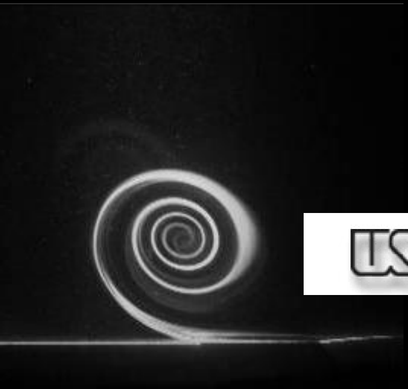
II SEMINÁRIO SOBRE MODELAGEM NUMÉRICA OCEANOGRÁFICA

IEAPM - November 2012

Jacyra Soares

Air-sea Laboratory

Group of Micrometeorology

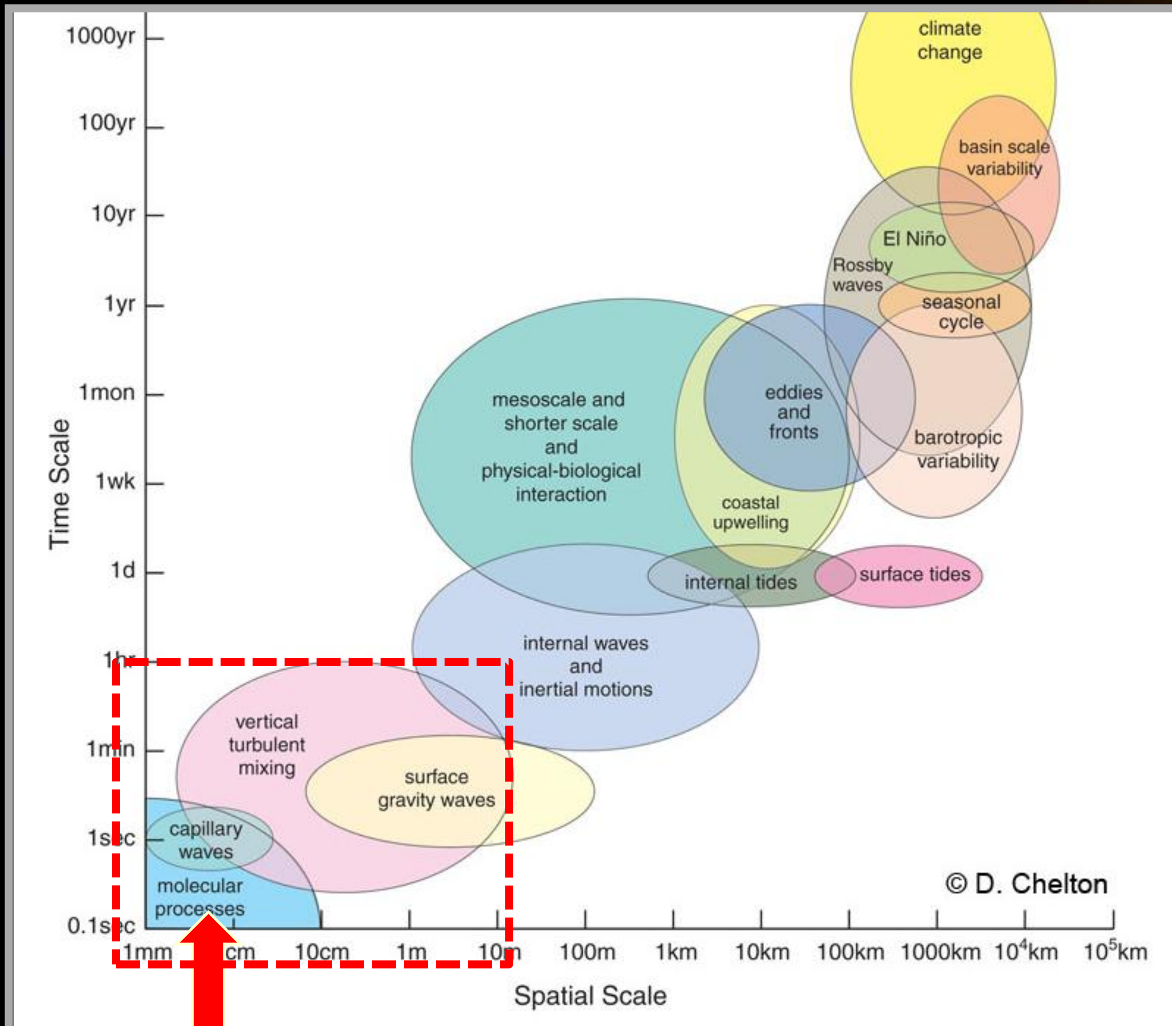


Observational and numerical issues related to the air-sea interface

- Space and time scales
- Air-sea coupling
- Future

Space and time scales

Space and time scales



- Global
- Sinoptic
- Mesoscale
- Microscale

Microscale → relevant phenomena is TURBULENCE

Turbulence

Turbulence is one of the unsolved problems in Physics.

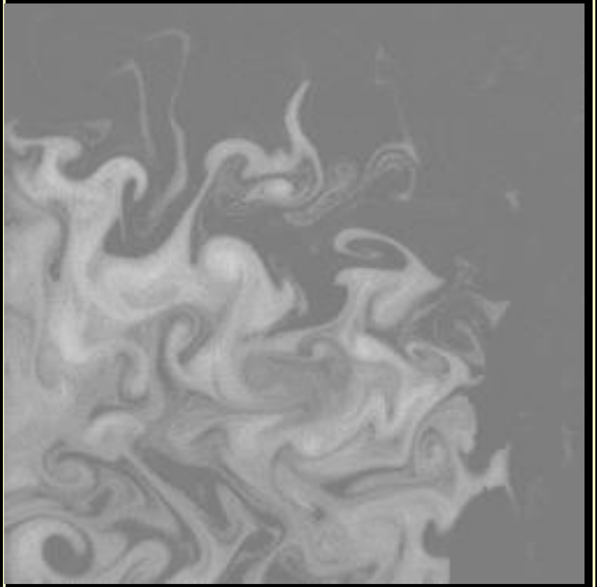
1 million dollar prize!

Clay Mathematics Institute

Dedicated to increasing and disseminating mathematical knowledge

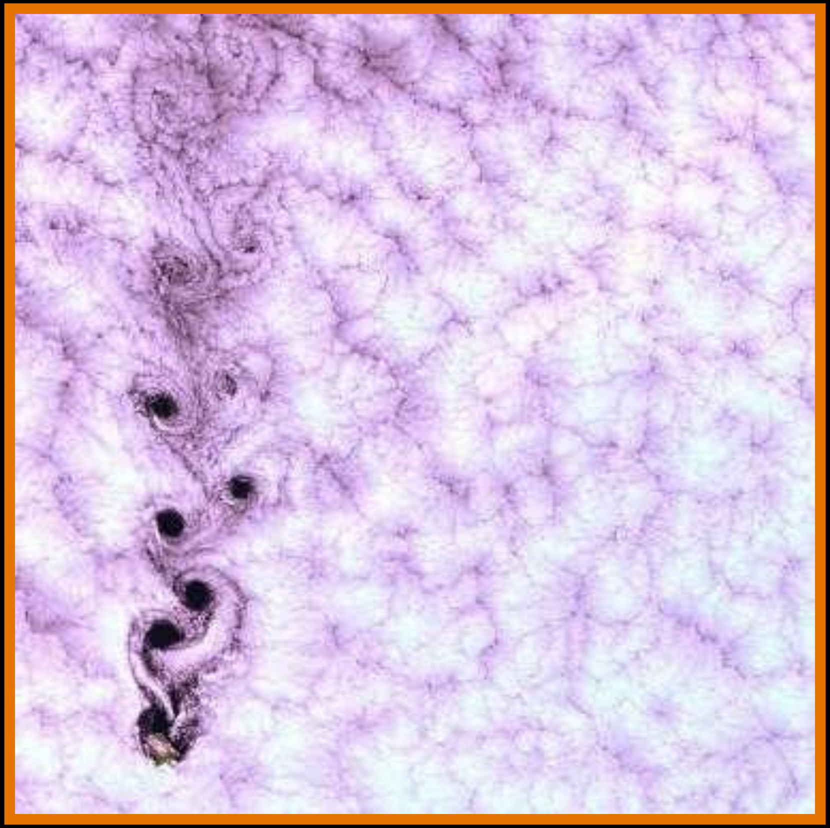
Navier-Stokes equation

Waves follow our boat as we meander across the lake, and turbulent air currents follow our flight in a modern jet. Mathematicians and physicists believe that an explanation for and the prediction of both the breeze and the turbulence can be found through an understanding of solutions to the Navier-Stokes equations. Although these equations were written down in the 19th Century, our understanding of them remains minimal. The challenge is to make substantial progress toward a mathematical theory which will unlock the secrets hidden in the Navier-Stokes equations.



From (http://www.claymath.org/millennium/Navier-Stokes_Equations/)

Remote sensing



Source: www.efluids.com

Remote Sensing:
Satellite image of Von Kármán Vortex Street, Selkirk Island.

Analogical modeling

Wind tunnel

Fonte: www.efluids.com

Numerical modeling

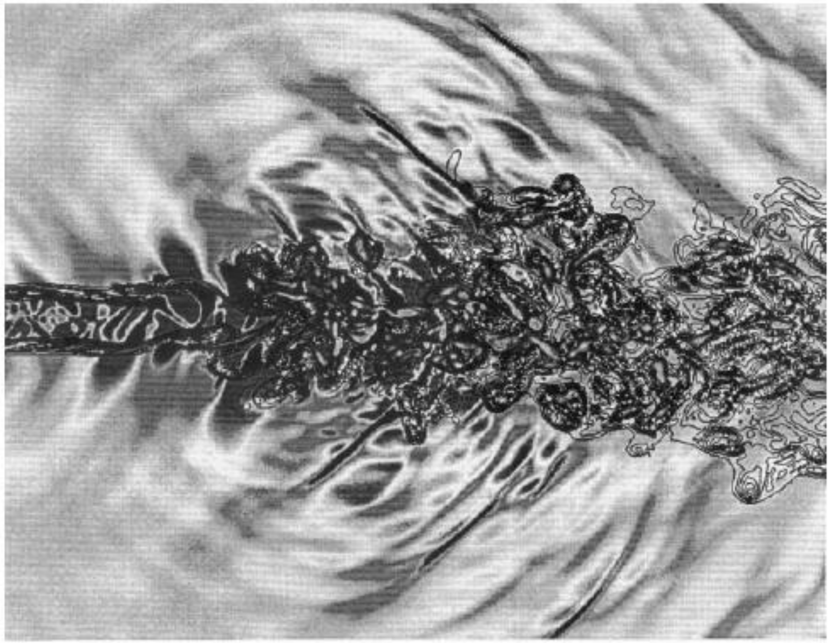


Figure 1 The sound radiated by a Mach 1.9 circular jet. Contours of vorticity (black) are overlaid on dilatation contours (gray). The computations were performed by J Freund, SK Lele & P Moin (unpublished information).

Direct numerical simulation.

Grids: 512^3

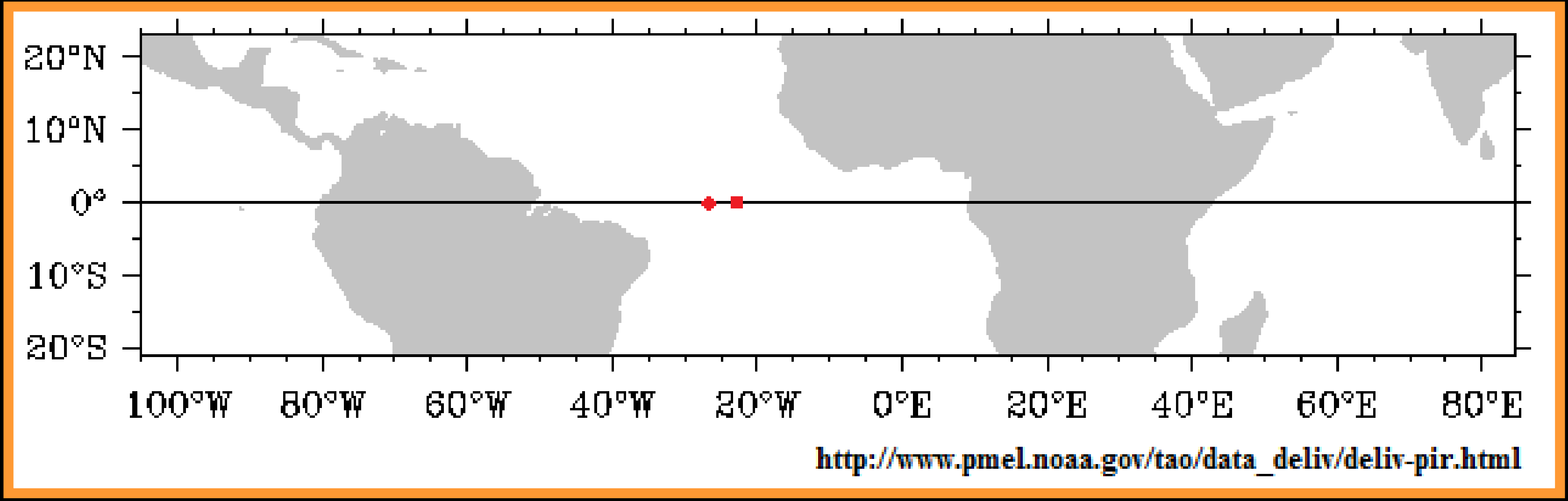
Source: Moin and Mahesh, 1998.

Equatorial Atlantic data

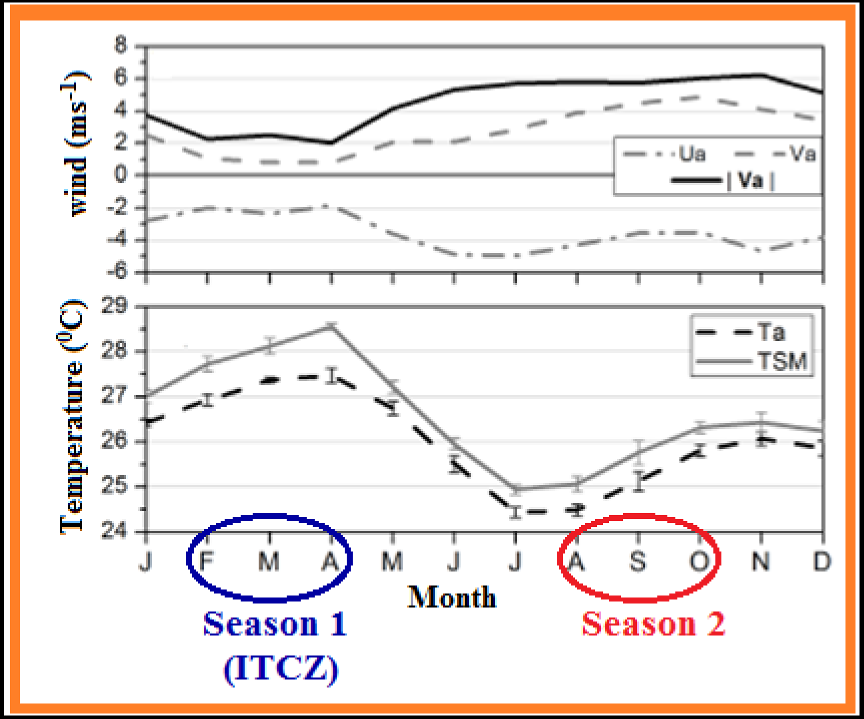
PIRATA → Upper boundary condition → SW↓ , T_a , U_a , V_a , RH, SST.

(Prediction and Research Moored Array over the Tropical Atlantic Ocean)

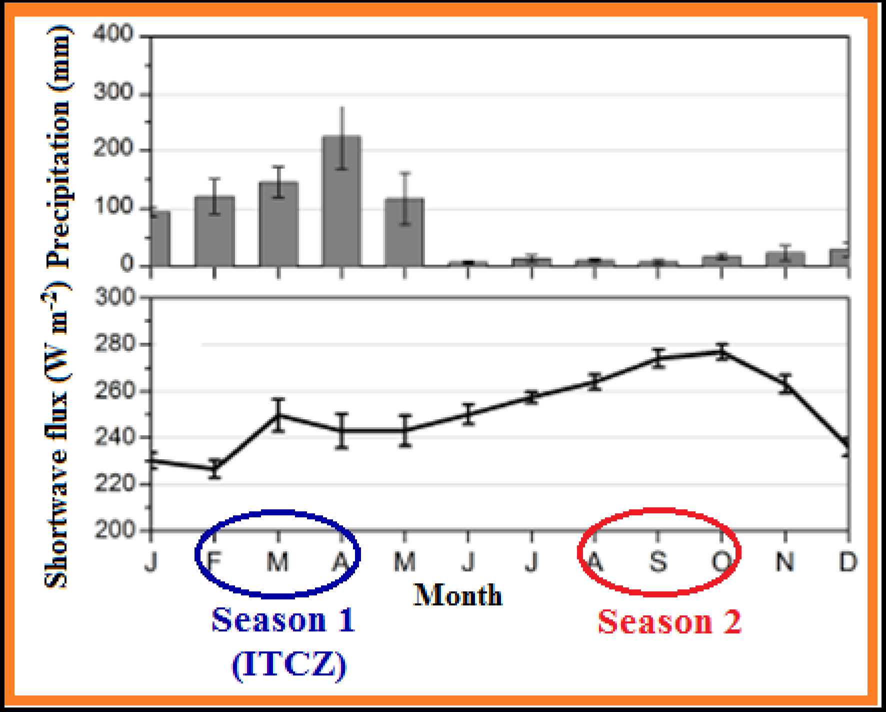
SRB-NASA → Closing the radiation balance → SW↑ , LW↑ , LW↓



