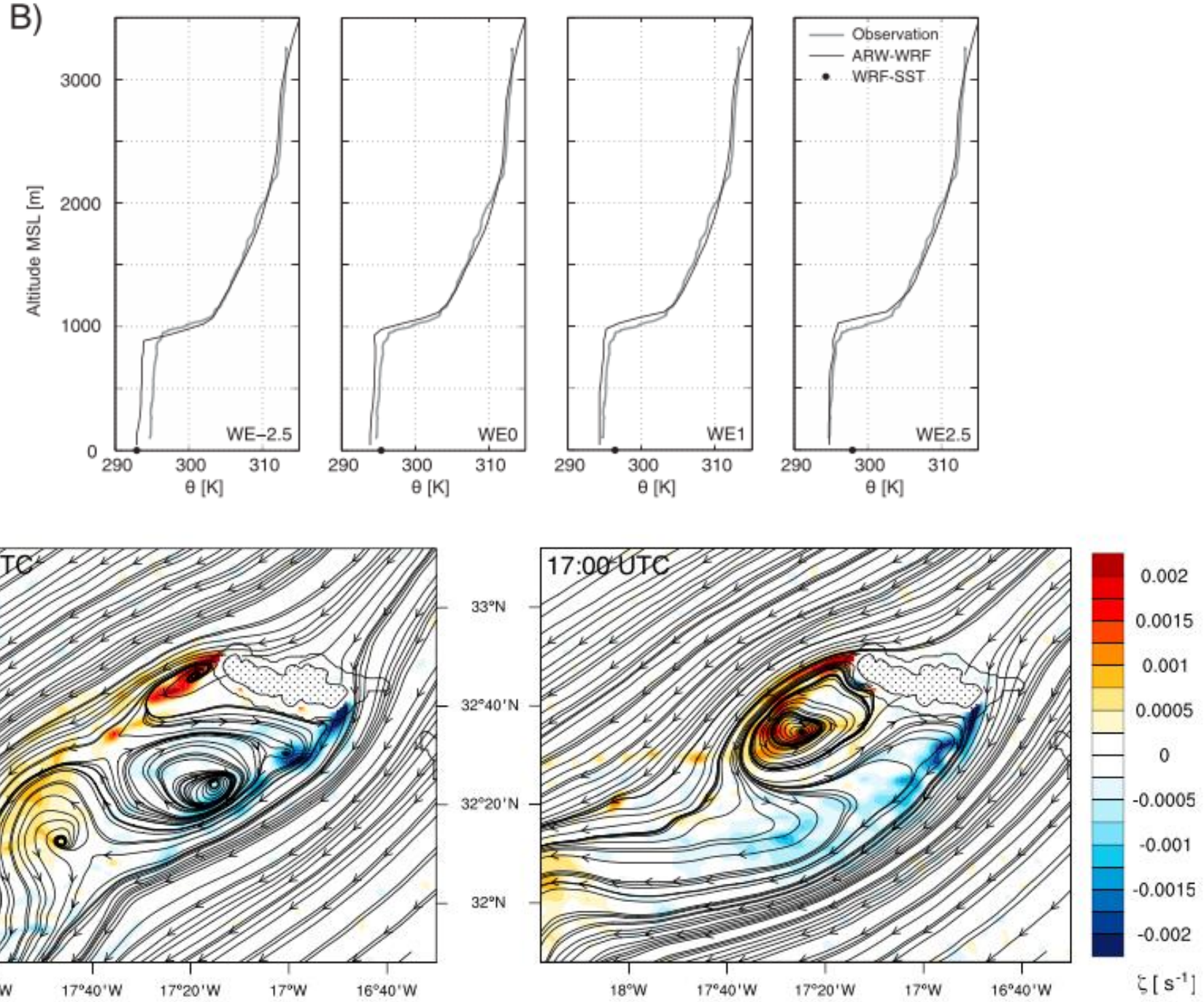
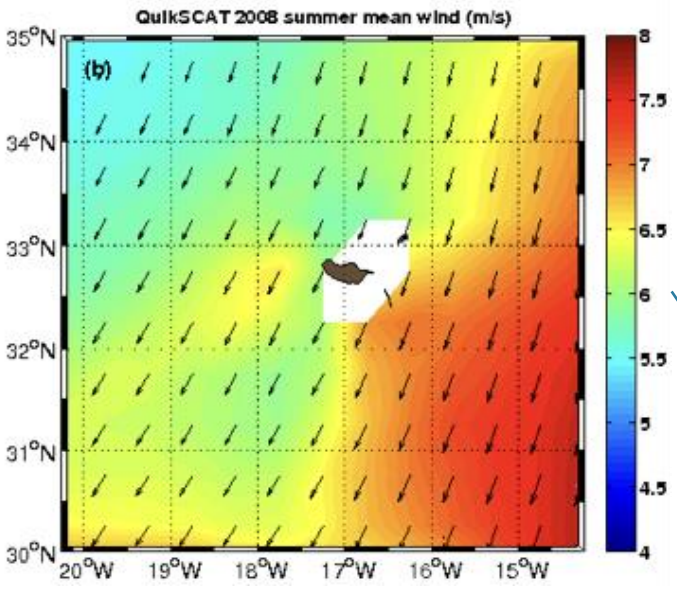

Wake formation
with vortices
Wake formation
with reversed flow
Wake formation
no reversed flow
Subcritical flow
no wake
Nondimensional Mountain Height
Upstream Froude Number
2.0
1.5
1.0
0.5
0
0
0.2
0.4
0.6
0.8
1


Sounding
IWAKE44
Sounding IWAKE45
33.5 N
33.0 N
32.5 N
32.0 N
18.0 W
17.5 W
17.0 W
16.5 W
16.0 W
1
2
3
4
5
6
7
8
9
10
EUFAR
European Facility
For Airborne
Research

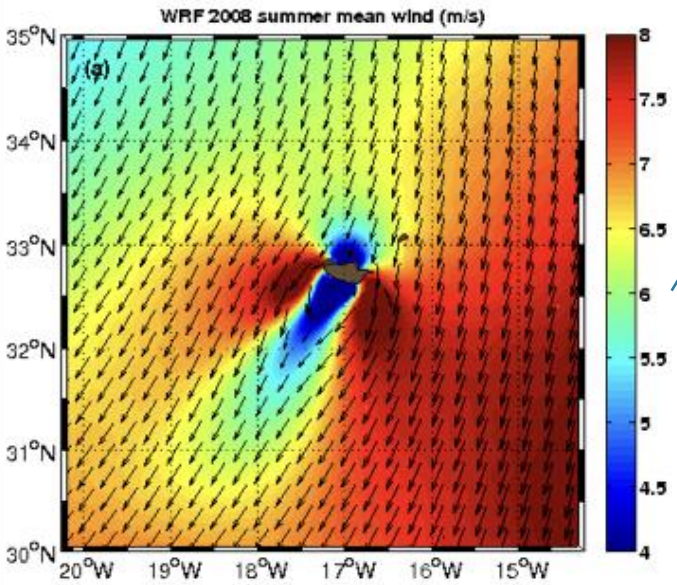

33.0 N
32.5 N
32.0 N
18.0 W
17.5 W
17.0 W
16.5 W
1 K
10 m/s


20100812-1150
33.5
33
32.5
32
31.5
31
-18
-17.8
-17.6
-17.4
-17.2
-17
-16.8
-16.6
-16.4
-16.2
-16
24
23.5
23
22.5
22
21.5
21
20.5
20
19.5
19


B)
Observation
ARW-WRF
WRF-SST
Altitude MSL [m]
0
1000
2000
3000
290
300
310
θ [K]
WE−2.5
WE0
WE1
WE2.5
14:00 UTC
17:00 UTC
33°N
32°40'N
32°20'N
32°N
18°W
17°40'W
17°20'W
17°W
16°40'W
0.002
0.0015
0.001
0.0005
0
-0.0005
-0.001
-0.0015
-0.002
ζ [s-1]



