***3rd Climate Change Symposium***
*Santos, Brazil March 21–27, 2015*

# Decadal variability for the Iberian Margin subsurface structure in response to global warming

***Patrícia Laginha Silva[1], Paulo Relvas[1] and A. Miguel Santos[2]***

**Patrícia Laginha Silva**

PhD student in Earth Sciences, Ocean and Environment,
speciality in Physical Oceanography
Master in Marine and Coastal Studies
Graduate in Oceanography

[1]**Centre of Marine Sciences**, CCMAR

University of Algarve
Gambelas *Campus*
ortugal

[2] Portuguese Institute for Ocean and Atmosphere, IPMA

# Doctoral work plan

**Title –** Long Term Variability of the Canary Current Upwelling System

## Objective:

- How does the structure of the Canary Current Upwelling System (CCUS) respond in decadal scales to the observed global warming?

**1)** Are the climatological patterns changing in the CCUS?

**2)** Which impact has the ocean warming in the mesoscale structure of the CCUS?

**3)** What is the consequence of ocean warming in the subsurface structure of upwelling?

**4)** Which consequences can we observe and expect in the ecosystem productivity?

**5)** How do the changes observed in the Canary System compare with the others EBUS?

## Subsurface study

Investigate the variability of the subsurface structure testing the hypothesis that its fluctuations contribute to changes in upwelling patterns.

Analyze the temporal evolution of the stratification and thermocline depth during the last decades and investigated to what extent the response of the upper ocean to upwelling favorable winds was affected by changes in this vertical structure.

Oceanographic cruises and international databases (mainly NODC)

## Canary Current Upwelling System, CCUS

- The CCUS is one of the major four Eastern Boundary Upwelling Systems (EBUS) of the world.
- The strong dynamic link between the atmosphere and the ocean in these regions makes them highly sensitive to global changes.