In situ data - PIRATA

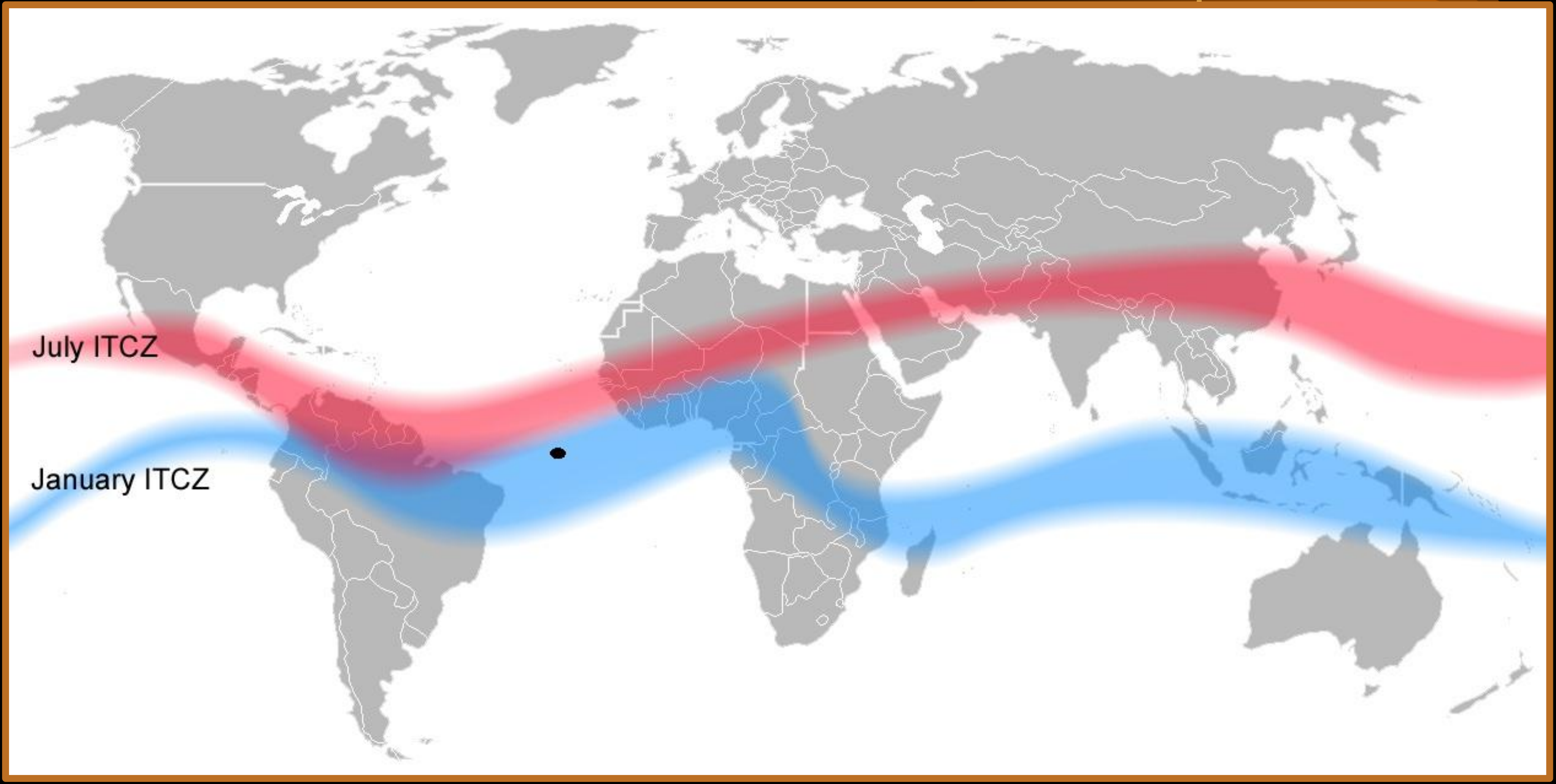


Atmosphere



PIRATA (0º , 23^0 W) – monthly average – 1999 to 2006

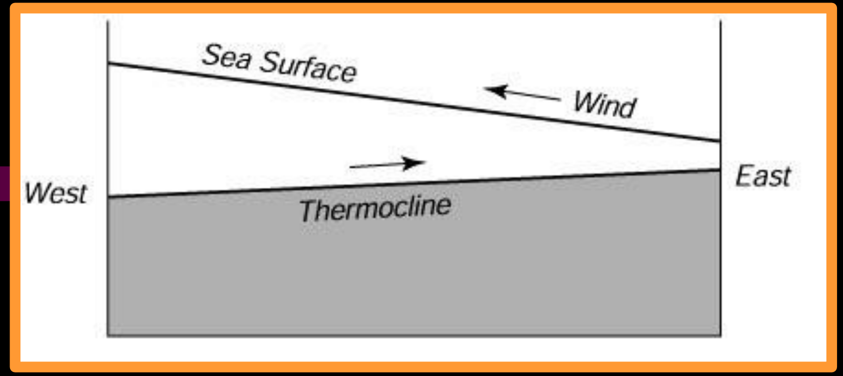
ITCZ displacement



PIRATA (0^o , 23^0 W) – monthly average – 1999 to 2006.

Equator - wind and current

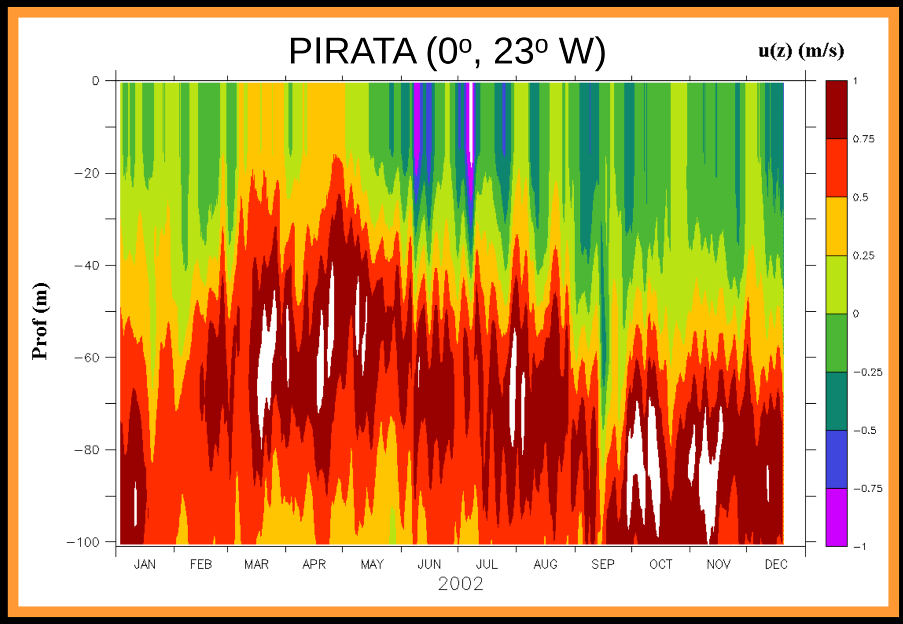
The eastward pressure gradient at the surface is balanced by the wind stress.



Cross-sectional sketch of the thermocline and sea-surface topography along the equator.

Below a few tens of meters , the influence of the wind stress is small, and the pressure gradient is unbalanced, leading to an accelerated flow toward the east:

equatorial undercurrent (EUC).



Column model

Numerical study of the equatorial Atlantic Ocean mixed layer using the GOTM model

General Ocean Turbulence Model (GOTM, Burchard et al., 1999)

GOTM:

- A computational tool that compiles different turbulence closure models;
- Column model.

Assimilation scheme

$$\partial_t X \propto -T_{assim}^{-1}\left(X - X_{obs}\right)$$

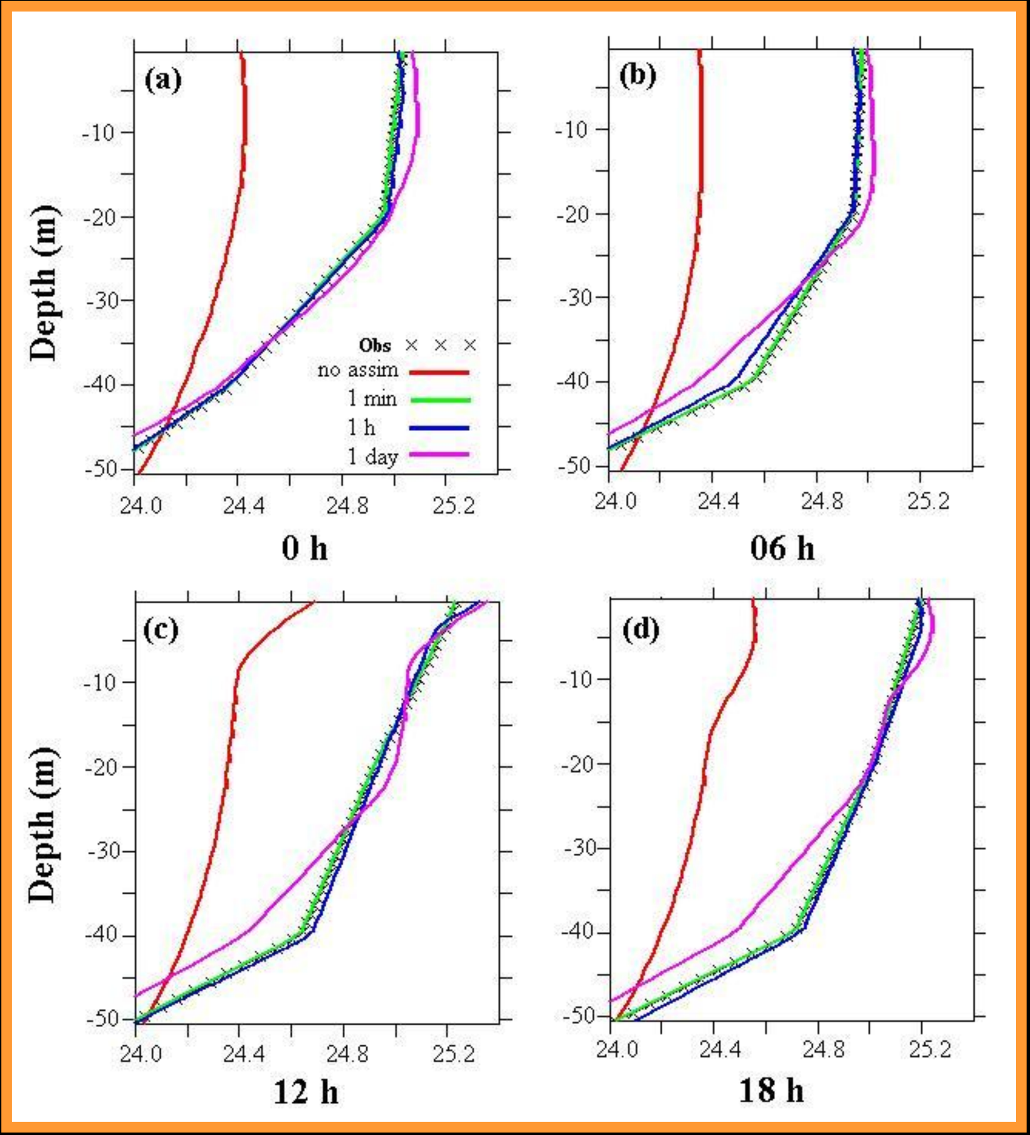
X: Variable prognosticated by the model

X_{obs} : Observed variable

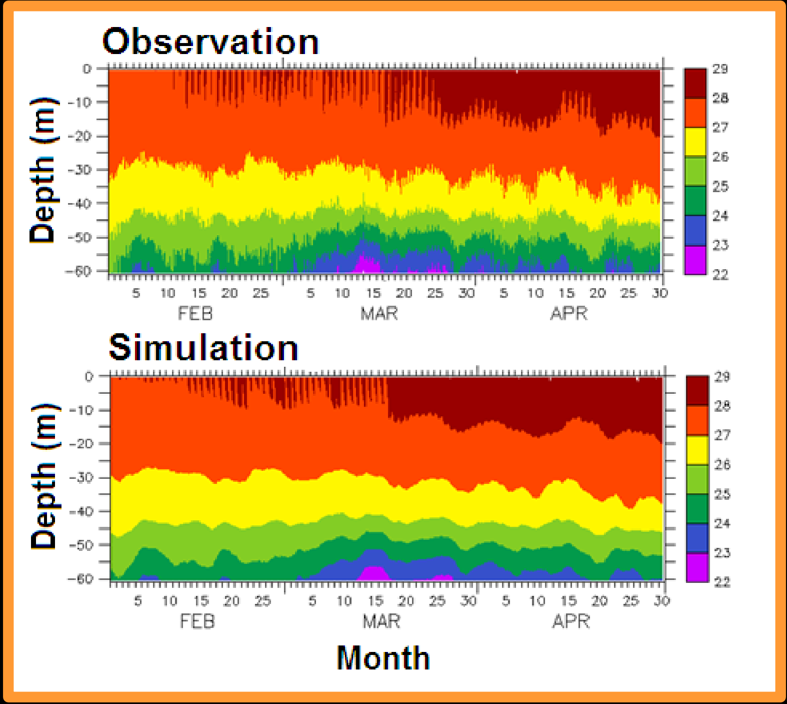
T_{assim} : Prescribed period of assimilation

T_{assim} = 1 day

Assimilation scheme

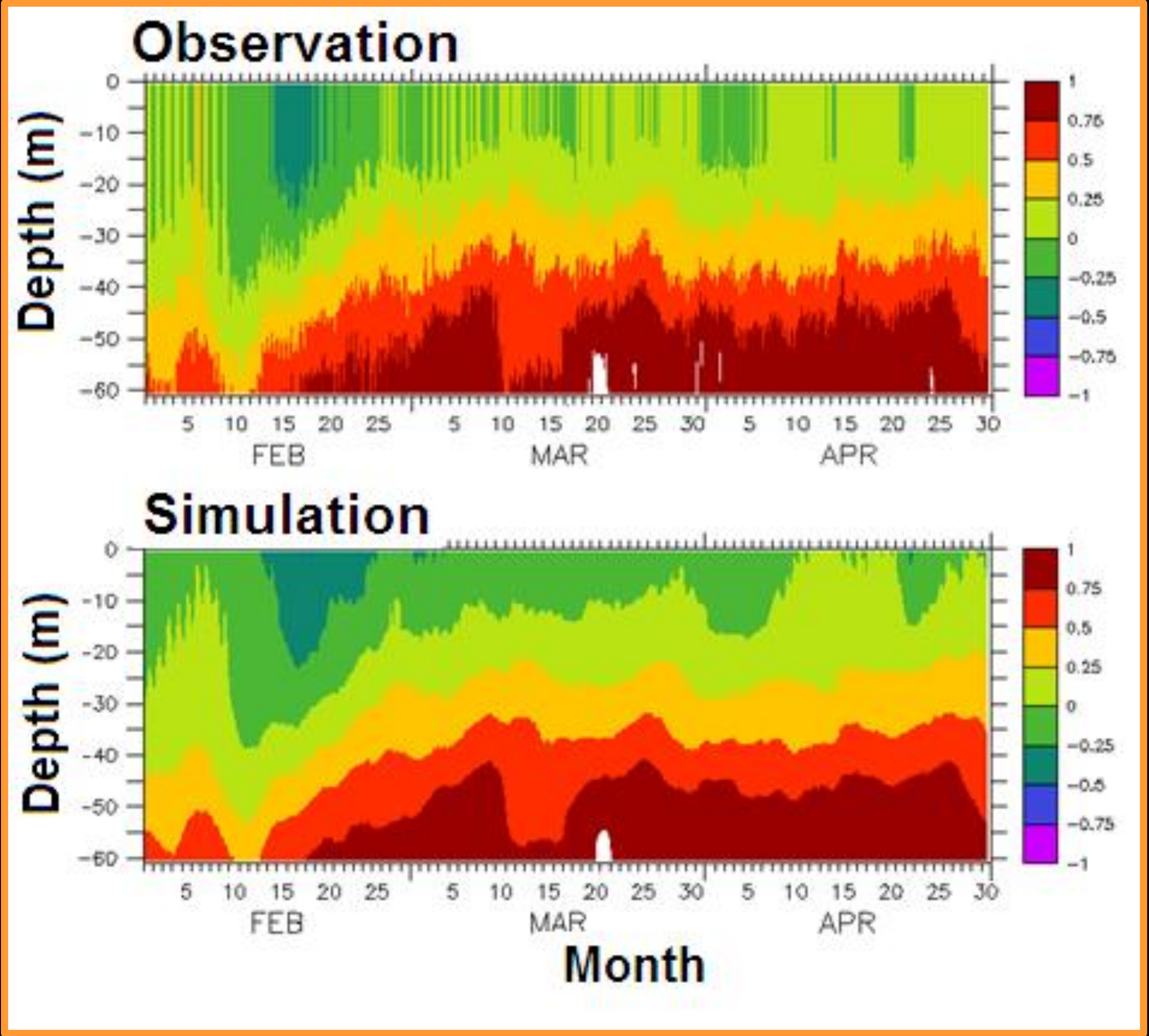


Sea temperature



$$\partial_t X \propto -T_{relax}^{-1}\left(X - X_{obs}\right)$$

Assimilation scheme



Zonal current

Season 1

κ-ε model

κ-ε model $\longrightarrow$ turbulent kinetic energy (κ) and dissipation rate of κ (ε).