ROMS



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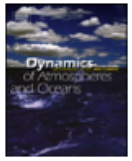

Wind mediated vorticity-generation and eddy-confinement, leeward of the Madeira Island: 2008 numerical case study

X. Couvelard [a,*], R.M.A. Caldeira [b,a], I.B. Araújo [b], R. Tomé [c,d]

[a] CCM - Center for Mathematical Sciences, Universidade da Madeira, Portugal
[b] CIIMAR/UP - Interdisciplinary Centre of Marine and Environmental Research, University of Porto, Portugal
[c] CCMMG, University of Azores, Portugal
[d] IDL, Lisbon University, Portugal

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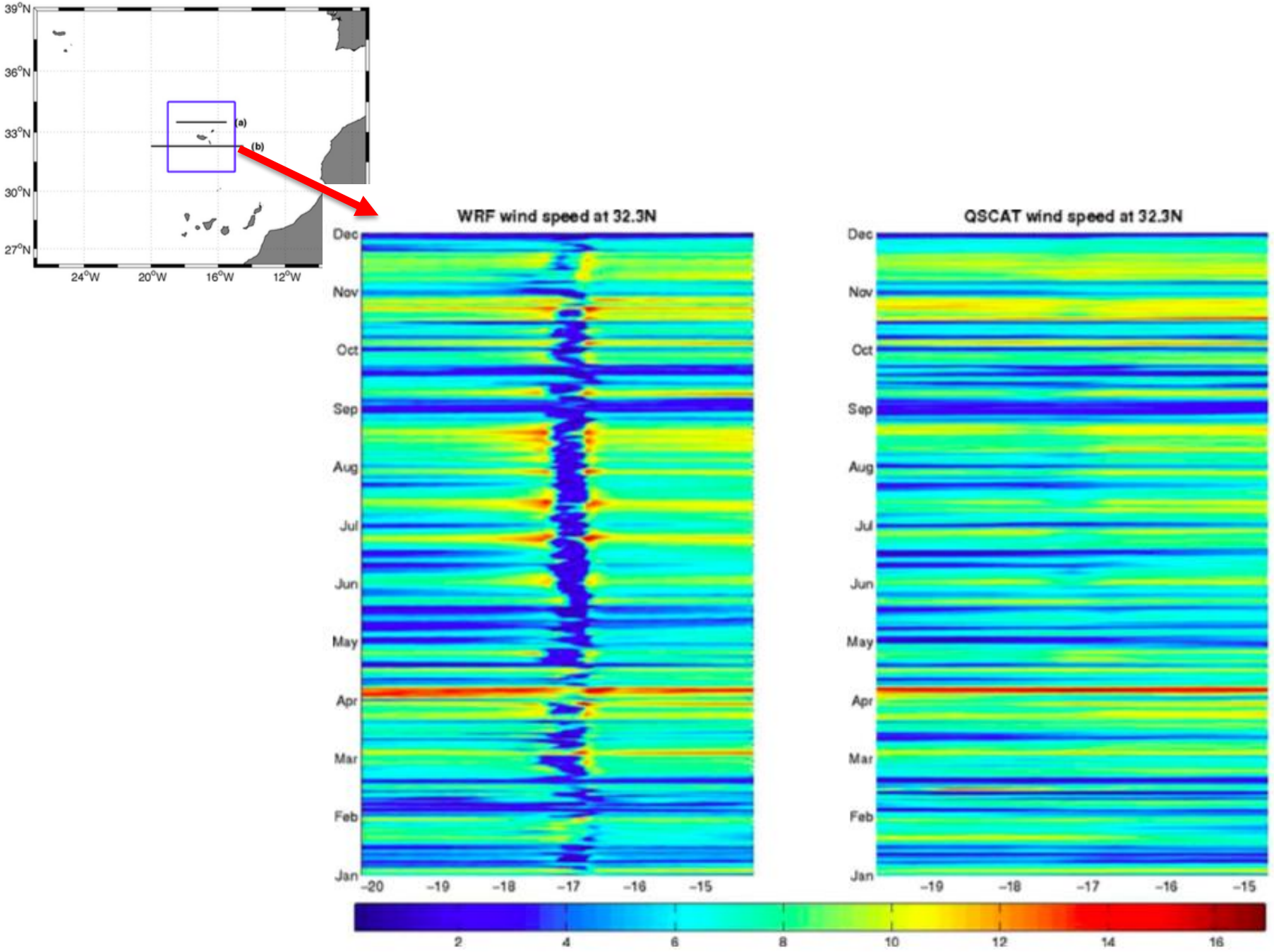
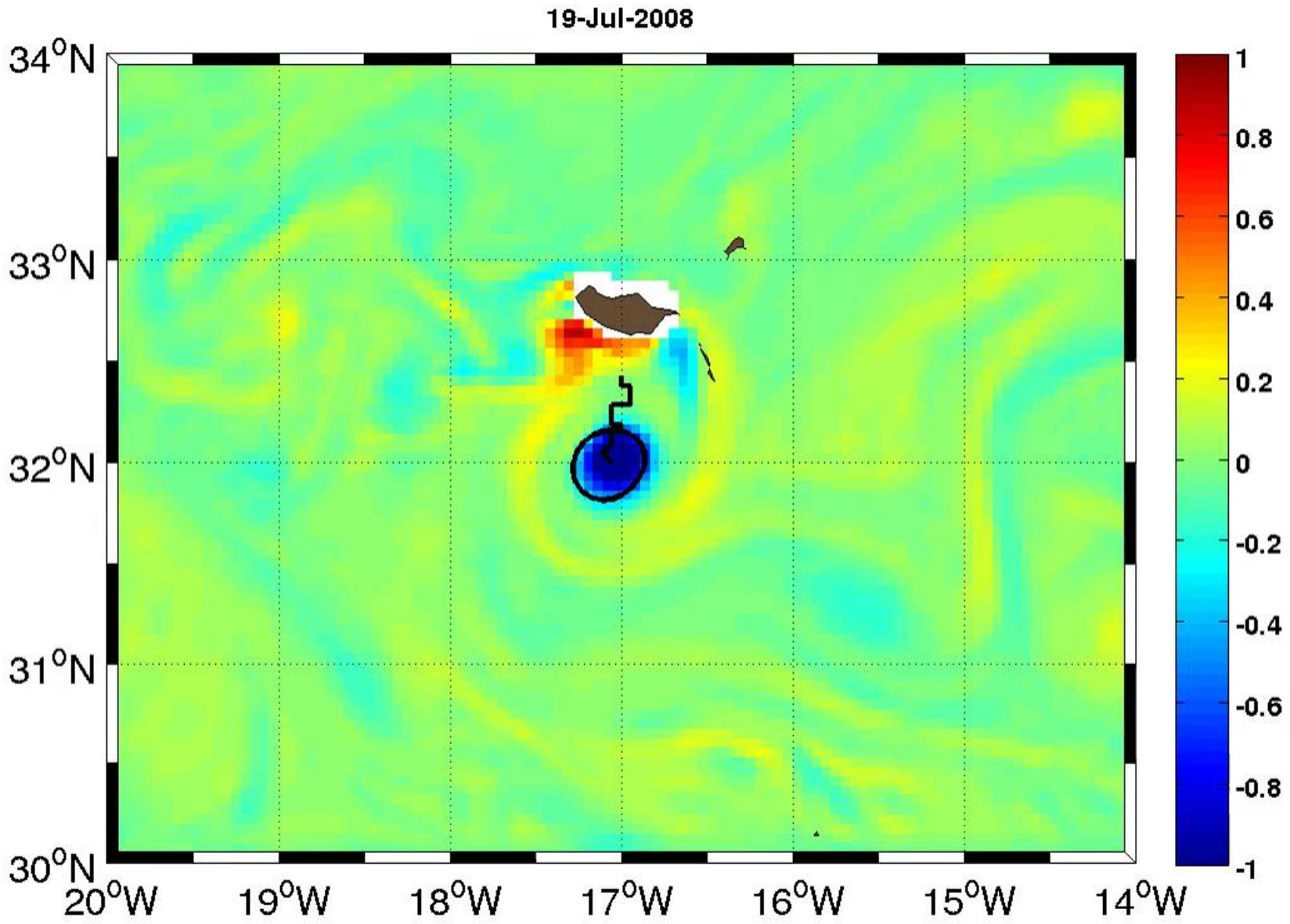
Oceanic wake
Eddy containment
Madeira Island