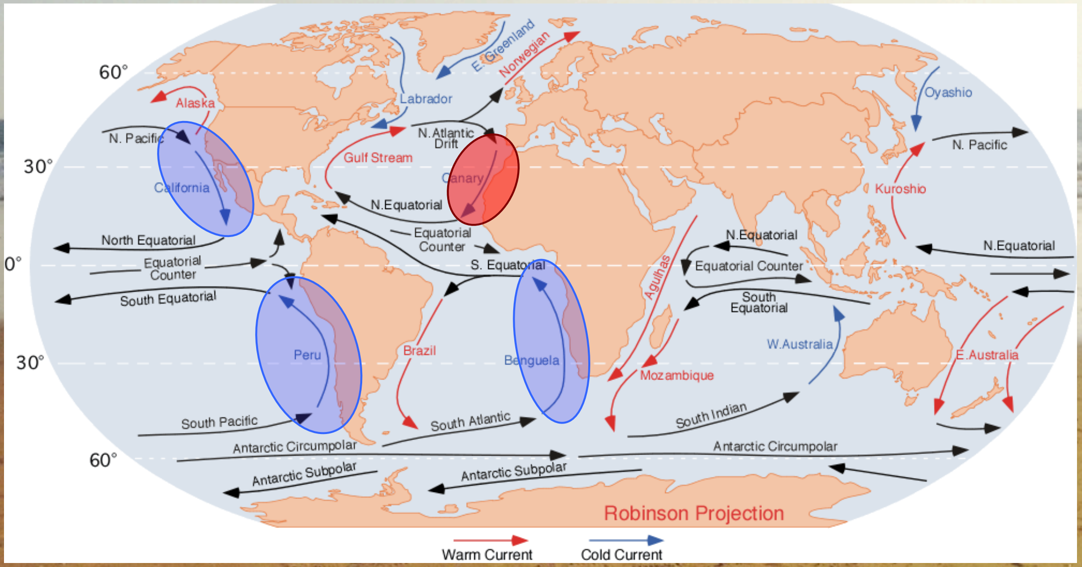



Figure 1 – Global ocean currents

# Canary Current Upwelling System, CCUS

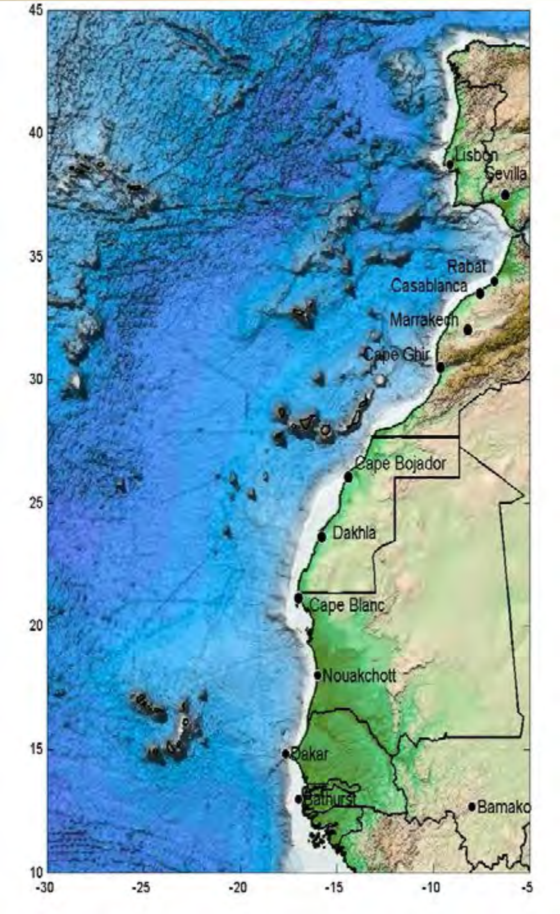



Figure 2 – Geographic localization of CCUS.

The CCUS extends from the northern Iberian Peninsula at 43ºN to the south of Senegal at approximately 10ºN.

Is a unique system since it is divided by the discontinuity imposed by the Mediterranean entrance in:

- a northern segment (Western Iberia) where the upwelling regime has a seasonal prevalence, roughly from <u>April to October</u>,
- a southern segment (NW Africa) were upwelling is:
  1. <u>permanent</u> in the northern part, although intensified during the summer months,
  2. and <u>seasonal</u> further south during winter months.

It has been recognized that the large circulation patterns of the CCUS is largely masked by the mesoscale circulation. The study of this phenomena contributes for a new perception of the physical processes associated to the north part of CCUS (Relvas *et al.*, 2007).

## *State-of-art*

Coastal Upwelling + Global warming

?

**Bakun (1990)**

$(CO_2)_{atm}$ ↑

Nocturne cooling ↓

Diurnal heating ↑

→ **INTENSIFICATION**

Atmospheric system of low thermal pressure

↓

Intensification of the equatorial wind

←

**INTENSIFICATION** of the coastal upwelling

but...

## *State-of-art*

**Santos et al. (2005), McGregor et al. (2007) and Narayan et al. (2010)**

The upwelling intensity increased, supporting the hypothesis of Bakun (1990)

**Lavin et al. (2000), Lemos & Pires (2004), Lemos & Sansó (2006) and Pardo et al. (2011)**

Decay of the upwelling intensity in the CCUS

# ...but they are contradictory results

**Belkin (2009) and Sherman et al. (2009)**

Warming consistent with middle and high latitudes

**Barton et al. (2013)**

Didn't find any clear evidence for the existence of coastal upwelling intensification

# Subsurface study

The study area is the **Iberia Peninsula Upwelling System** (IPUS) from 43º to 36ºN and from -30º to -5ºW.

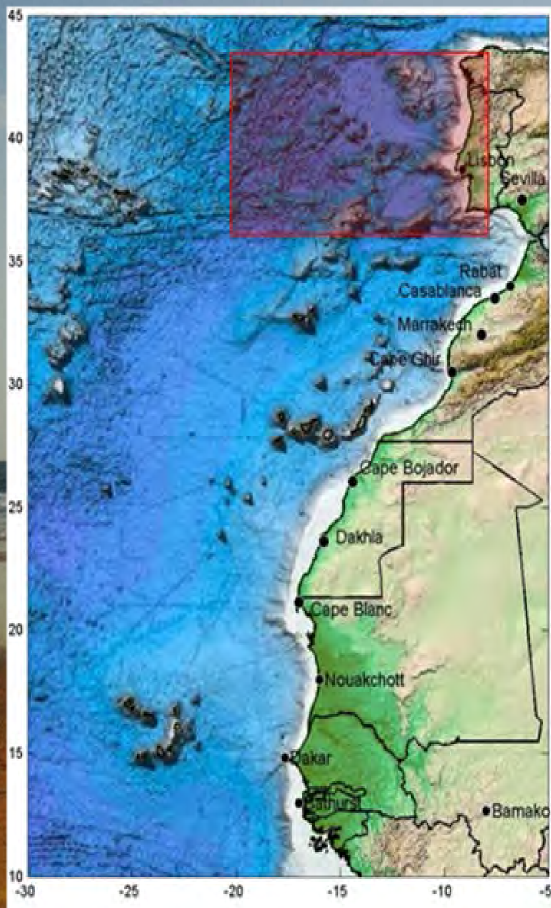



Figure 3 – Study area localization north of the CCUS.