The prognostic equations for κ and ε:

$$\frac{\partial \kappa}{\partial t} - \frac{\partial}{\partial z}\left(\frac{\nu_t}{\sigma_\kappa}\frac{\partial \kappa}{\partial z}\right) = P + B - \varepsilon$$

$$\frac{\partial \varepsilon}{\partial t} - \frac{\partial}{\partial z}\left(\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial z}\right) = \frac{\varepsilon}{\kappa}(c_{1\varepsilon}P + c_{3\varepsilon}B - c_{2\varepsilon}\varepsilon)$$

σ_k, σ_ε, $c_{1\varepsilon}$, $c_{2\varepsilon}$, $c_{3\varepsilon}$ are empirical constants

σ_k is Schmidt number for k ($\approx$1.0)

σ_ε is Schmidt number for ε ($\approx$1.3)

$c_{1\varepsilon} \approx 1.44$

$c_{2\varepsilon} \approx 1.92$

$c_{3\varepsilon} \approx -0.4$ (unstable layer) and $\approx$1.0 (stable layer)

P is the shear production of k: $P = -\overline{u'w'}\frac{\partial \bar{u}}{\partial z} - \overline{v'w'}\frac{\partial \bar{v}}{\partial z}$

B is the buoyancy production/dissipation of k: $B = \frac{g}{\rho}\overline{u'\theta'}$

- Upper boundary condition

Momentum

$$-\left(\overline{u'w'}\right)_0 = \frac{\tau_0^x}{\rho_0}$$

$$-\left(\overline{v'w'}\right)_0 = \frac{\tau_0^y}{\rho_0}$$

(Fairall et al., 2003)

Heat

$$-\left(\overline{\theta'w'}\right)_0 = \frac{Q_n}{\rho_0\ c_p} = \frac{SW + LW + Q_e + Q_h}{\rho_0\ c_p}$$

k - Zero flow   S – Zero flow

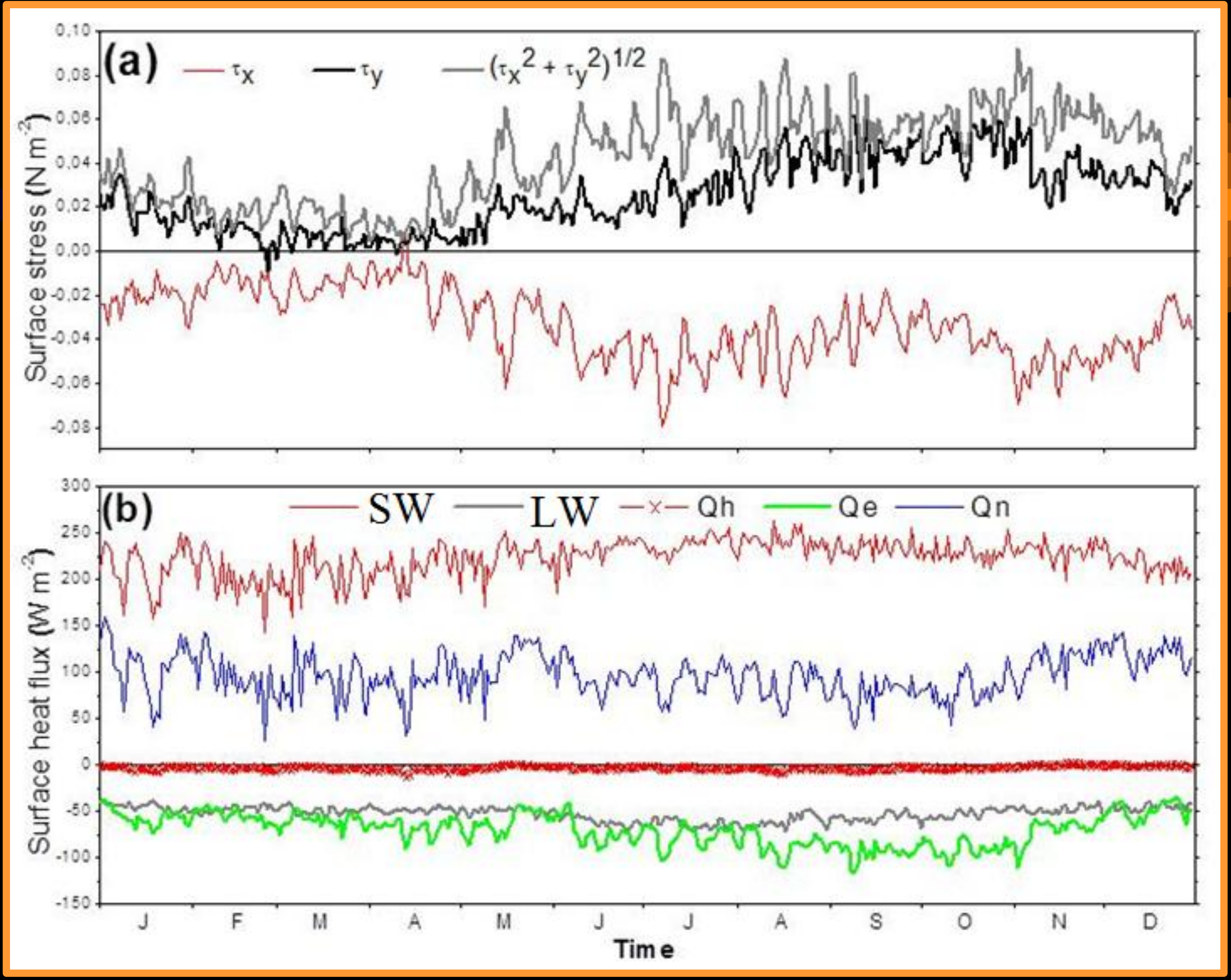
ε – Flow condition derived from the law of the wall:

$$\frac{\partial}{\partial z}\left(\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial z}\right) = -c_l \frac{\nu}{\sigma_\varepsilon}\frac{k^{3/2}}{0{,}4\,(z+z_0)^2}$$

- Lower boundary condition

Rigid lid and zero flow, considering the bottom as a hard surface.

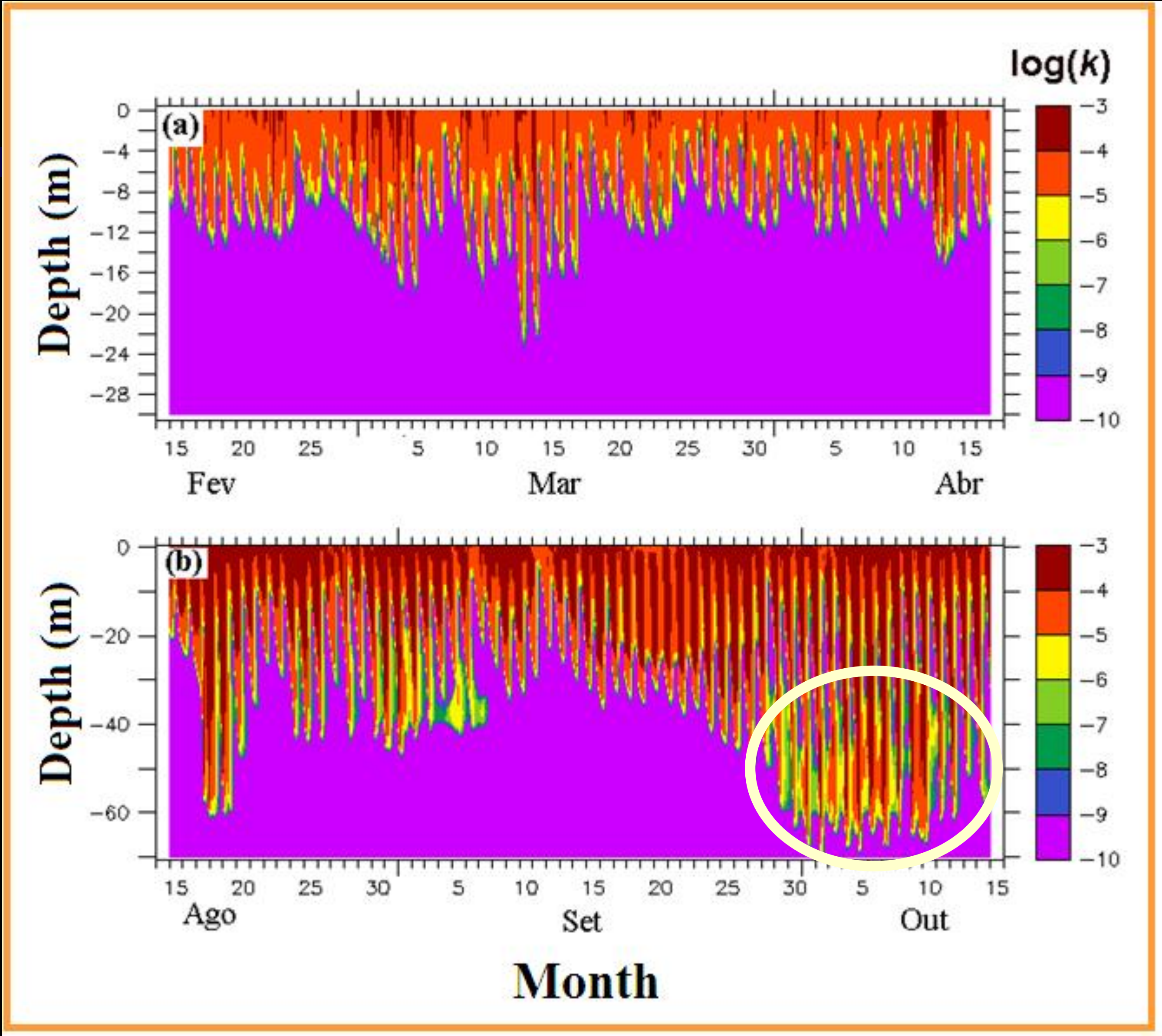
Surface fluxes



Positive net surface heat flux corresponds to the heat gained by the ocean.

Turbulent kinetic energy

Season 1



Season 2

Criterion of h_{oml}
$\log(k) \geq -5$

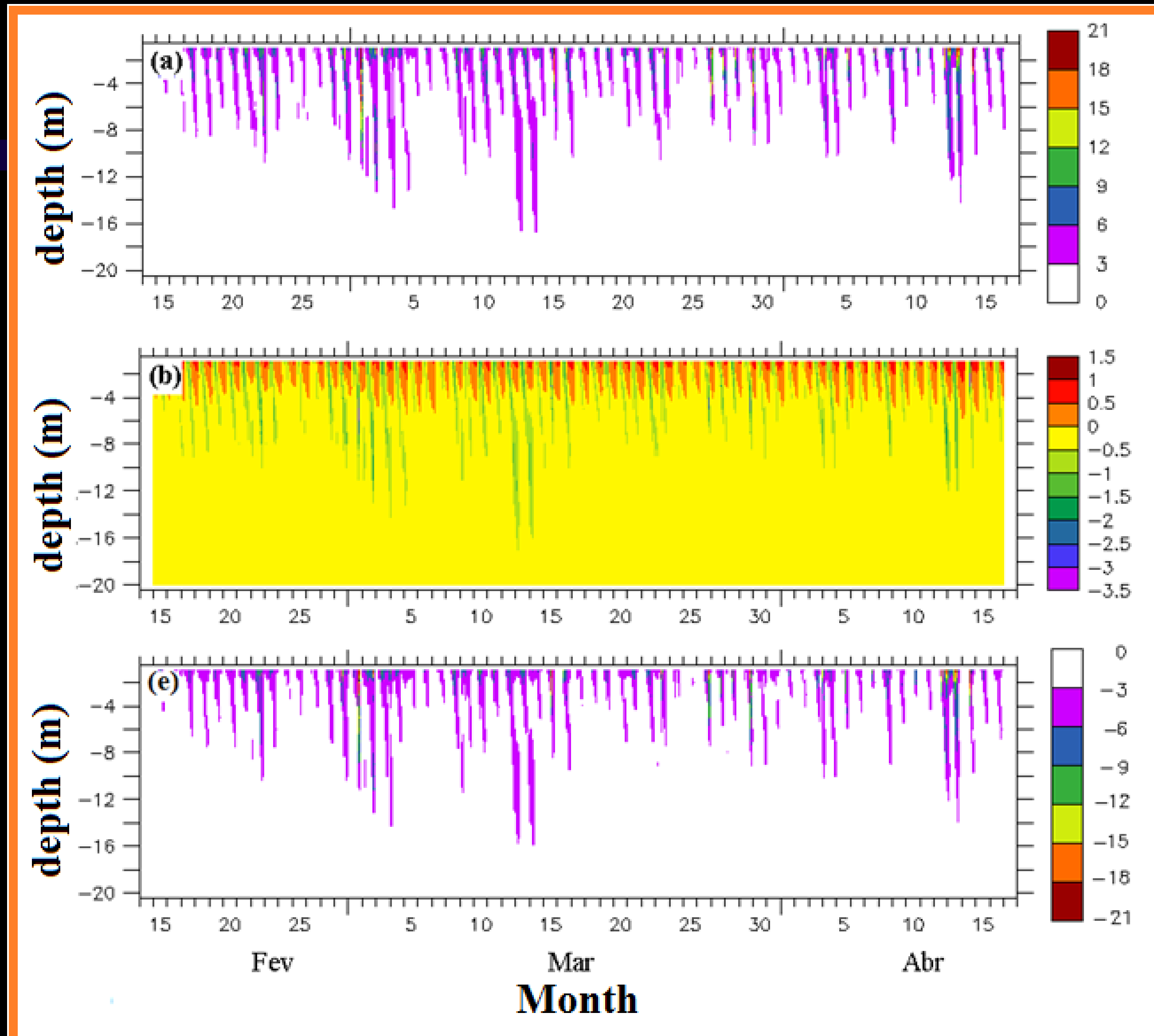
k equation terms – Season 1

Mechanical production

Thermal production\ dissipation

Rate of viscous dissipation

(10^{-7} m^2 s^{-3})



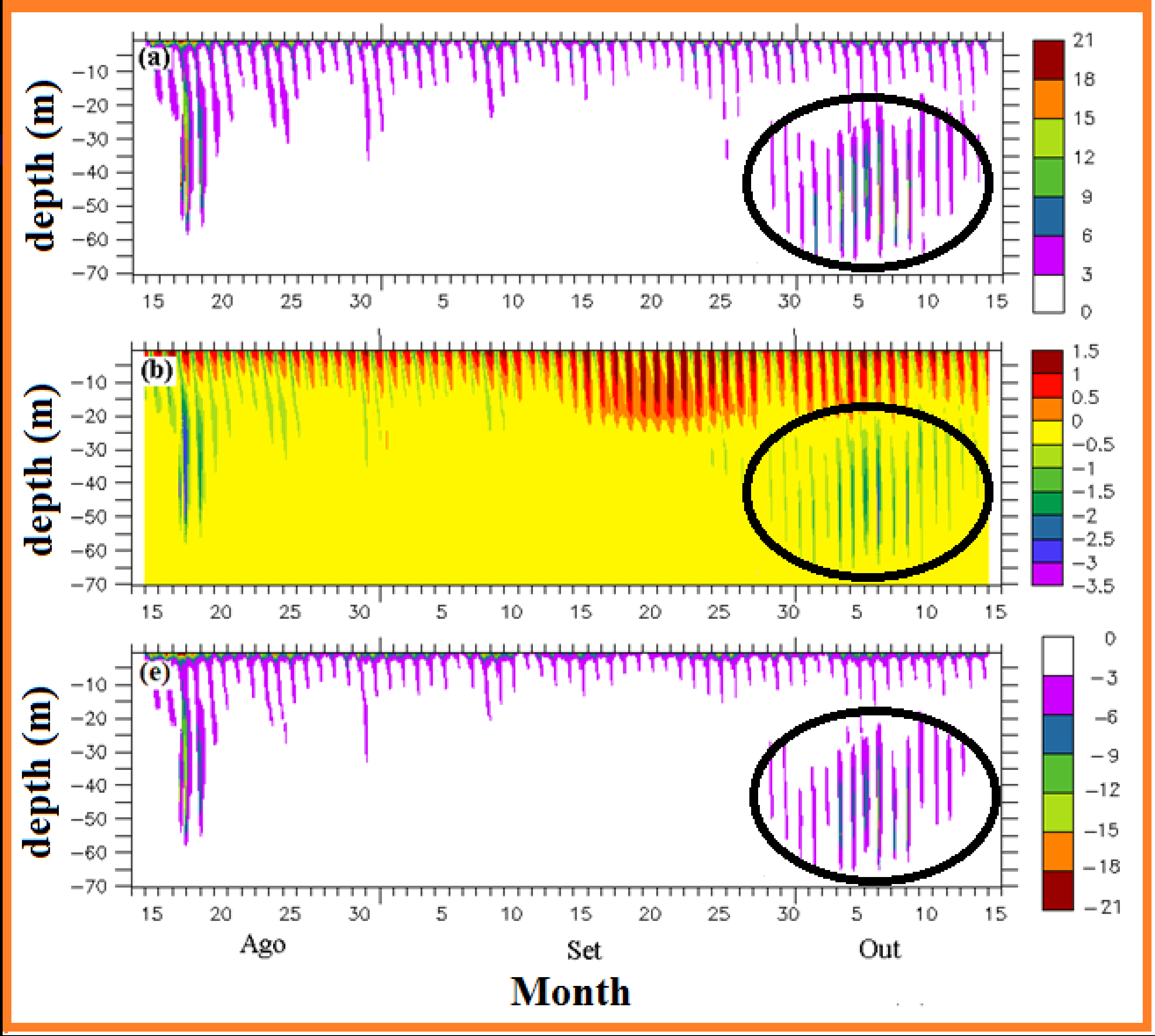
k equation terms – Season 2

Mechanical production

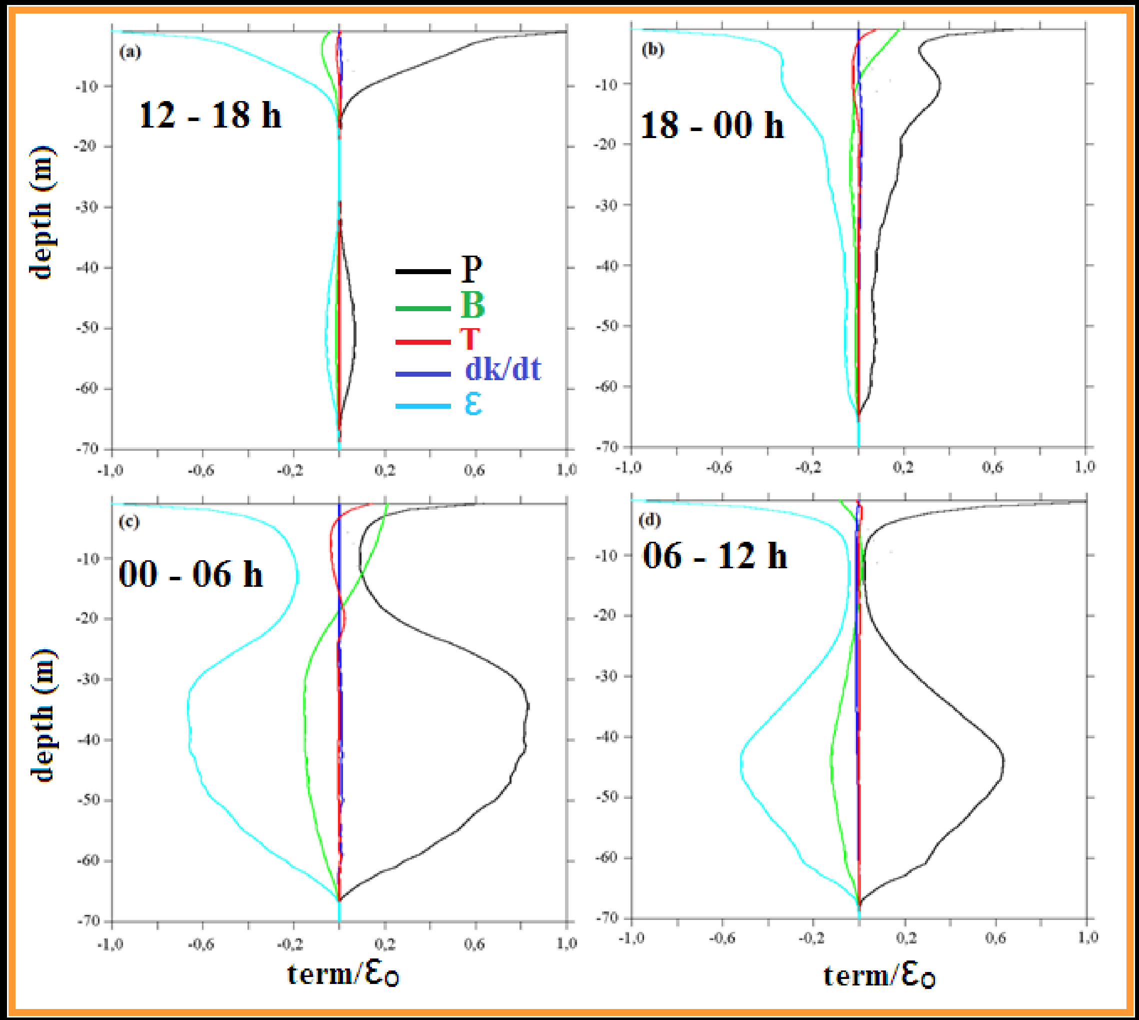
Thermal production\
dissipation

Rate of viscous dissipation

$(10^{-7}\ m^2\ s^{-3})$



Diurnal evolution of κ-equation terms



Average vertical profile of the *k-equation terms* ***normalized by the viscous dissipation rate of k at the surface (ε_0), averaged from October 1 to 10.***