ABSTRACT

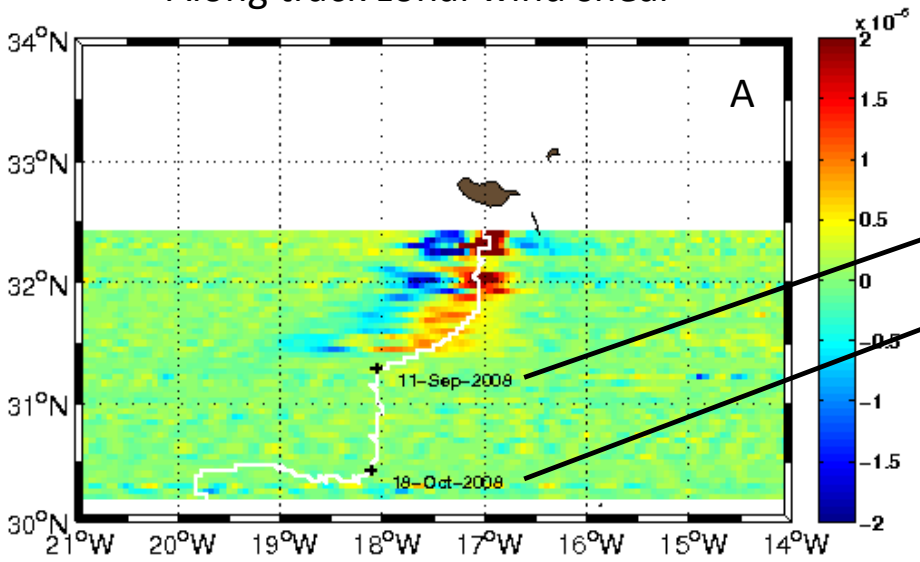
This study assesses the influence of the atmospheric wind-wake of the Madeira Island on oceanic-eddy generation. Ocean surface wind fields derived from the QuikSCAT scatterometer were compared to the Weather Research and Forecast (WRF) modeled winds at 6 km resolution. The main difference between the two wind products is found southwest of Madeira where QuikSCAT's spatial resolution [0.5°] does not resolve the near-field atmospheric wake dynamics. Nevertheless, high resolution wind extracted from ENVISAT Advanced Synthetic Aperture Radar (ASAR) confirms that WRF is able to realistically reproduce the island-induced wind-wake. The Regional Oceanic Modeling System (ROMS) was used to simulate the oceanic effects of the wind-wake. A "no-wind-wake" case was simulated with ROMS using the QuikSCAT wind, whereas the WRF wind was used for an island-induced wind-wake simulation. Oceanic surface kinetic energy and vorticity are found to increase during the summer months concurrently with strong wind-wake episodes resolved by WRF. The downstream propagation of this oceanic vorticity, as a result of the shedding of the leeward eddies, was captured with an eddy tracking algorithm. In the initial stage, the oceanic leeward eddy corridor was delimited by the zonal wind-shear. This study suggests that the wind-wake is the main contributor to the generation and containment of the oceanic eddies in the lee of the Madeira Island.

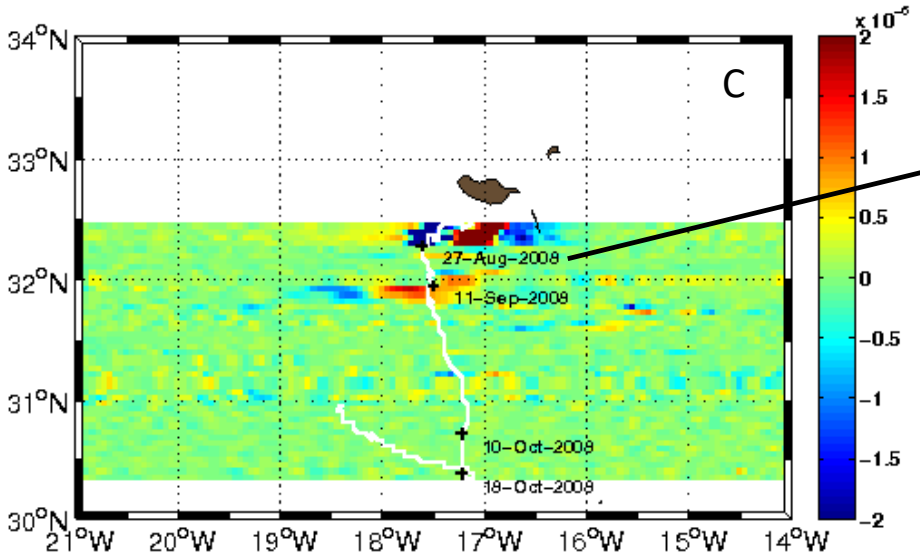

39°N
36°N
33°N
30°N
27°N
24°W
20°W
16°W
12°W
(a)
(b)
WRF wind speed at 32.3N
QSCAT wind speed at 32.3N
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
−20
−19
−18
−17
−16
−15
2
4
6
8
10
12
14
16


19-Jul-2008
34°N
33°N
32°N
31°N
30°N
20°W
19°W
18°W
17°W
16°W
15°W
14°W
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