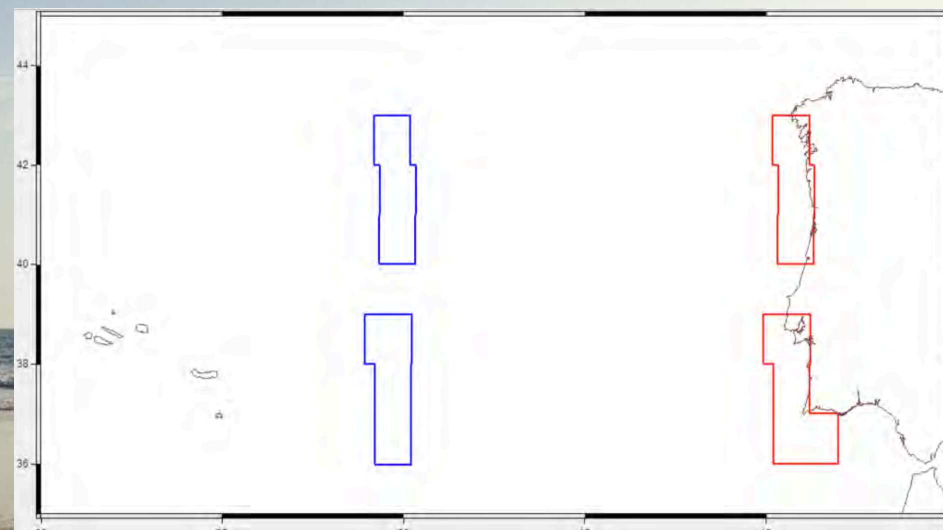
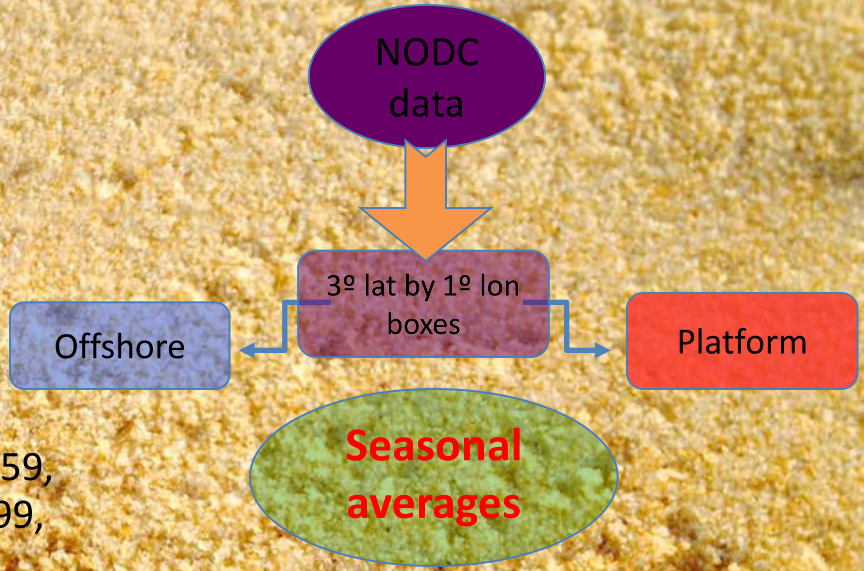


Figure 4 – Localization of the subareas North and South of the Iberia Margin and longitudinal areas: red – platform and blue – offshore.