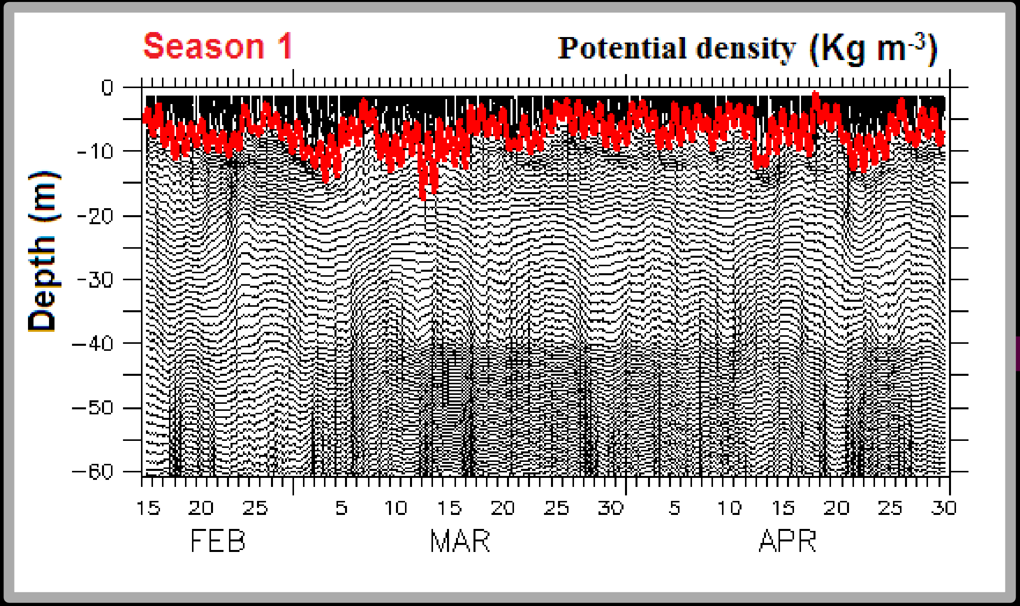
Criterion for estimating the depth of the OML (h_{oml})

Source	Criterion
de Boyer Montegut et al. (2004) ($h^{0.03}$)	$\Delta\theta=0.2^{o}$ C $\Delta\rho=0.03$ kg m^{-3}
Wang et al. (1998) ($h^{0.01}$)	$\Delta\rho=0.01$ kg m^{-3}
GOTM (h^{k})	$k=1 \times 10^{-5}\ m^{2}\ s^{-2}$

$\Delta\rho$ = 0.01 Kg m^{-3} → depth at which potential density differs from that of the surface by 0.01 Kg m^{-3}.

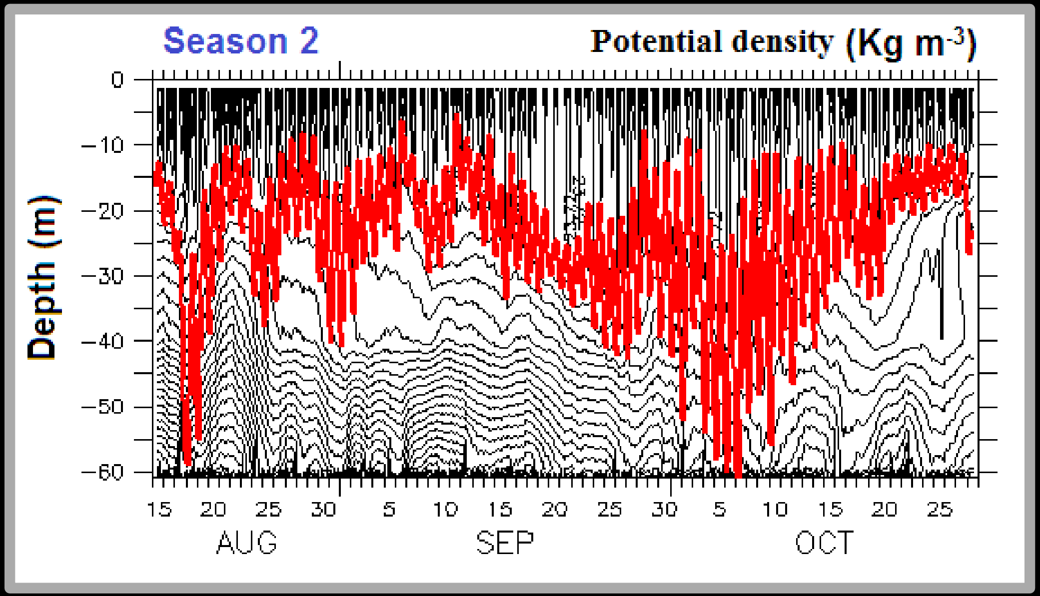
$\Delta\rho$ = 0.03 Kg m^{-3} → depth at which potential density differs from that of the 10 m depth by 0.03 Kg m^{-3}.

Depth of the OML



Potential density contour interval of 0.03 kg m^{-3}.

The thick red lines indicate the (h_{oml}) estimated using a TKE threshold of 10^{-5} m^2 s^{-2}.

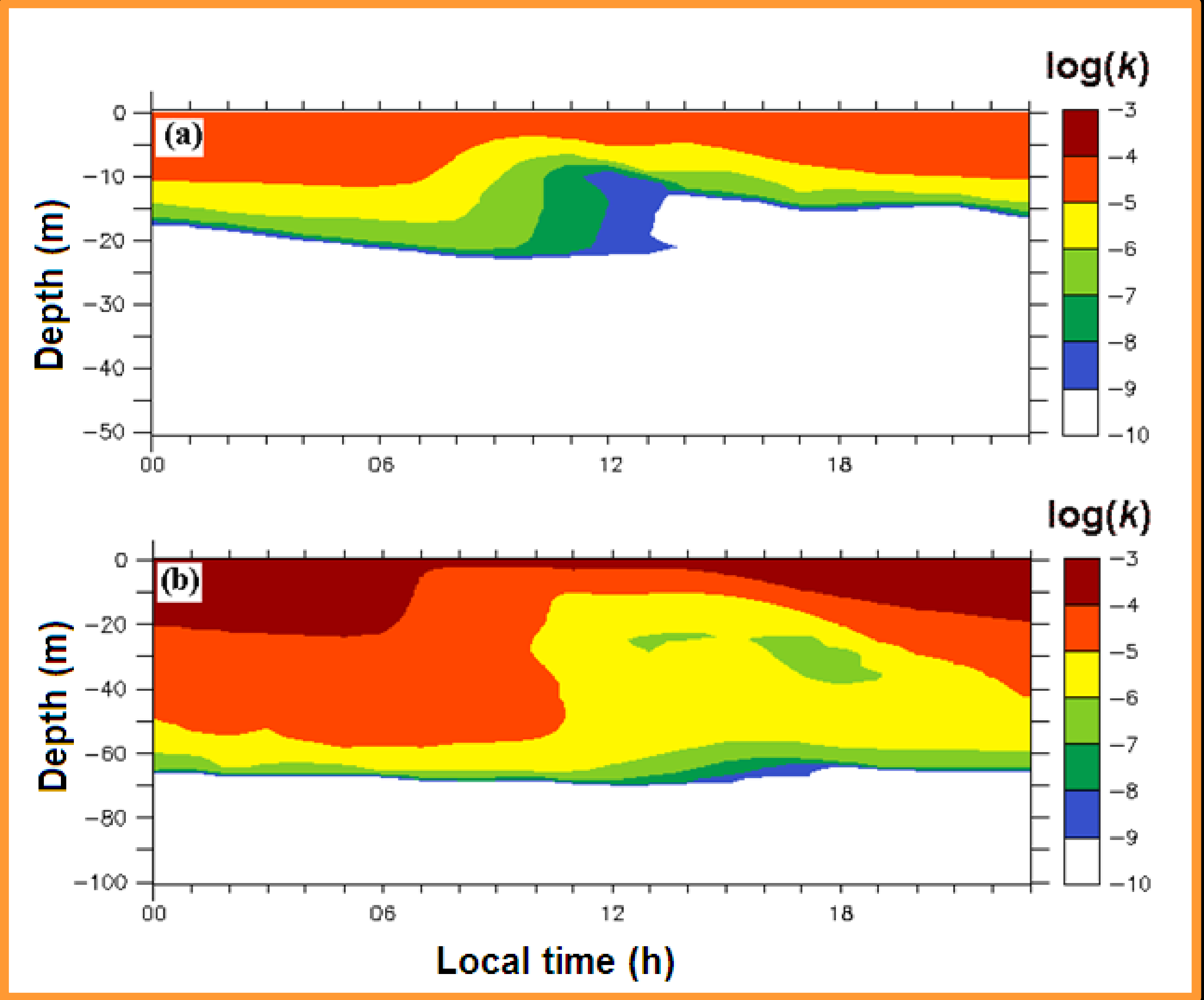


Turbulent kinetic energy – diurnal cycle

Season 1

Season 2

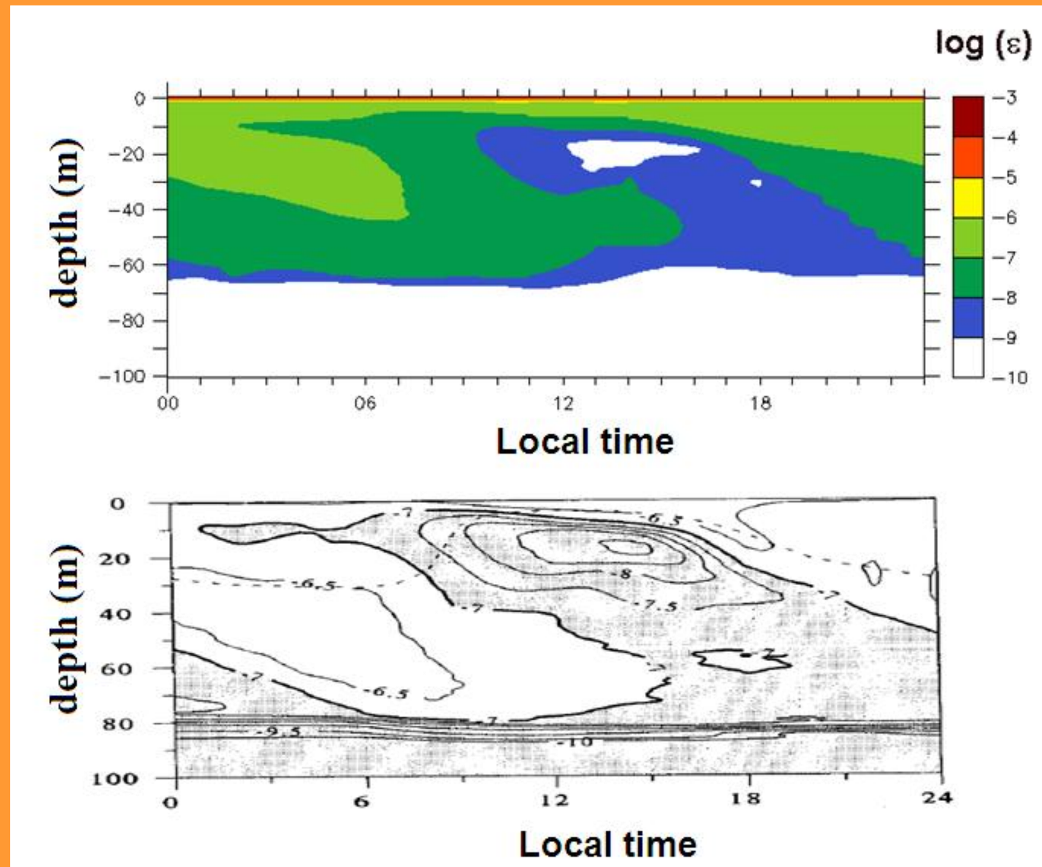
Criterion of h_{oml}
$\log(k) \geq -5$



Comparison

Dissipation rate [log(ε)]

GOTM
Equatorial Atlantic
Average from
Aug, Sep, Out.



Wang *et al*. (1998)
Equatorial Pacific
(1 day simulation)

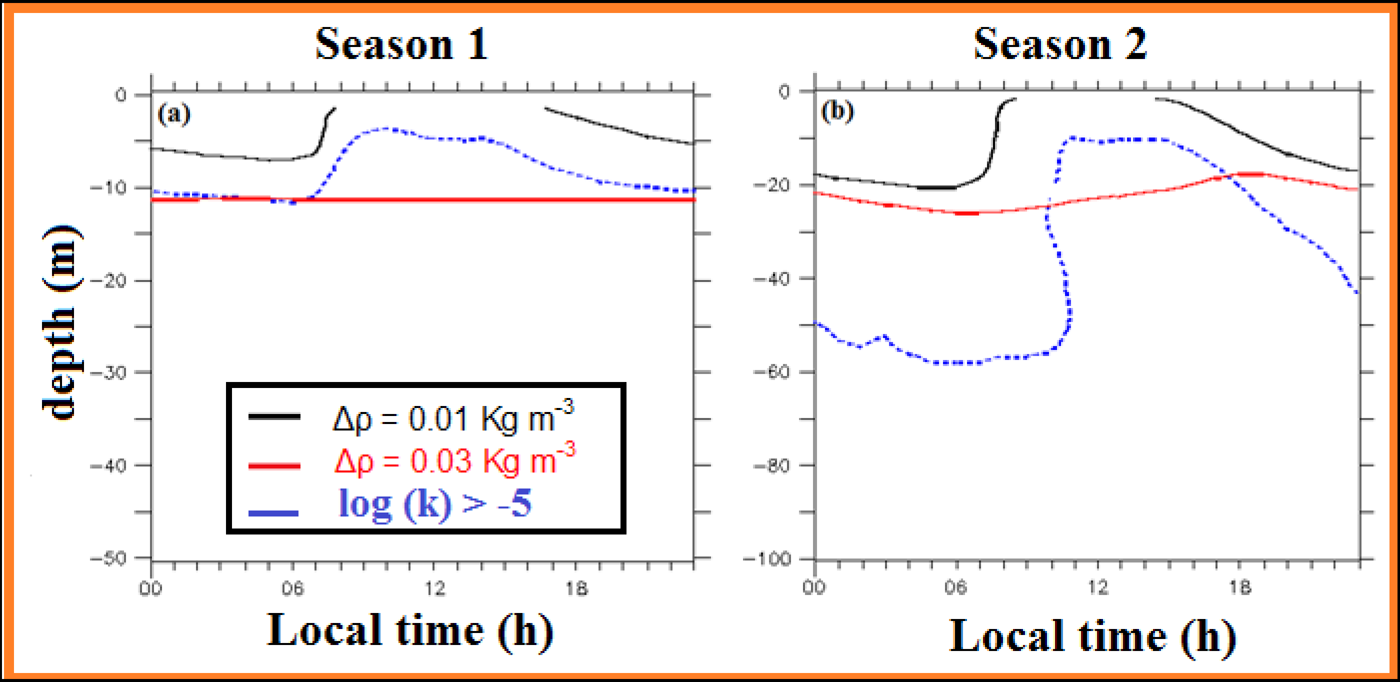
Turbulence criterion
log(ε) ≥ -7

The numerical results were consistent with previous studies in the equatorial Pacific.

Remarks

- Mechanical production → most important term.