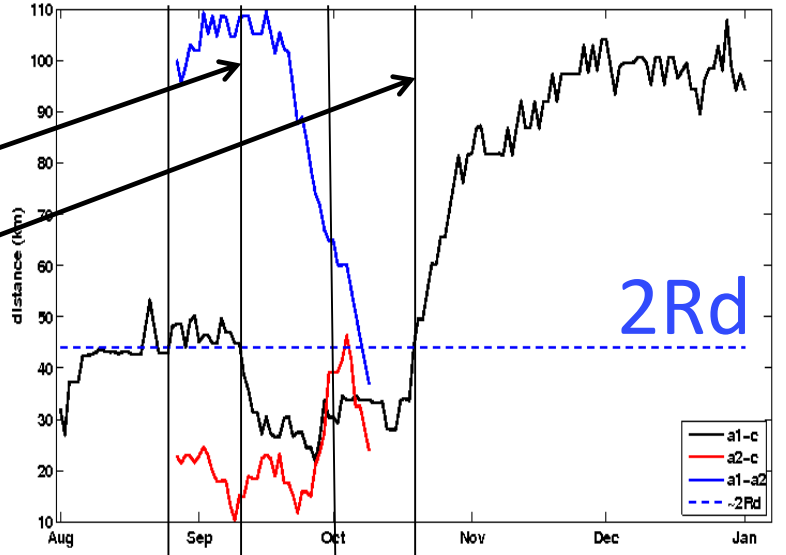
Wind-induced oceanic eddy-confinement

Along track zonal wind shear

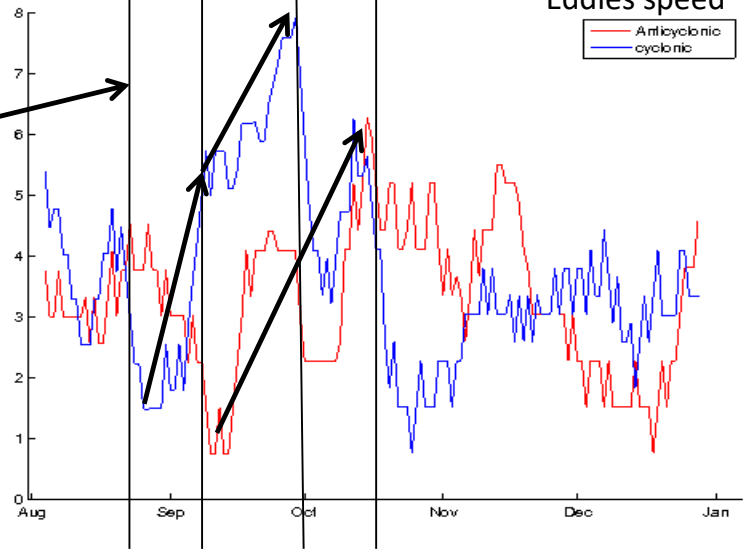


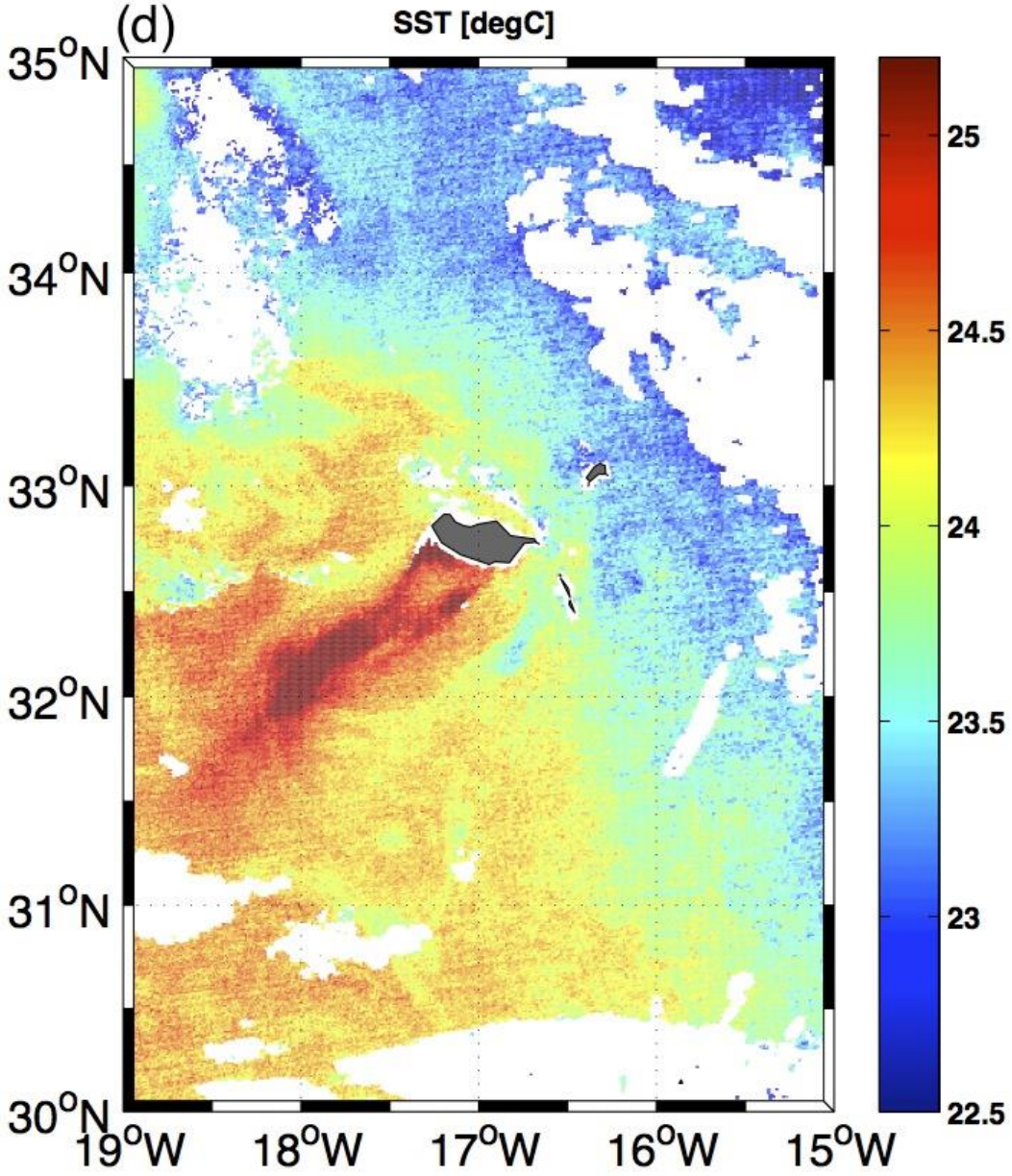


Eddy-eddy distance



Eddies speed





AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2013JC009493

Key Points:
- First sampling of a mesoscale anticyclone lee of Madeira
- Wind forced and long-term residence time
- Intrathermocline eddy which might contribute to the Madeira MODE water

Correspondence to:
R. M. A. Caldeira,
rui.caldeira@ciimarmadeira.org

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Evolution of an oceanic anticyclone in the lee of Madeira Island: In situ and remote sensing survey

Rui M. A. Caldeira[1,2], Alexandre Stegner[3,4], Xavier Couvelard[2,5], Isabel B. Araújo[1], Pierre Testor[6], and Alvaro Lorenzo[7]

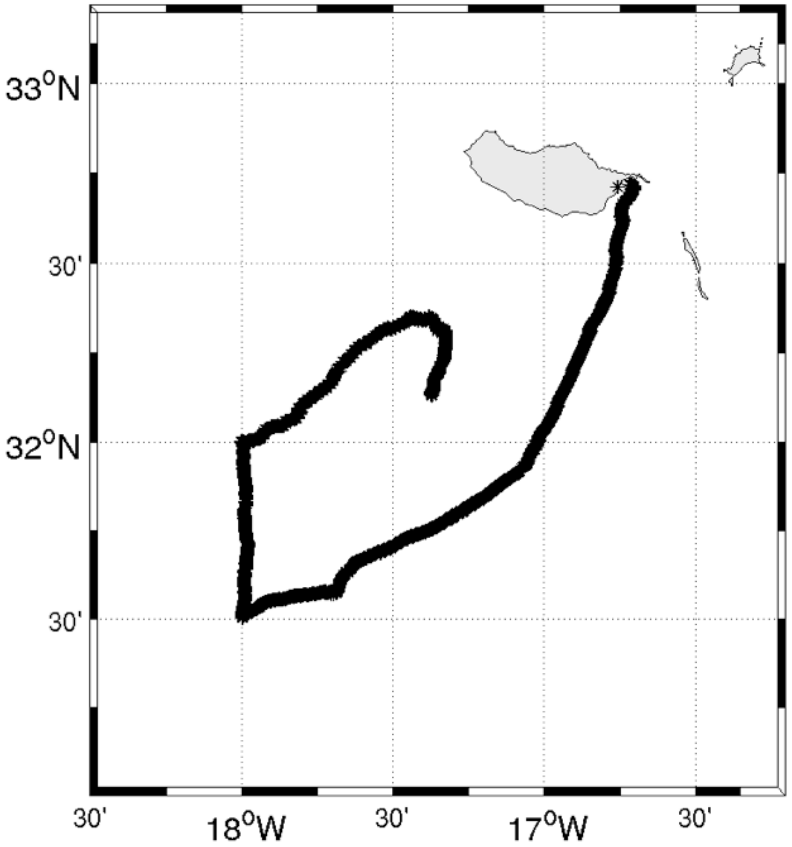
[1]CIIMAR-Interdisciplinary Centre of Marine and Environmental Research, University of Porto, Porto, Portugal, [2]CCM-Center for Mathematical Sciences, University of Madeira, Funchal, Portugal, [3]Laboratoire de Météorologie Dynamique, École Polytechnique, Palaiseau, Paris, France, [4]UME, ENSTA Centre de l'Yvette, Chemin de la Huniere, Palaiseau, Paris, France, [5]Laboratoire de Physique des Océans, Plouzané, France, [6]LOCEAN-IPSL, Laboratoire d'Oceanographie et du Climat, Université Pierre and Marie Curie, Paris, France, [7]PLOCAN-Plataforma Oceánica de Canarias, Las Palmas, Canary Islands, Spain