# **Subsurface study:** methodology




**Standard depths:**
- 0, 10, 20, 30, 50, 75, 100, 125, 150m binned every 5m

**Temporal period:**
- 1950 to 2013 (64 years)
- 6 decades and a four years period (1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009 and 2010 - 2013)

*in situ* temperature

Salinity (PSS-78)

**Potential density**
TEOS-10 algorithm (IOC, SCOR & IAPSO, 2010).

**Spiciness** (Flament, 2002)

- High **spiciness**: warm and salty water
- Low **spiciness**: cold and less salty water

## Subsurface study

Offshore subsurface characterization

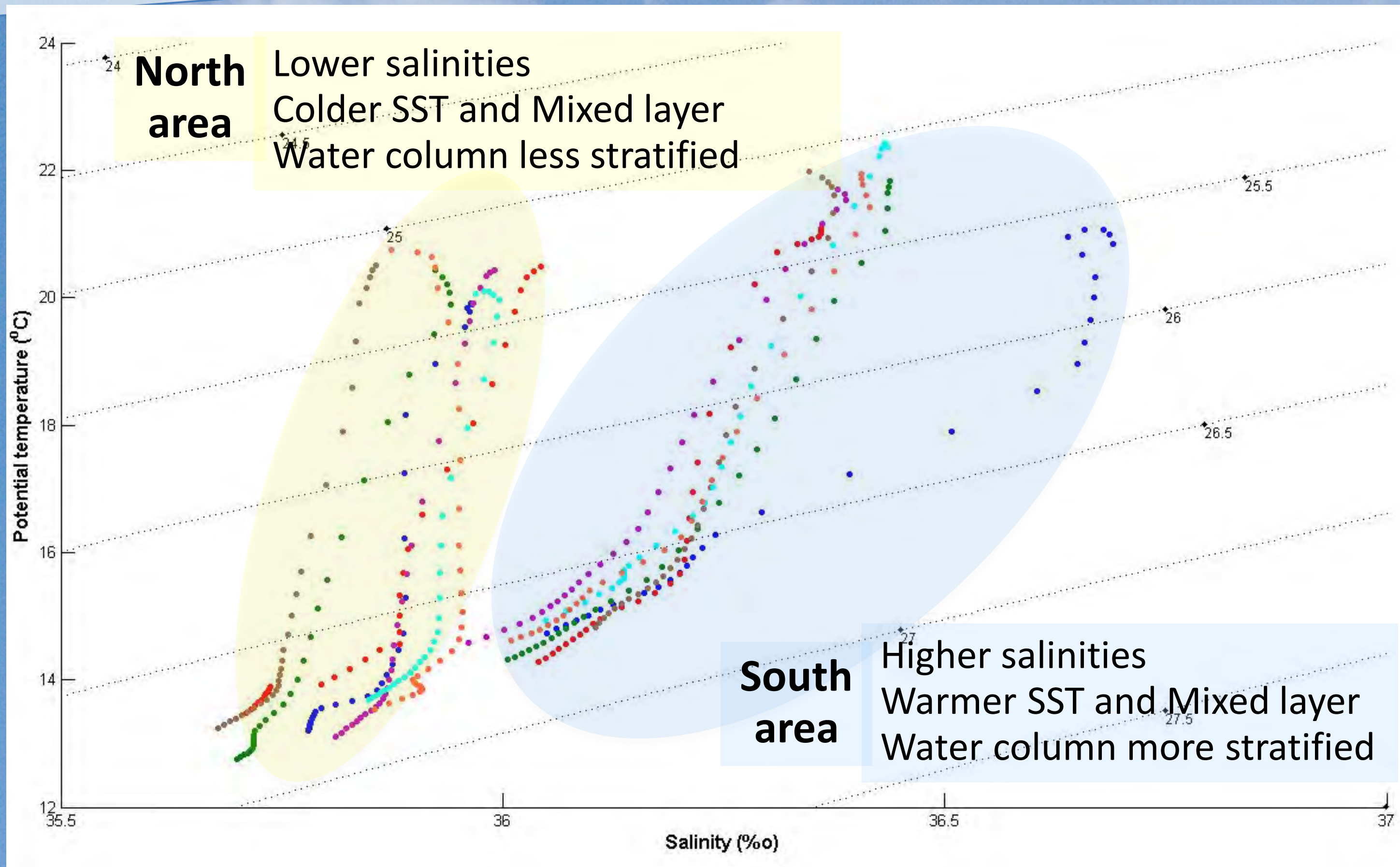



Figure 5 – θ-S diagram with both offshore areas: north at the left side and south at the right side. Each colours represent different temporal periods: 1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009 and 2010-2013.