- Buoyancy term → important producing turbulence to ~ 30% of the OML depth during night and during the day dissipating turbulence;



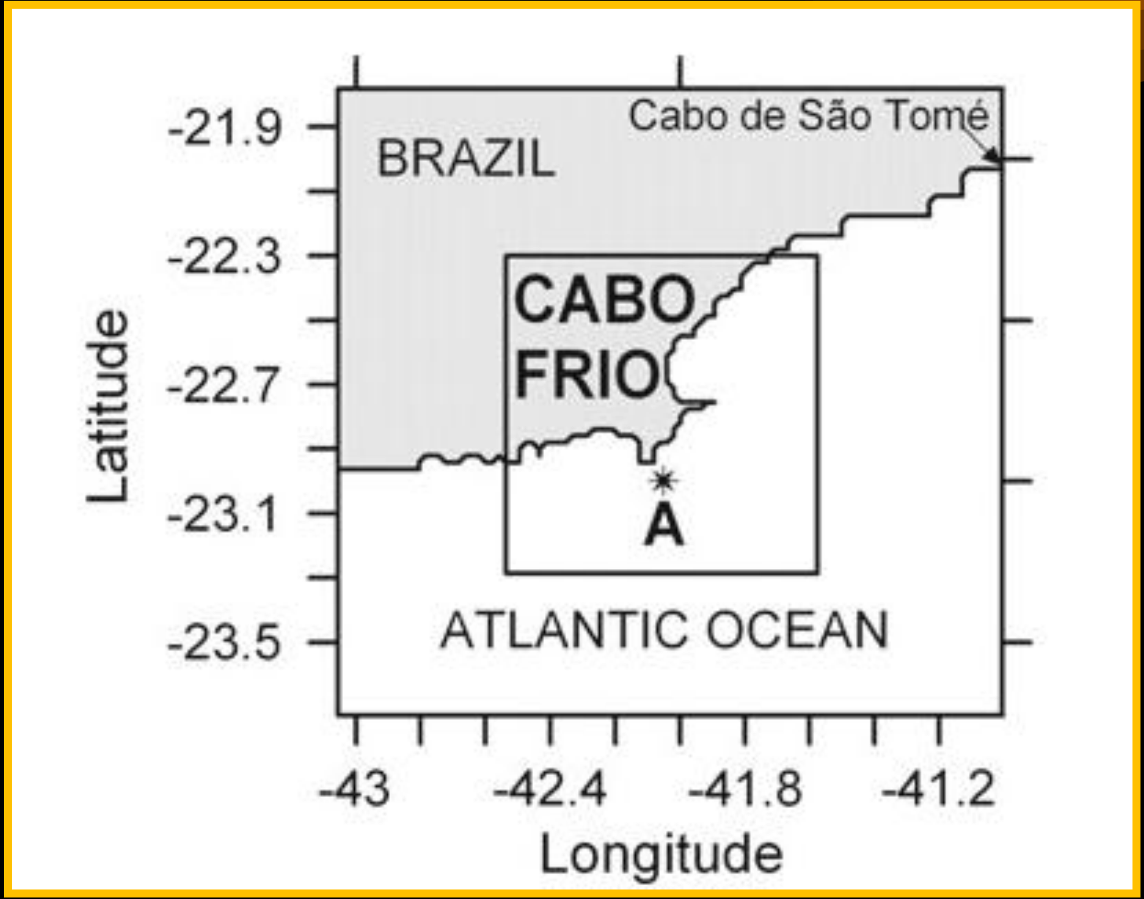
Future work

•To investigate the generation of the deep-cycle turbulence (unrelated to surface forcing generated turbulence) including the surface and internal gravity waves.

•To couple the GOTM with an atmosphere second order turbulence model.

Air-sea coupling

Cabo Frio

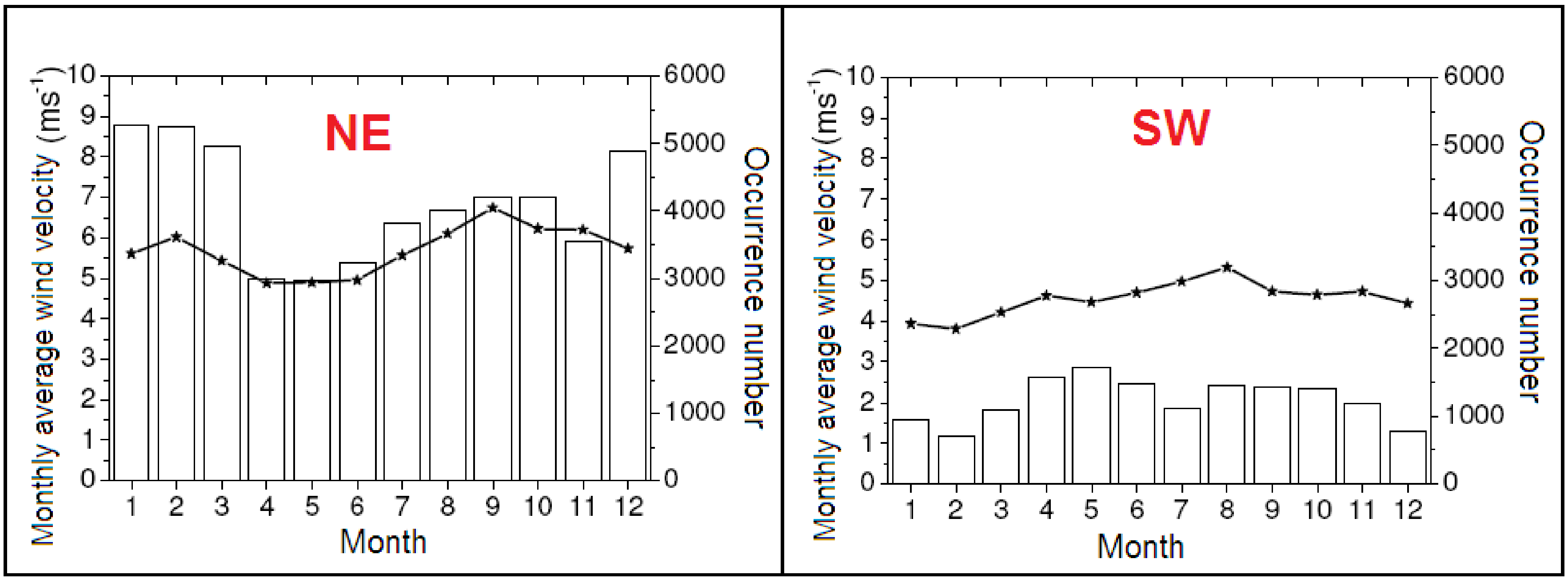


Cabo de São Tomé
BRAZIL
CABO FRIO
A
ATLANTIC OCEAN
-21.9
-22.3
-22.7
-23.1
-23.5
Latitude
-43
-42.4
-41.8
-41.2
Longitude

Cabo Frio observational data

Research	Local	Data	Period	Frequency	Instrument
Leite (2005)	(22°59,16’ S 42°03,98’ W)	Surface wind	Summer 2001	Hourly average	Meteorological buoy
	(22°59,280’ S 42°06,733’ W)		Winter 2001		
Oda (1997)	Meteorological station (number 83719) (22,879° S 42,018° W)	Surface wind	1970 to 1980	Hourly	Anemograph
	“Companhia Nacional de Álcalis” (22,9604° S 42,0313° W)	SST	1970 a 1980	Hourly	Atmospheric sounding
	(22° 57’ 58” S 42° 01’ 40” W)	Surface wind Air temperature Mixing ratio	Summer (09/01/1995) Winter (04/08/1995)	Different times	Atmospheric sounding
Dourado and Oliveira (2001)	(23° 00’ S 42°08’ W)	Air temperature Mixing ratio	Winter (07-10 July 1992)	1 atmospheric sounding each 4 hours	Atmospheric sounding
		Sea temperature vertical profile		1 oceanic sounding each 4 hours	Oceanic sounding

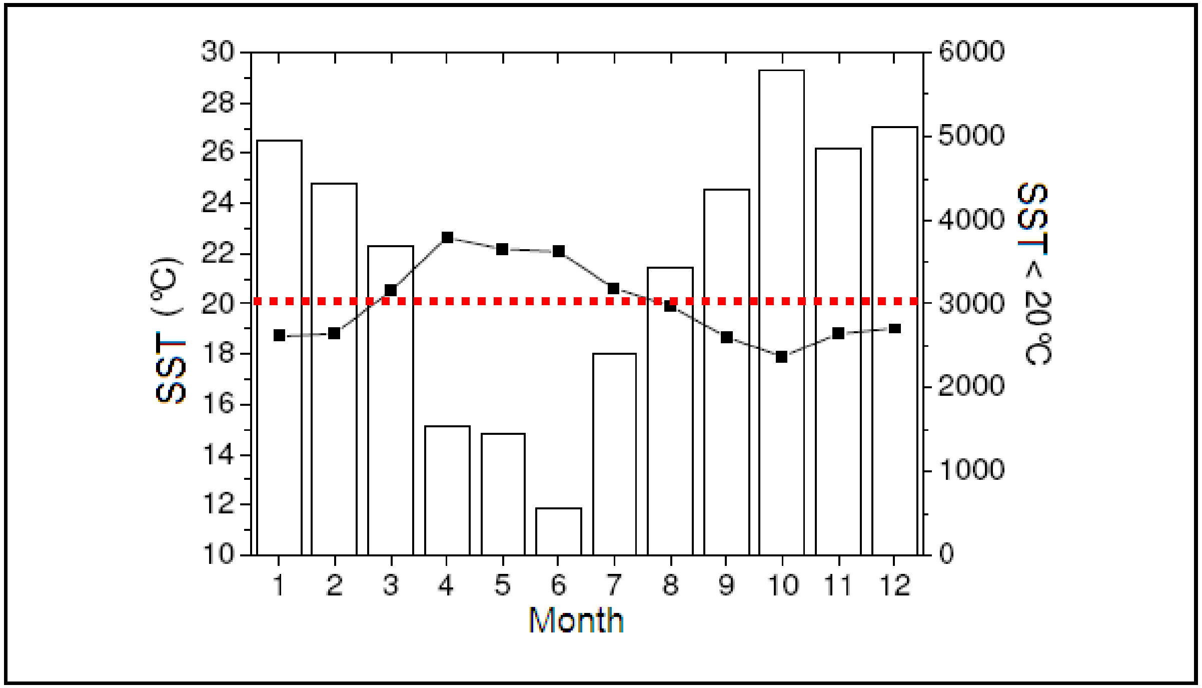
Observed wind



Monthly average wind velocity and number of occurrences (column). Data from 1970 to 1980.

Max 8760

Observed SST



Monthly average SST and number of occurrence of TSM < 20 °C (column). 1970 to 1980.

Cabo Frio - Upwelling region

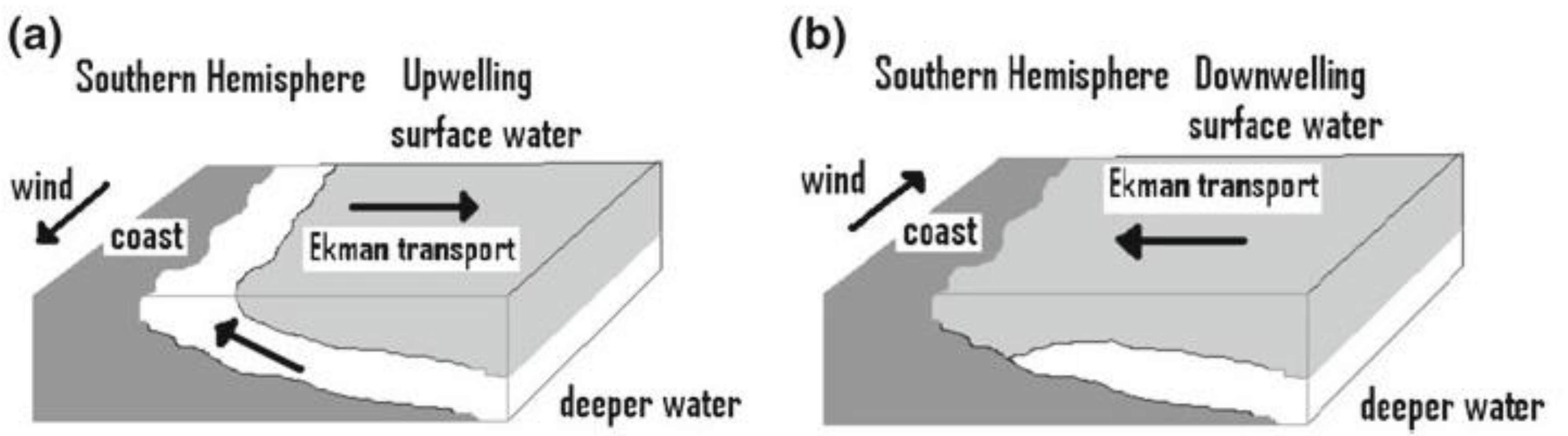


Fig. 1 Scheme of the Ekman transport during **a** coastal upwelling favorable wind and **b** coastal downwelling favorable wind

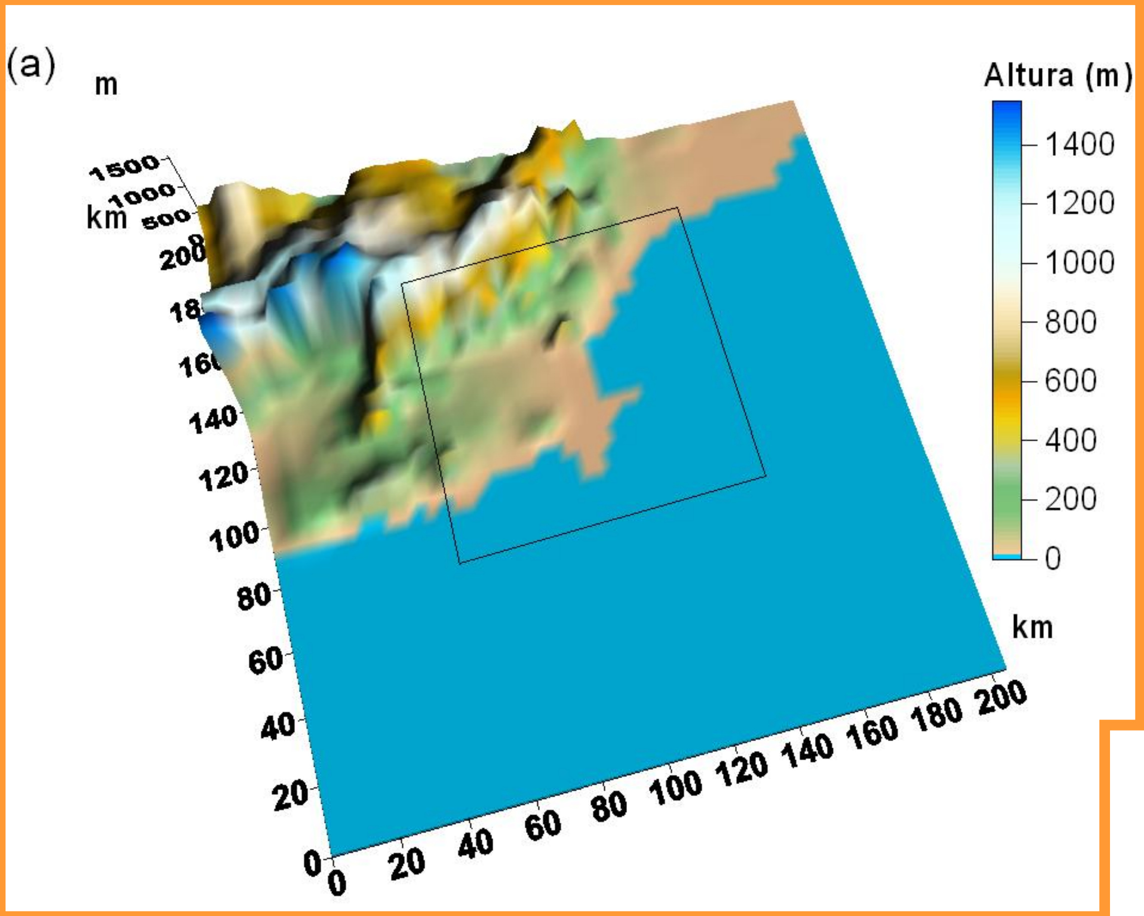
- A semi-permanent high pressure center (South Atlantic High Pressure system) causes NE winds.
- Coastal upwelling.
- Passage of cold fronts cause SW winds.

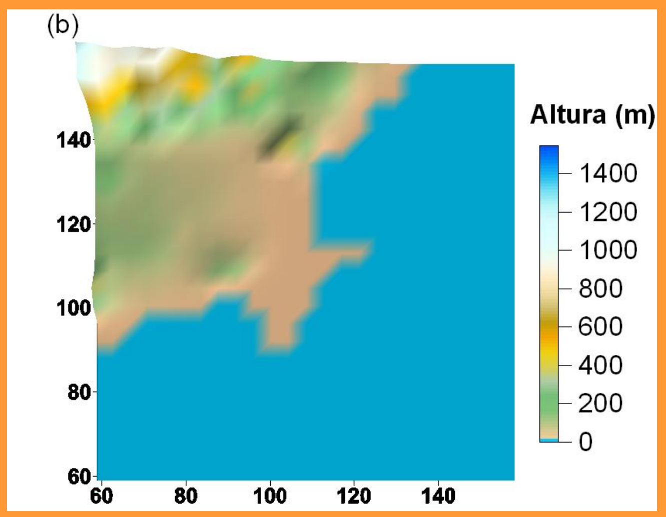
Atmospheric model

Non hydrostatic Mesoscale Vorticity Model (TVM)

- Vorticity equations.
- Tridimensional.
- Incompressible.
- Boussinesq approximations.
- Sigma coordinates.
- The atmospheric surface layer uses the Monin-Obukhov Similarity Theory.