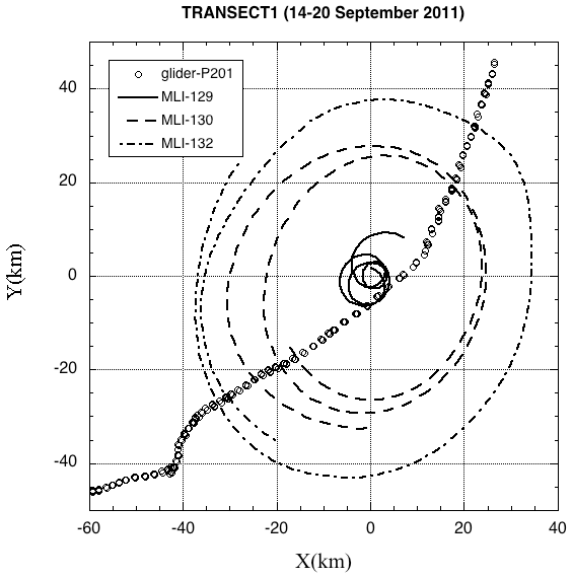
Abstract Island wakes are areas of a strong eddy activity influencing the availability and transport of organic matter in the ocean which, in turn impact biological productivity. Despite this, eddy formation in the lee of North Atlantic tropical islands is scarcely documented, except for the Canary Islands. Moreover, the occurrence of anticyclones leeward of Madeira has seldom been detected. During the summer of 2011, a multiplatform approach, combining satellite data with in situ measurements, was used to study an anticyclonic eddy generated in the lee of the Madeira Island. The main objective was to confirm recent numerical evidence suggesting that orographically perturbed winds can induce anticyclonic eddies leeward of Madeira, particularly during summer months. The high resolution sampling of the eddy's interior shows a strong downwelling of ≈100 m of the isopycnal layer below the mixed layer, typical of intrathermocline eddies. The 25 km radius of this anticyclonic structure exceeds the local deformation radius by a factor of 2. The vortex Rossby number remained moderate (Ro = 0.26) even if the relative core vorticity reached a finite value ($\zeta/f = -0.7$). The occurrence of strong trade winds (10–15 m s^{-1}) prior to the detection of the first surface eddy signatures (July 2011) concurrent with opposite flowing geostrophic currents, shows that the orographic wind forcing is the main mechanism for generating this mesoscale long-lived eddy. After leaving the shelter of the island, the eddy traveled northwesterly following a perpendicular net Ekman transport pathway at a speed of 5 km/d, for at least 2 months. An interaction with a cyclonic partner generated in the area helped precipitate the northward trajectory. This study presents the first clear evidence of a wind-induced mesoscale anticyclone in the lee of Madeira.

1. Introduction

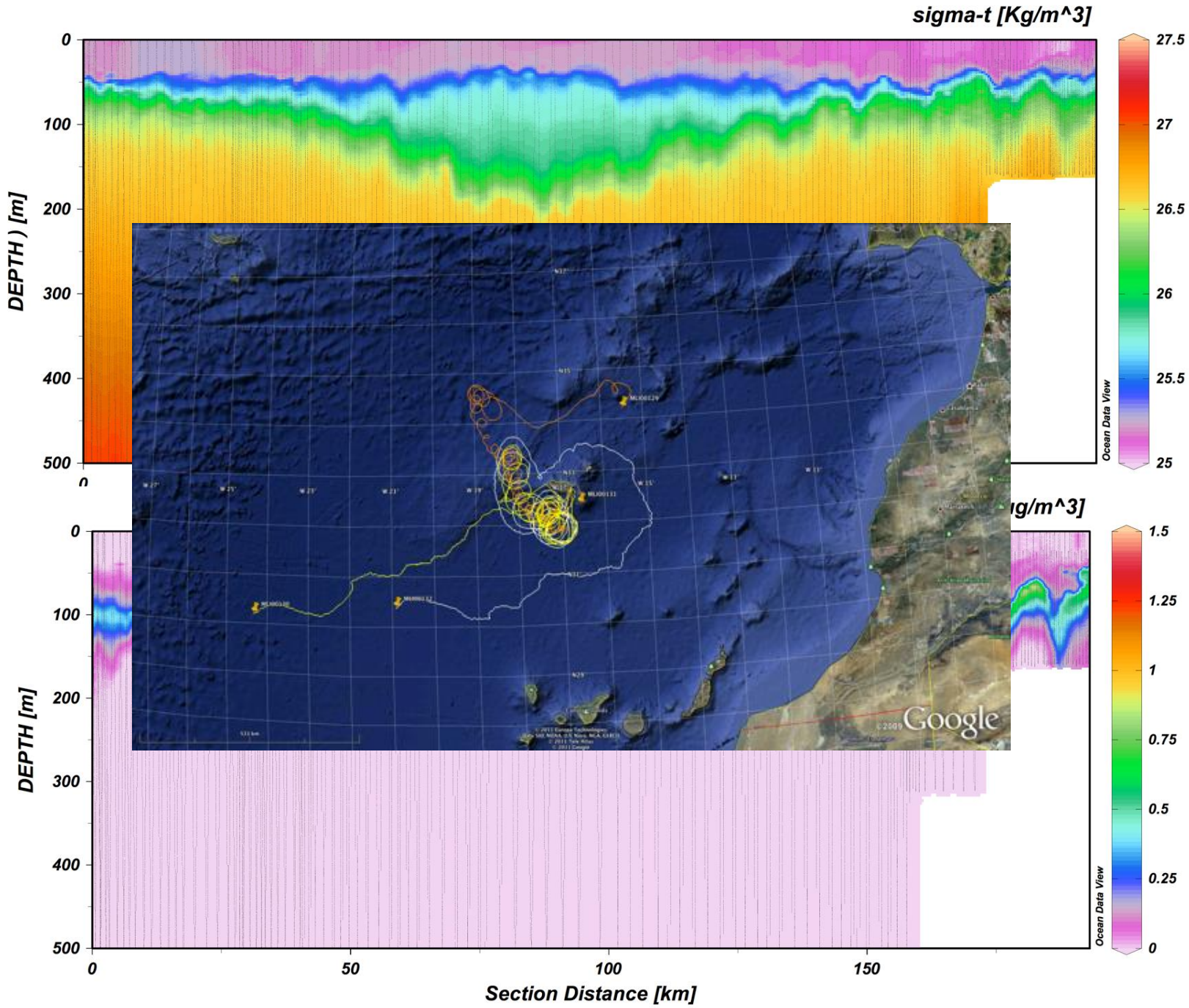
Island wakes are the location of a strong eddy activity, which have important biological consequences to the formation and transport of organic matter. Cyclonic vortices bring nutrients from deeper-layers into the euphotic zone, promoting biological growth [*Hasegawa*, 2004; *Hasegawa et al.*, 2009], whereas anticyclones are known to concentrate and transport biological matter in the upper thermocline over long distances [*Mackas and Galbraith*, 2002; *Ladd et al.*, 2009; *Jia et al.*, 2011]. Thus, cyclonic eddies have a cold core of upwelled water at the surface while anticyclonic vortices are characterized by a warm surface signature [*Aristegui et al.*, 1994; *Caldeira et al.*, 2002; *Caldeira and Marchesiello*, 2002]. Both cyclonic and anticyclonic eddies can be detected by altimetry data. However, due to its coarser resolution (1/3°) the vortex detection from sea surface height anomalies are restricted to large mesoscale eddies. Higher resolution is available on thermal sensors (up to 250 m for MODIS) but due to intense solar radiation and clear skies a warm wake is omnipresent during the summer months leeward of subtropical islands such as Madeira and Canaries. This phenomena could mask the high Sea Surface Temperature (SST) signature characteristic of anticyclonic eddies [*Caldeira et al.*, 2002]. Hence, the remote sensing detection of warm anticyclones in the near wake is probably less efficient than in the open ocean. Therefore, in order to fully characterize island wake eddies it is necessary to perform a multiplatform survey, combining satellite products with in situ measurements supplemented by numerical and laboratory studies.

Several studies have sampled cyclones and anticyclones forming leeward of islands and archipelagos located in the deep ocean [*Sangrà*, 2005; *Sangrà et al.*, 2007; *Hasegawa*, 2004; *Chavanne et al.*, 2010; *Jia et al.*, 2011].



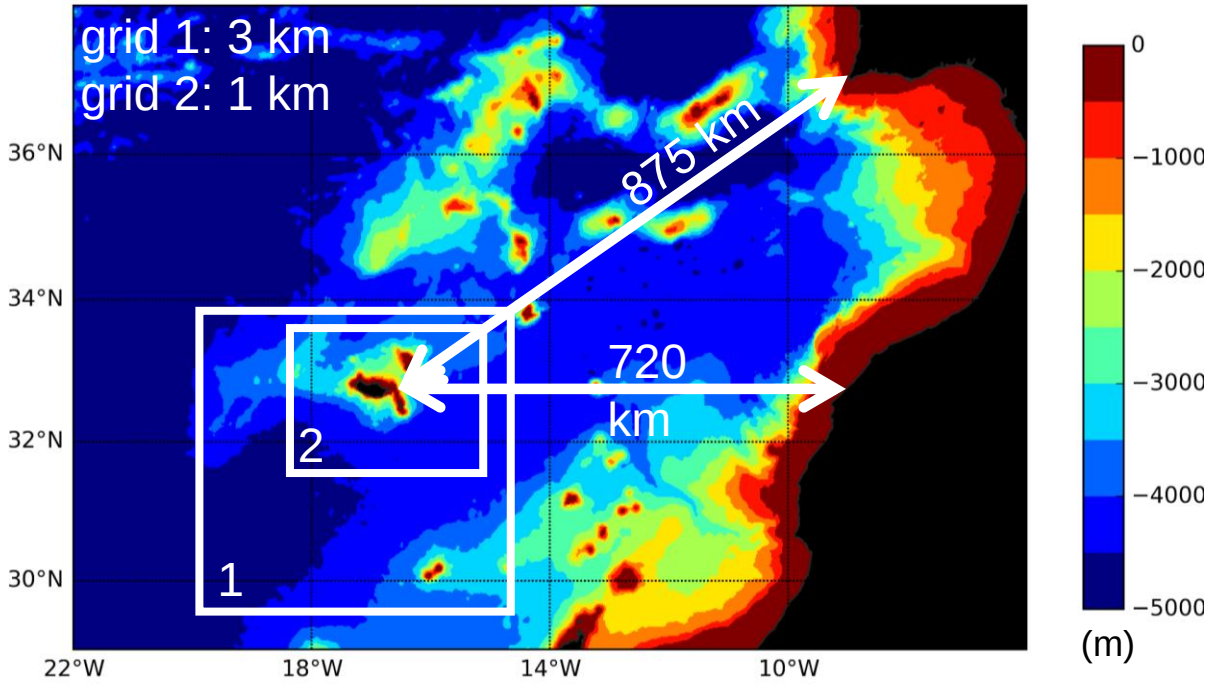


Slocum G2 W/ ADCP


sigma-t [Kg/m^3]
DEPTH) [m]
0
100
200
300
400
500
27.5
27
26.5
26
25.5
25
Ocean Data View
Google
DEPTH [m]
1.5
1.25
1
0.75
0.5
0.25
0
0
50
100
150
Section Distance [km]

ONGOING / FUTURE WORK

Coupled Model (WRF⇔ROMS => COAWST)



WRF options

cloud microphysics:
WRF Single-Moment 3-class scheme
longwave radiation:
Rapid Radiative Transfer Model
shortwave radiation:
Dudhia scheme
surface layer:
Eta similarity scheme
planetary boundary layer:
Mellor-Yamada-Janjic scheme

- WRF - SRTM a 3” (~90m)
- CORINE land cover

- ROMS - GEBCO a 30”
- Tides

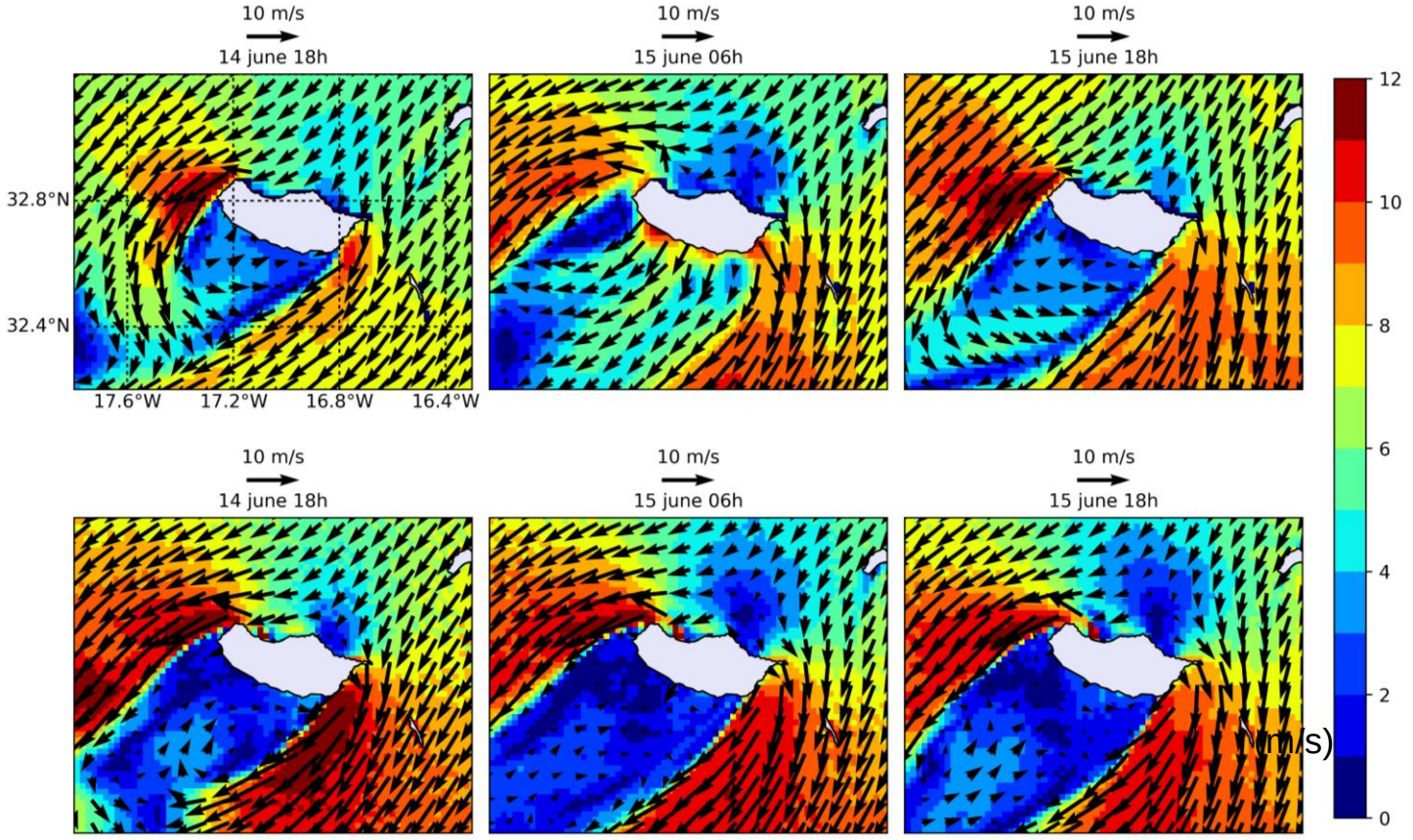
Initial and boundary conditions
WRF – GFS (1°)
ROMS – HYCOM (1/12°)