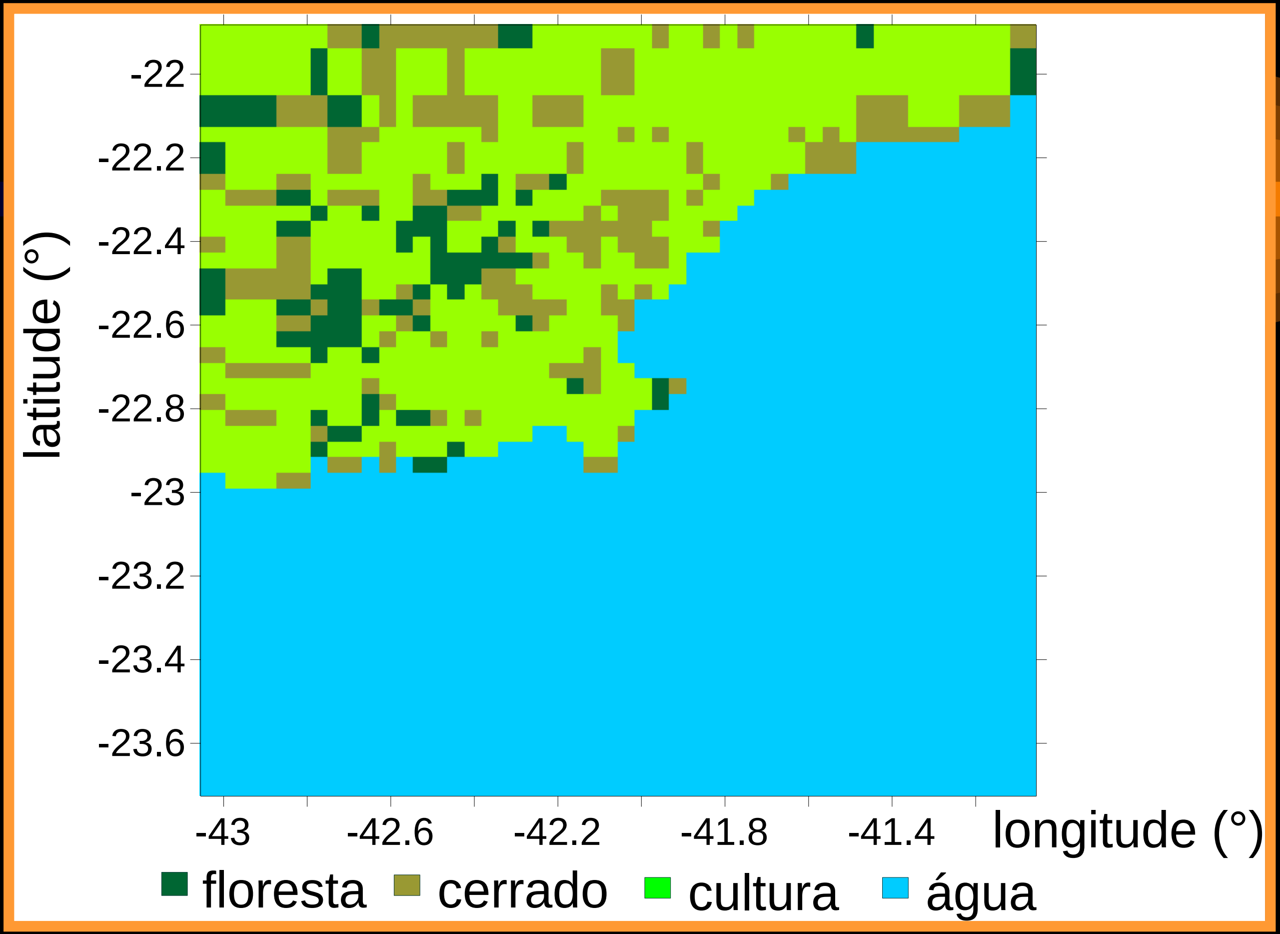
Topography





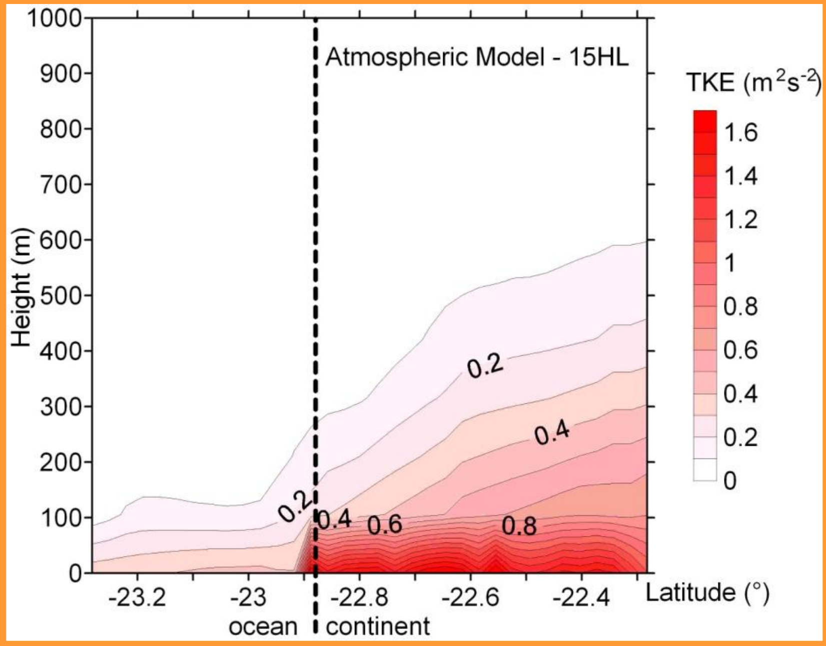
- The local topography was a determining factor in the local atmospheric circulation and indirectly influences the phenomenon of coastal upwelling;

Land use

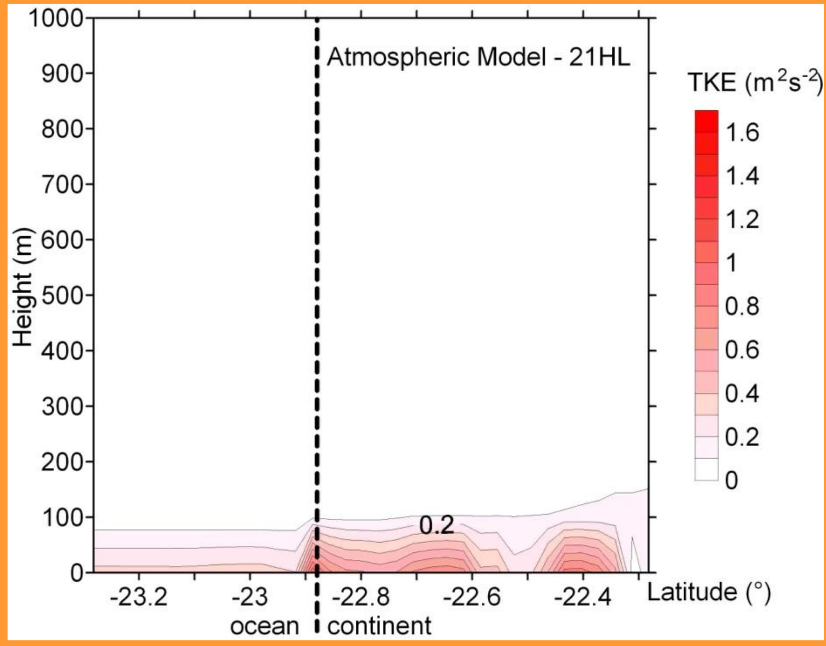


- Land use has minor role in the local atmospheric circulation.

Atmospheric model



Upwelling condition

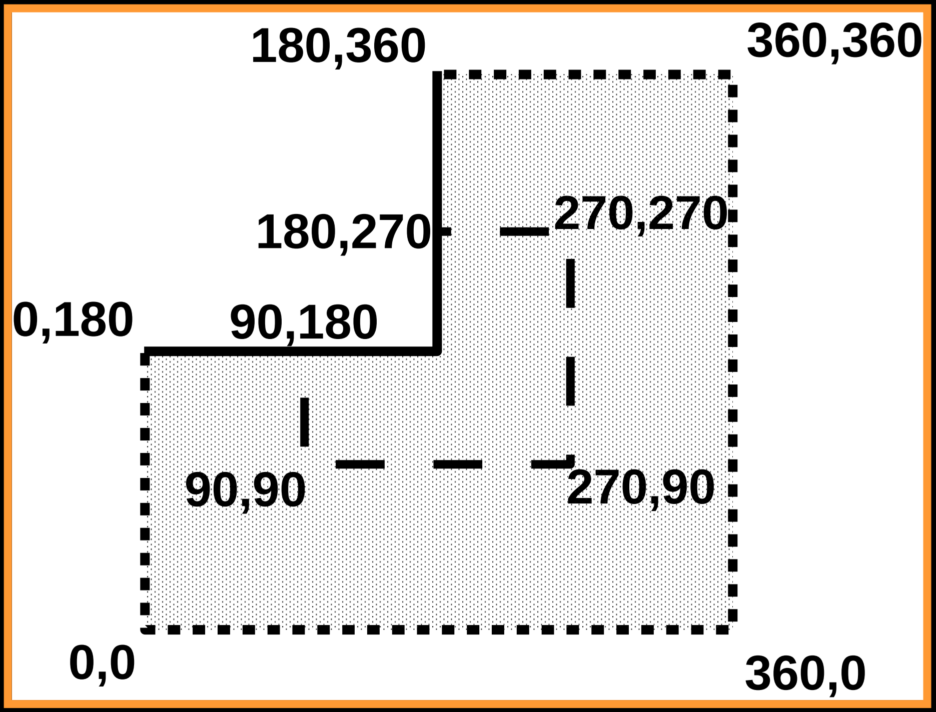


Ocean model

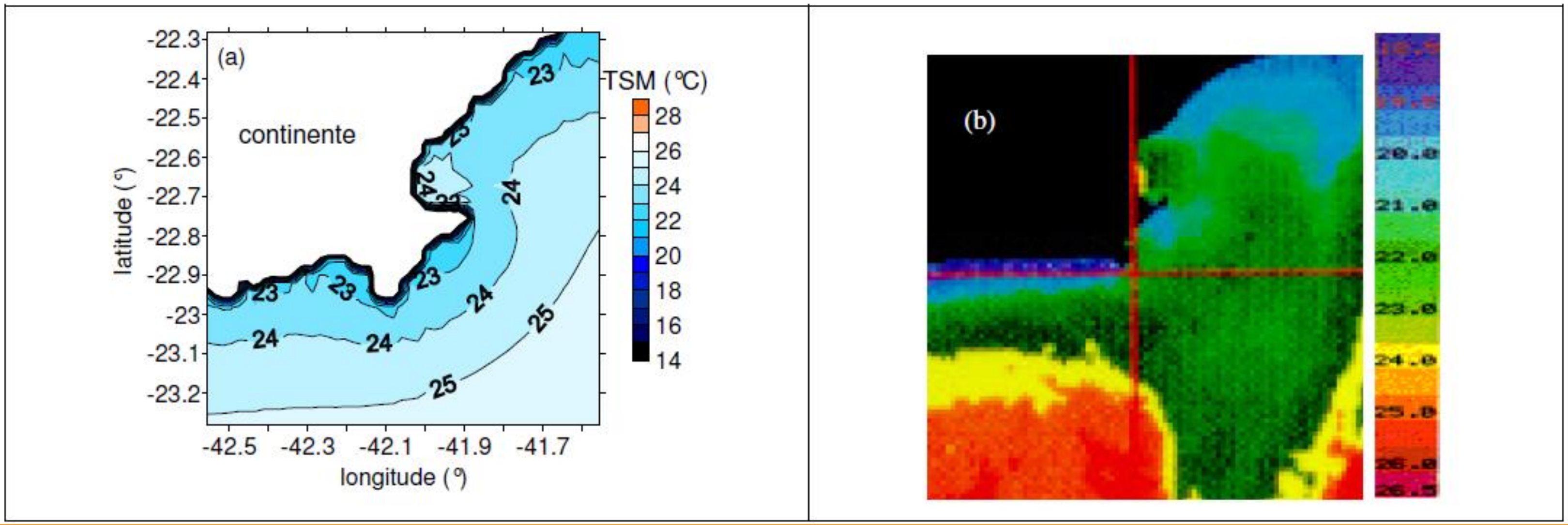
- Bi-dimensional, 1 ½ layers.
- Deep layer inert.
- Surface layer uses nonlinear equations and vertically integrated momentum, continuity and heat.
- Finite differences: advanced in time and centered in space.

Ocean model

Grid points equal to the atmospheric model in the horizontal directions.

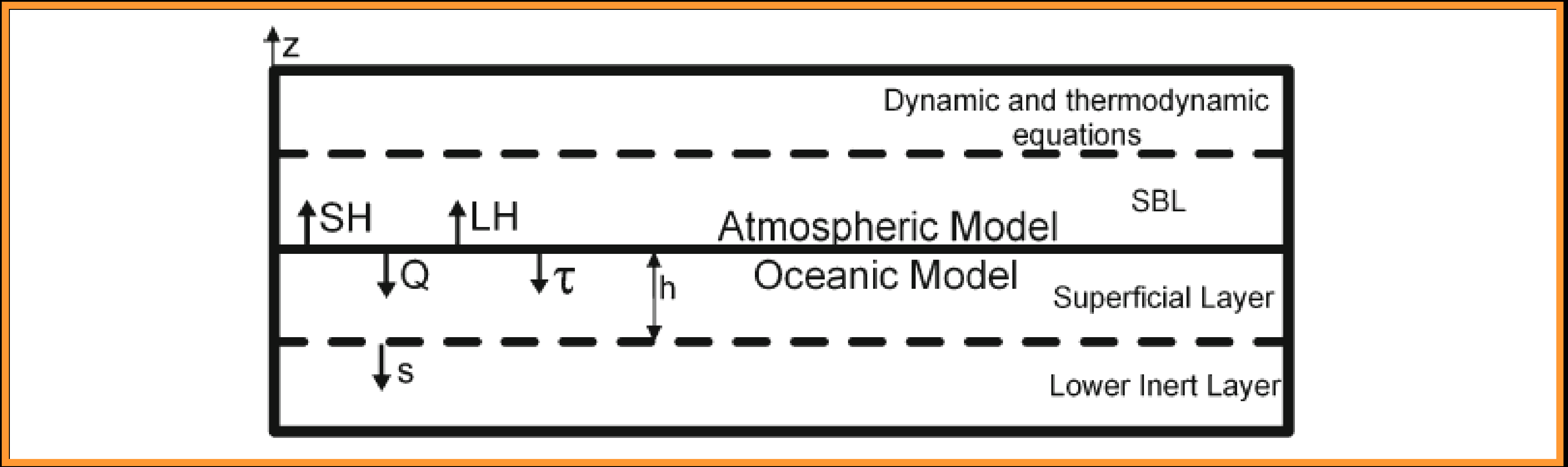


Ocean model



SST field after 2 days of ocean model integration. Line interval equal 1° C.
NOAA-12 satellite (28 Jan 1993).

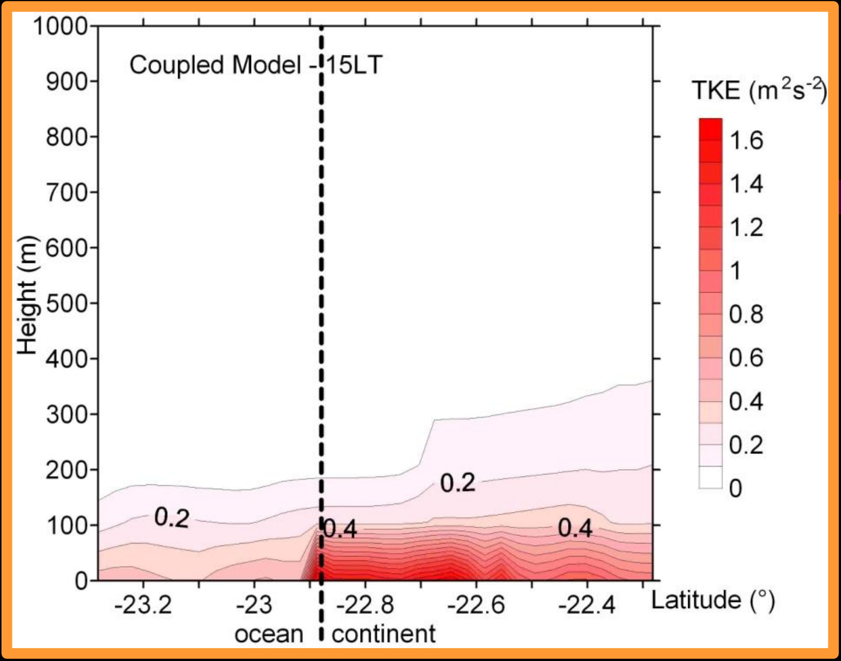
Model coupling

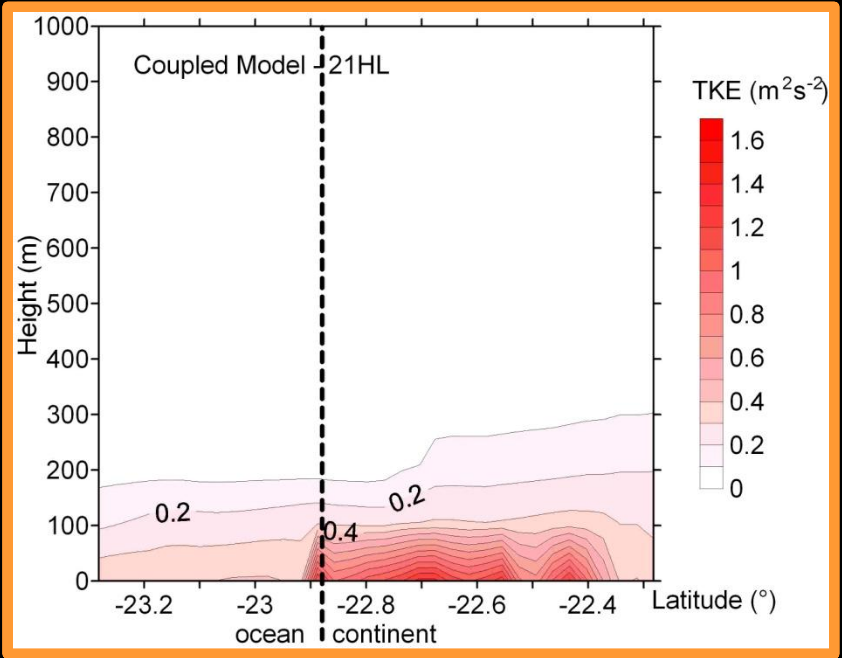


SH → sensible heat flux
LH → latent heat flux
Q → surface heat flux
ζ → momentum flux from the atmosphere to the ocean
s *→ source/ sink of heat across the interface*
H *→ thickness of the oceanic superficial layer.*