COAMPS Vs COAWST

surface wind

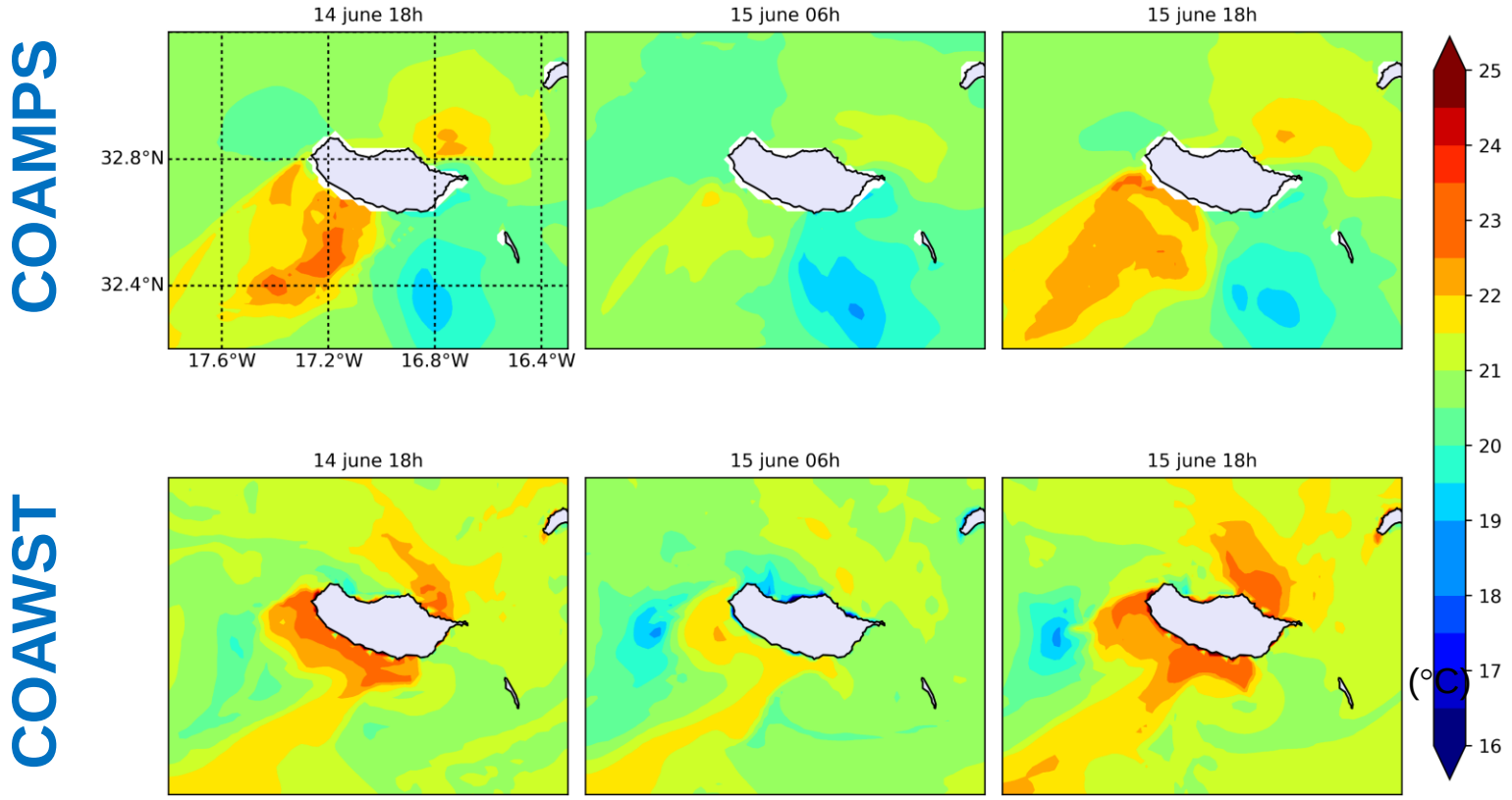
COAMPS 2 km

COAWST 1 km



COAMPS Vs COAWST

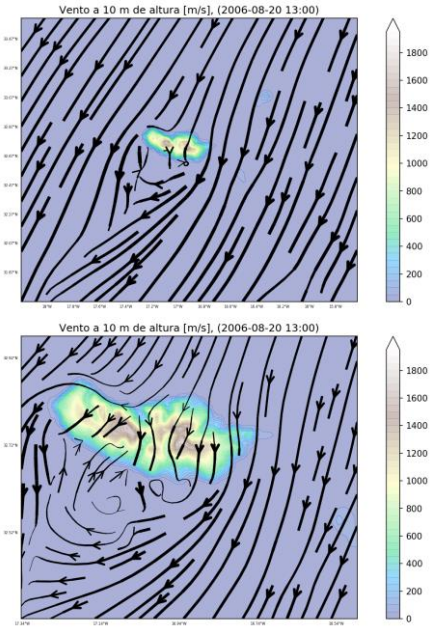
SST



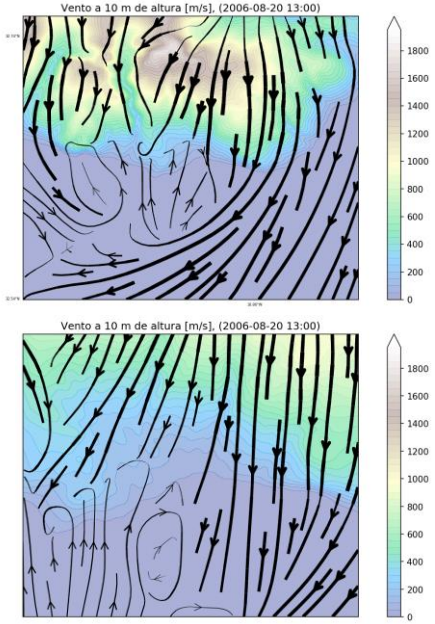
Coastal – Urban Impacts

Mountain ⇔ Sea breezes

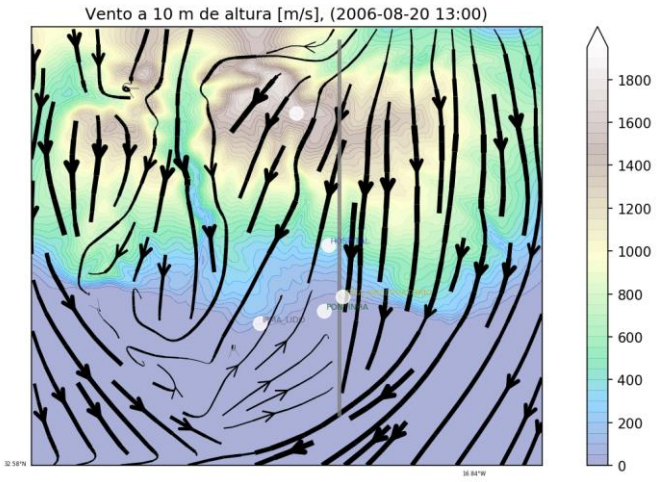
Mesoscale



WRF-LES Setup 1 (300M)