Δt (atm) = 30 s and Δt (ocean)= 600 s

Coupled model

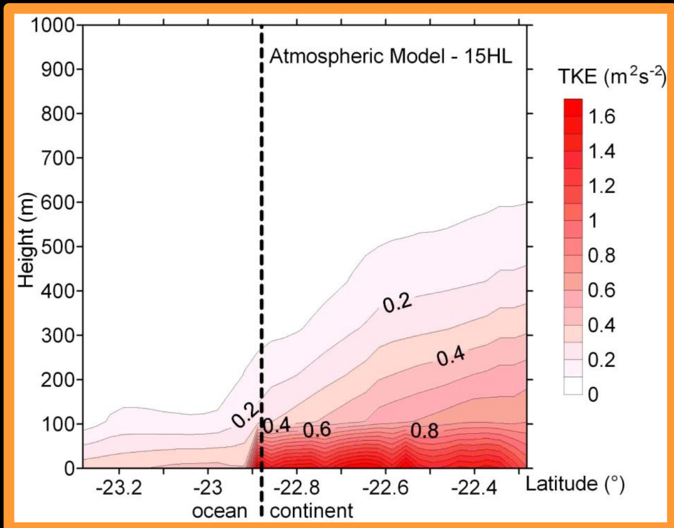


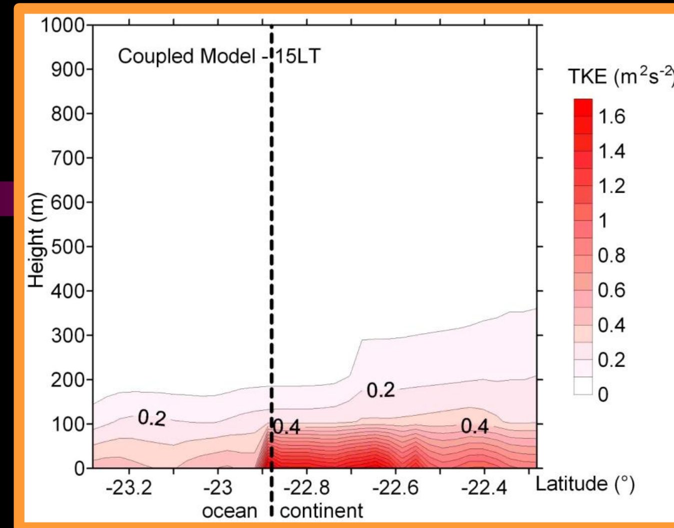


Upwelling condition

Atmospheric

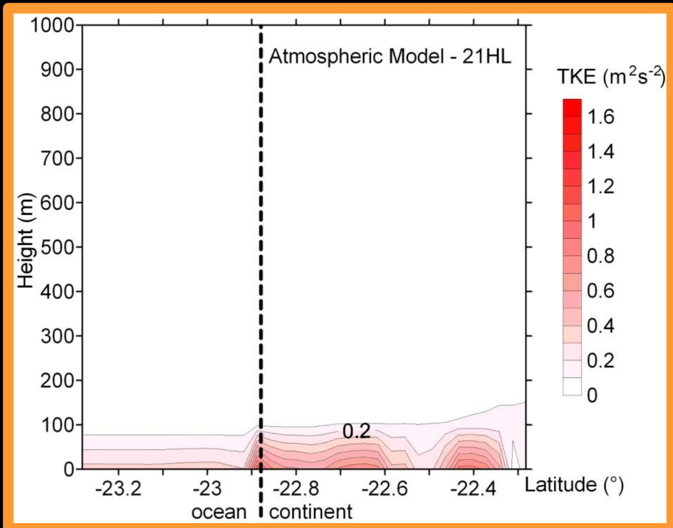
Coupled model

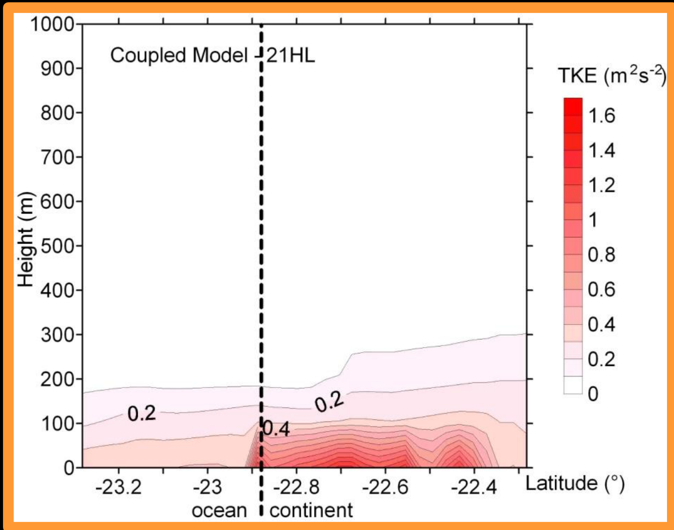




T cte of 20°C

Upwelling condition





Remark

- The results indicate that accurate models of coastal upwelling processes can require representations of ocean–atmosphere interactions on short temporal and spatial scales.

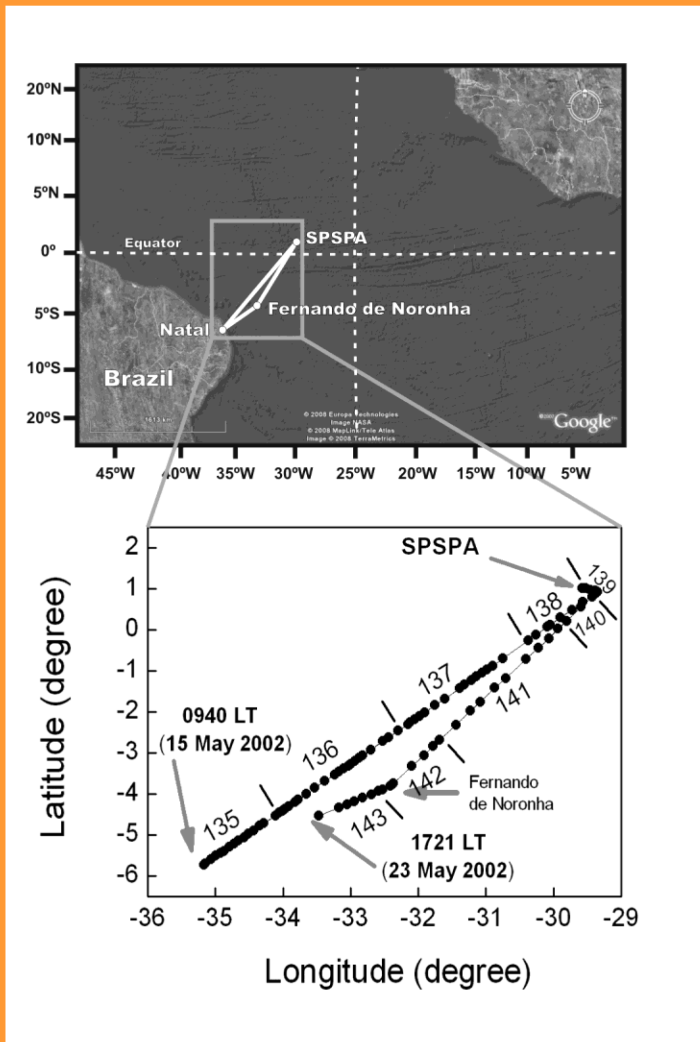
Where to go?

FluTuA

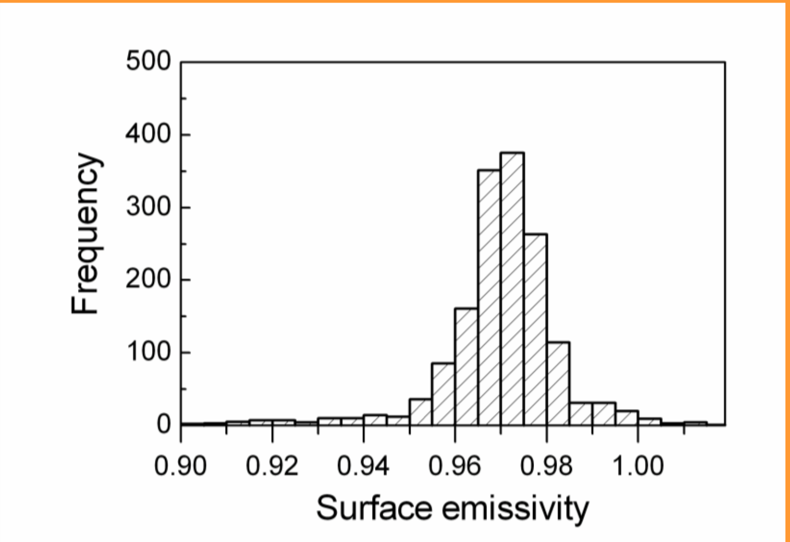
– Observational campaign of May 2002 (mobile platform)

– Observational campaign of December 2008 (tower)

FluTuA
Observational campaign May 2002

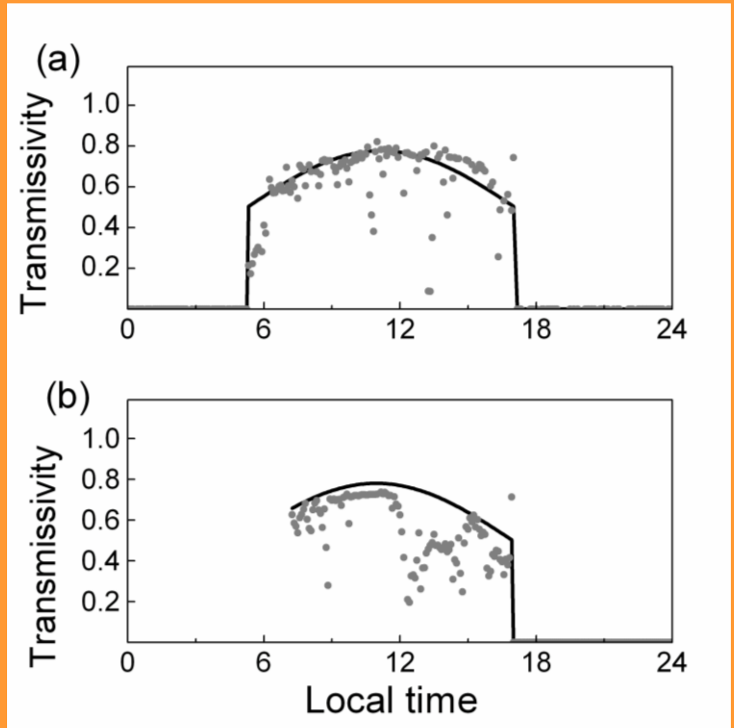


Surface emissivity



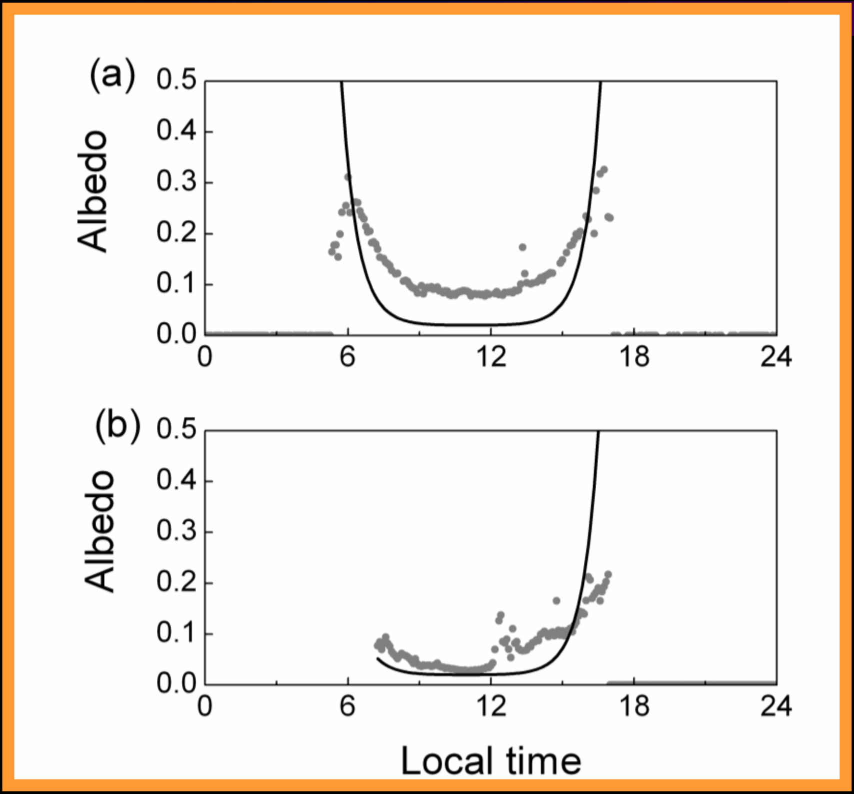
$\varepsilon = 0.97$ Surface emissivity

Broadband atmospheric transmissivity

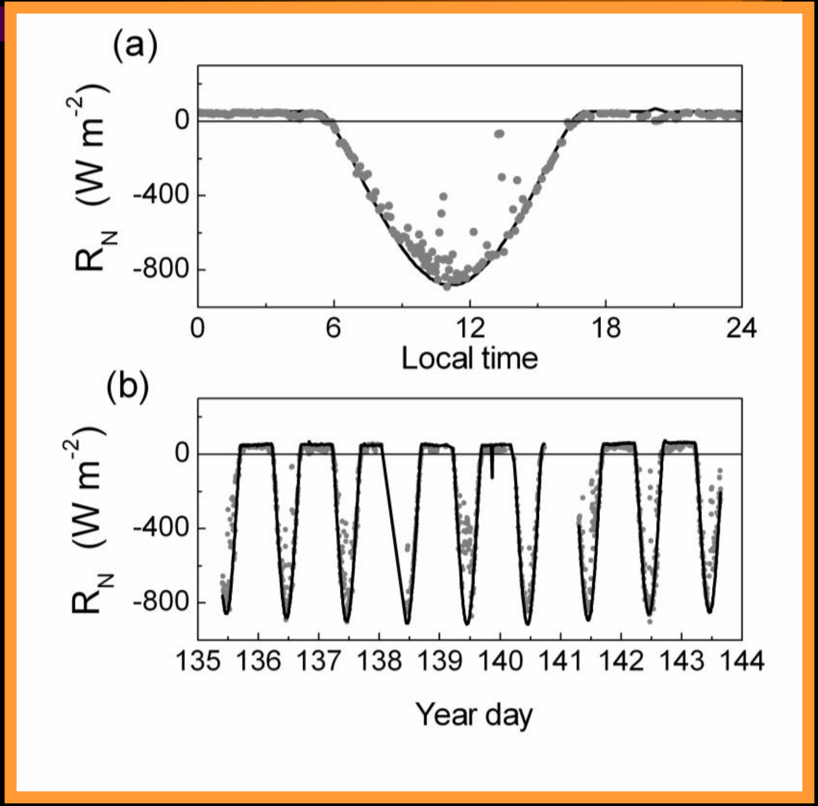


$$\Gamma = 0.5 + 0.3 \cos Z$$

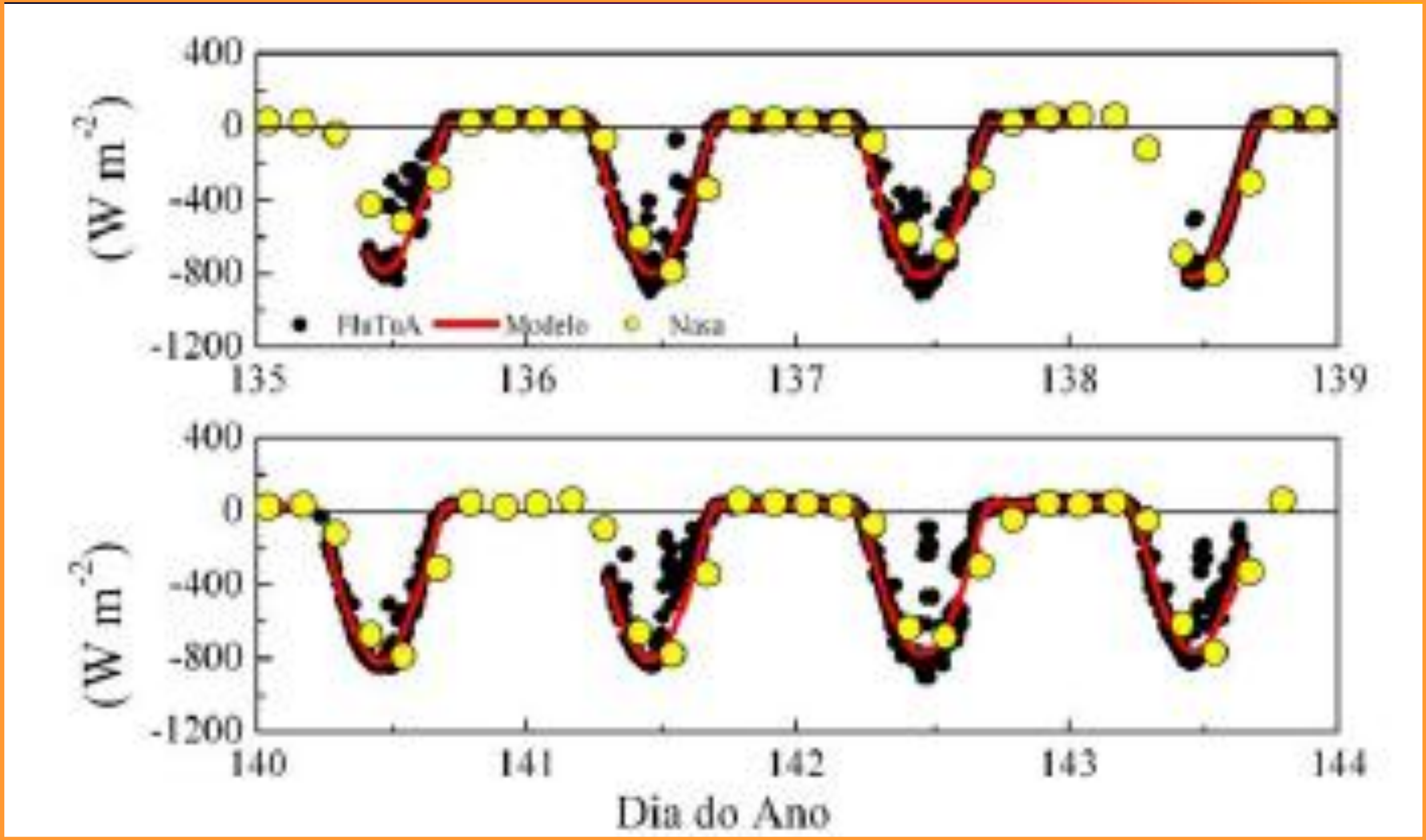
Surface albedo



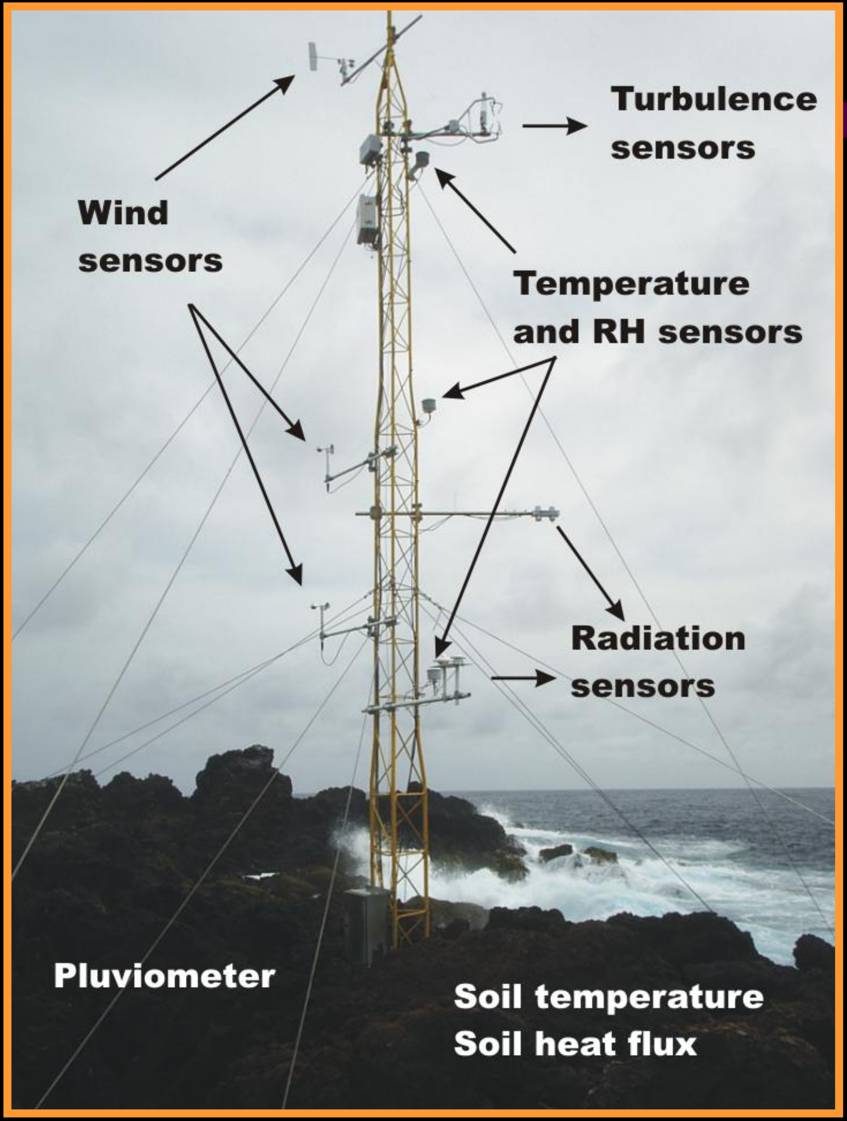
Net radiation



Comparison with satellite estimate (SRB/NASA project)

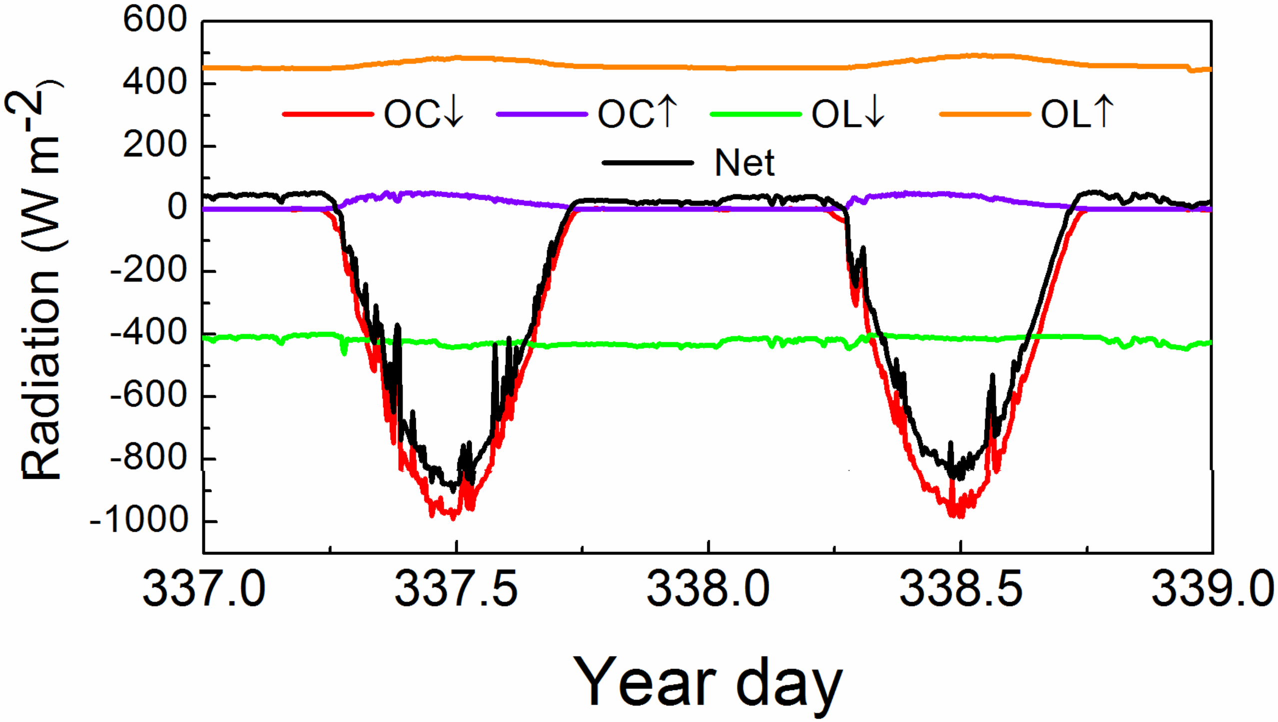


FluTuA
Observational campaign December 2008

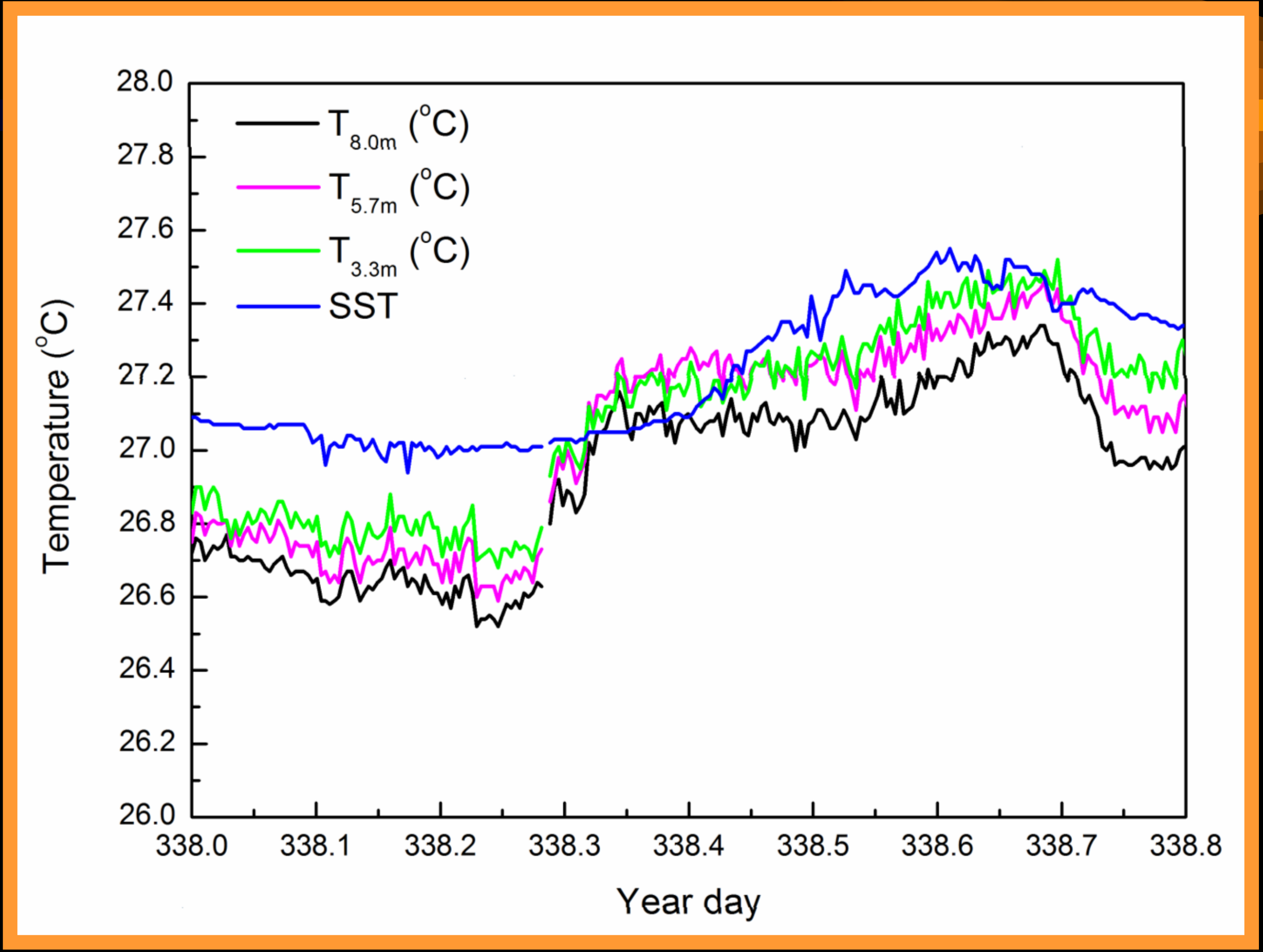


São Pedro and São Paulo Archipelago

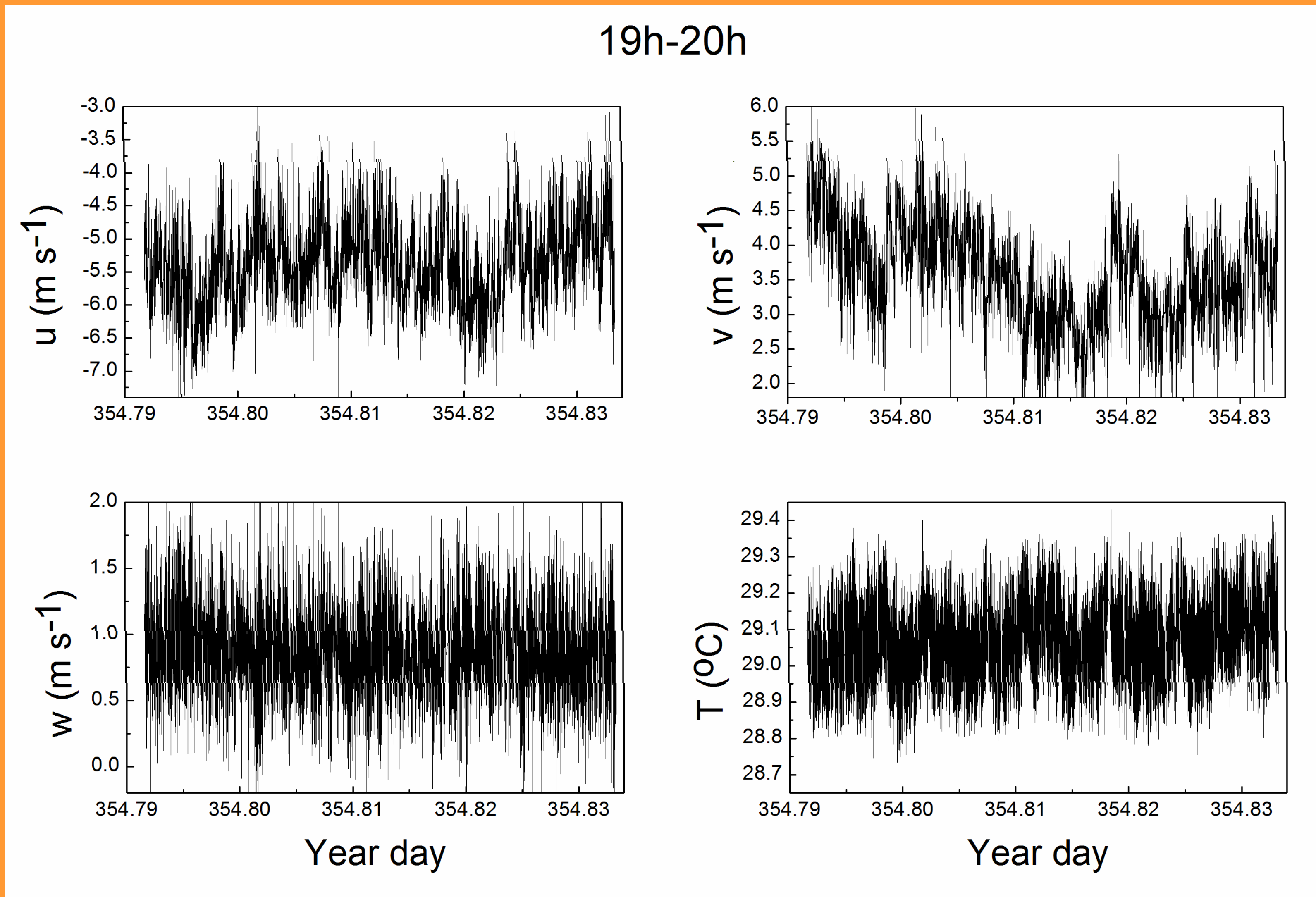
Radiation balance



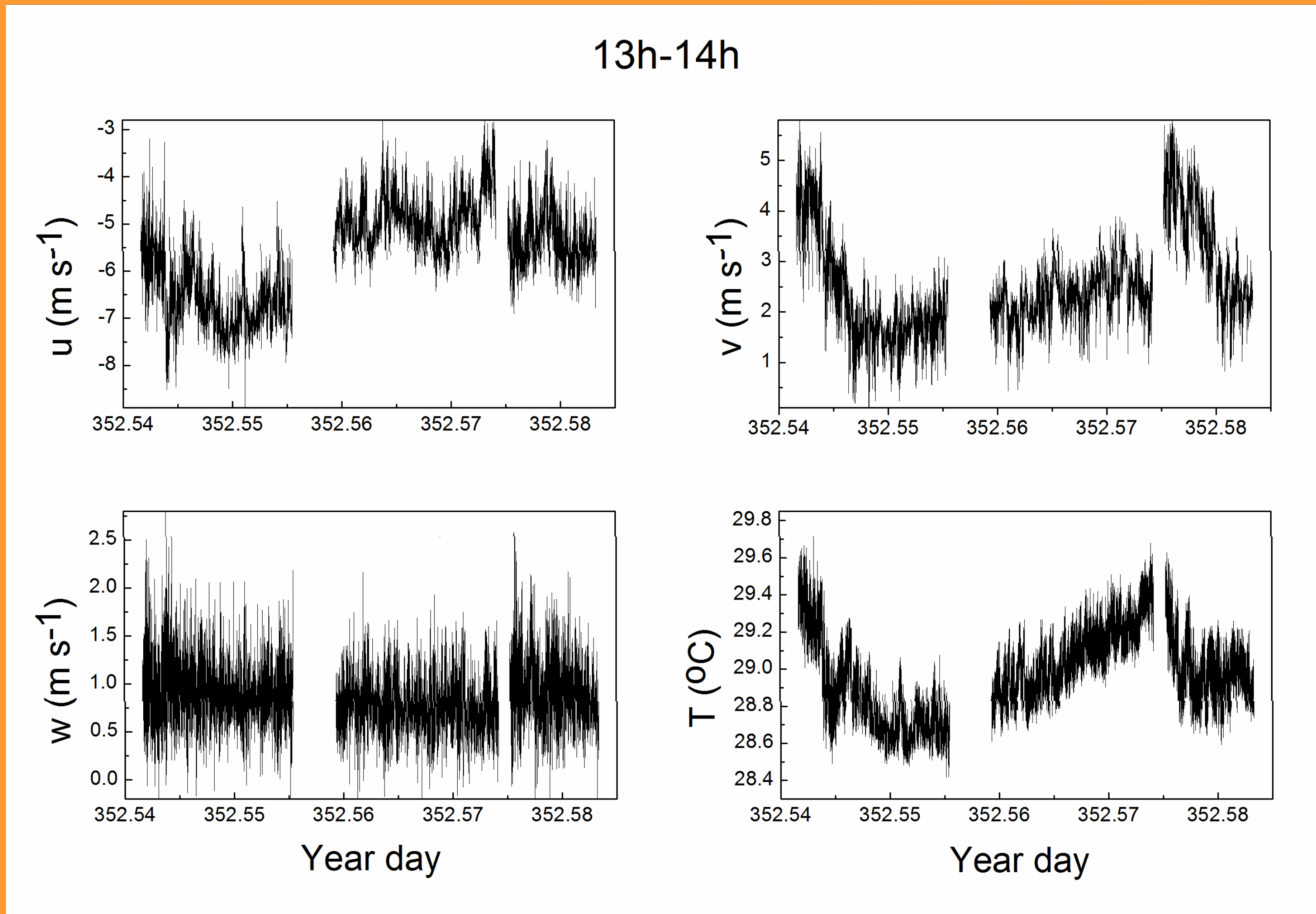
Air temperature and SST



Turbulence – nighttime conditions (20 Hz)



Turbulence – daytime conditions (20 Hz)



Remarks

•Model results depend in part on imperfect parameterizations of boundary layer turbulence, so that conclusions about these dynamics based purely on simulations must be treated with caution.

•Results indicate that air–sea interaction on short temporal and horizontal scales may play a central role in controlling essential elements of ocean circulation.

•It is necessary in situ high frequency measurements.

References

http://www.iag.usp.br/meteo/labmicro/publicacoes/index.html

Soares, J., Oliveira, A. P., Codato, G., Escobedo, J. F.: Local and regional features of surface radiation fluxes over the Tropical Atlantic Ocean near Sao Pedro and Sao Paulo Archipelago: evidence of small scale upwelling. *Nature Environment and Pollution Technology*. (in press).

Ribeiro, F. N. D., Soares, J., Oliveira, A. P., 2011: A coupled numerical model to investigate the air¿sea interaction at the coastal upwelling area of Cabo Frio, Brazil. *Environmental Fluid Mechanics*, v.11, 551 – 572.

Skielka, U. T., Soares, J., Oliveira, A. P., Servain, J., 2011: Diagnostic of the diurnal cycle of turbulence of the Equatorial Atlantic Ocean upper boundary layer. *Natural Science*, v.03, 444 – 455..

Ribeiro, F. N. D., Soares, J., Oliveira, A. P., 2011: The co-influence of the sea breeze and the coastal upwelling at Cabo Frio: a numerical investigation using coupled models. *Brazilian Journal of Oceanography*, v.59, p.131 – 144.

Skielka, U. T., Soares, J., Oliveira, A. P., 2010: Study of the equatorial Atlantic Ocean mixing layer using a one-dimensional turbulence model. *Brazilian Journal of Oceanography*, v.58, 57 – 69.

Bacellar, S.A., Oliveira, A. P., Soares, J., Servain, J., 2009: Assessing the diurnal evolution of surface radiation balance over the western region of Tropical Atlantic Ocean using in situ measurements carried out during the FluTuA Project. *Meteorological Applications*, v.16, 255 – 266.

Thank you!