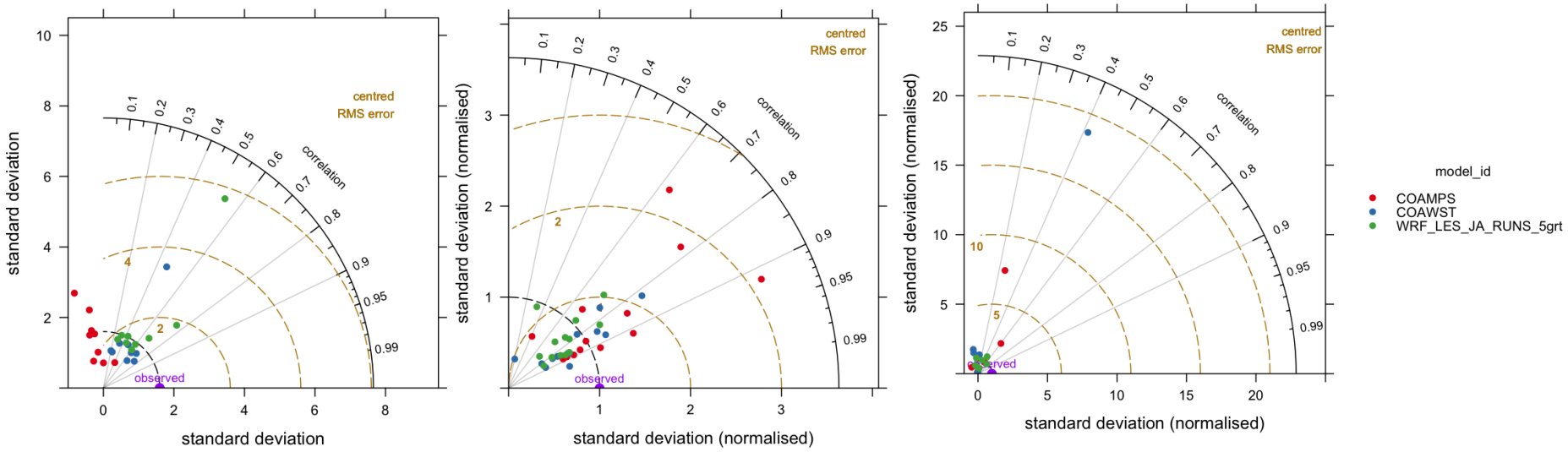
WRF-LES Setup 2 (100M)



2006-08-20 (CFSv2 => WRF)

Inter-model Statistics

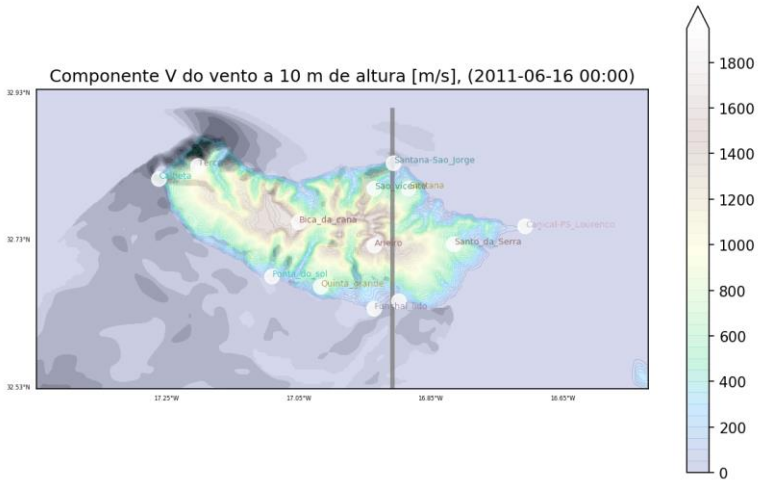
Wind_speed ***Air Temperature*** ***Wind_direction***

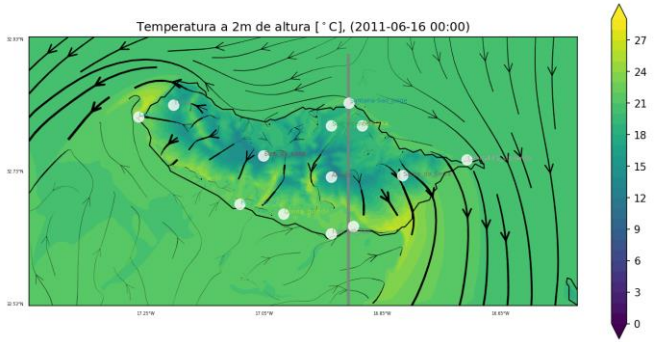


Sea breeze generation

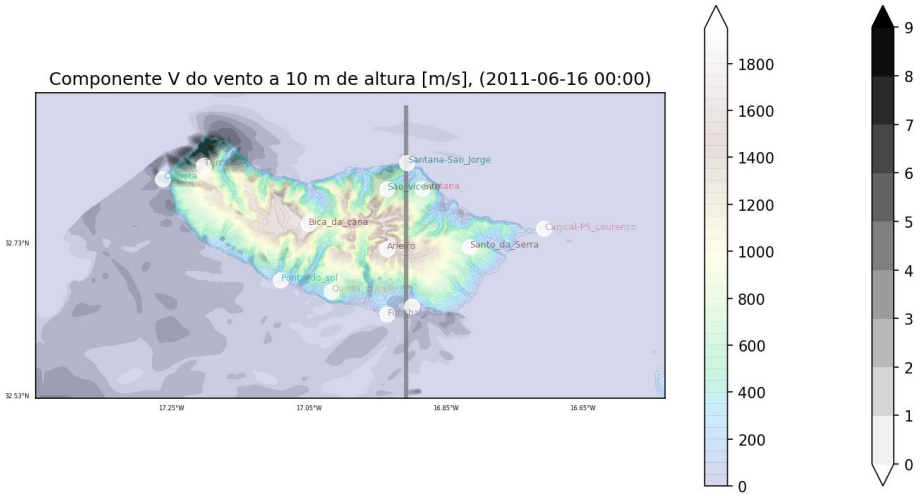
- WRF-LES with surface heat fluxes (on/off);
- Predominant wind is from north, representing N-S wind (V) component.

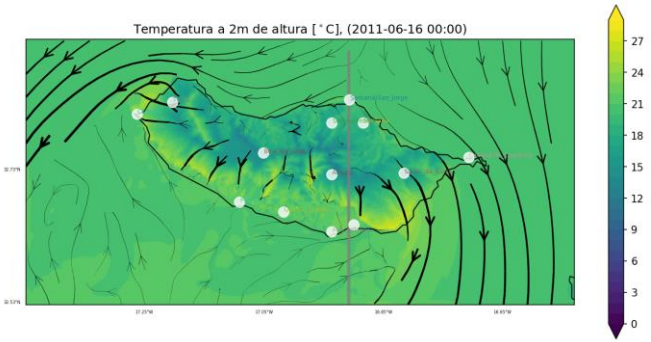
Isfflx=0 (adiabatic)





Isfflx=1






Thank you!

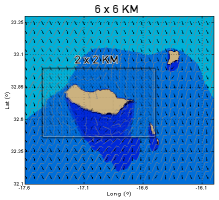
New Forecasting System

Coupled ⇔ systems

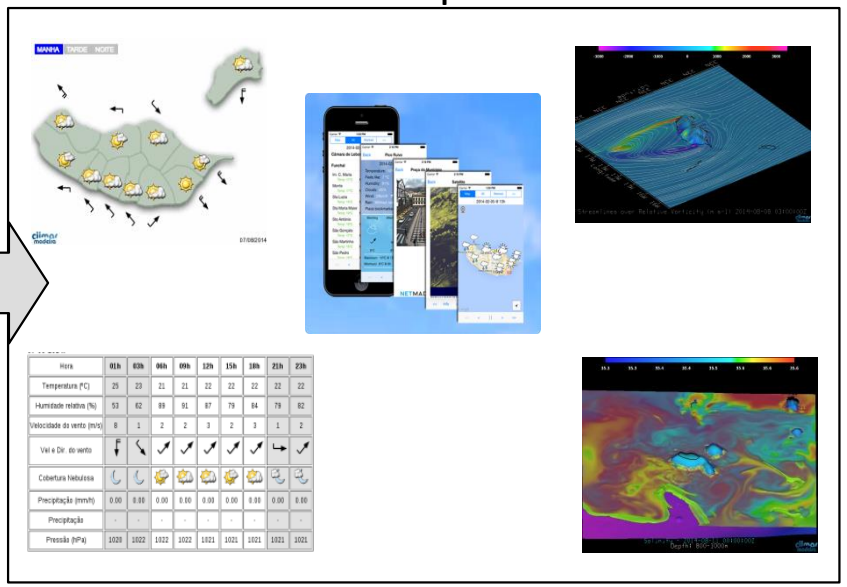
WRF ⟷ ROMS

COAWST

SWAN



Deliver data / information in different platforms



Case Studies