**Subsurface study**

Platform subsurface characterization

**Overall**
Platform water colder than in offshore
*More distinct at north waters*

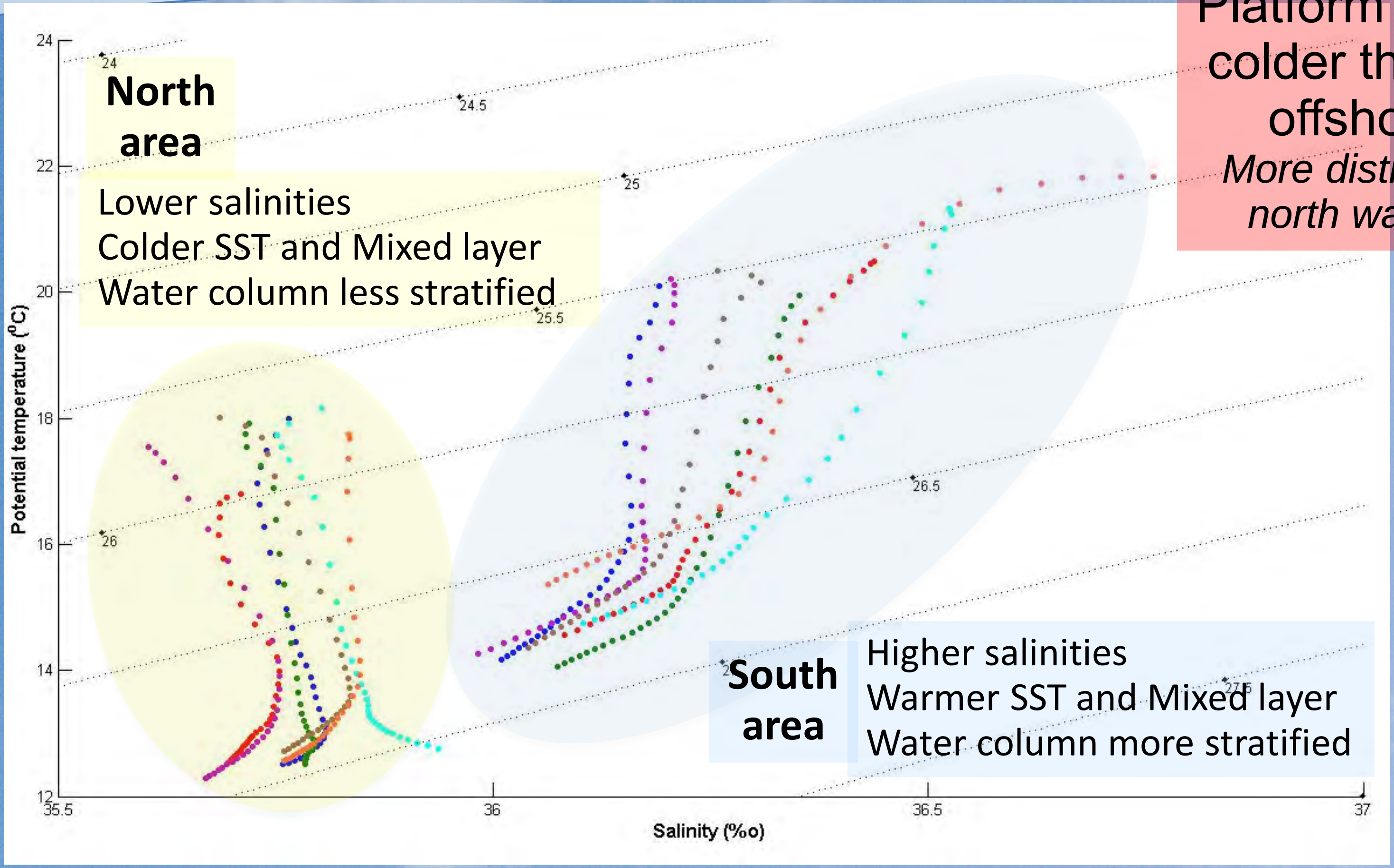



Figura 6 – θ-S diagram with both offshore areas: north at the left side and south at the right side. Each colours represent different temporal periods: 1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009 and 2010-2013.

# IPUS temporal evolution

## Temperature and Salinity

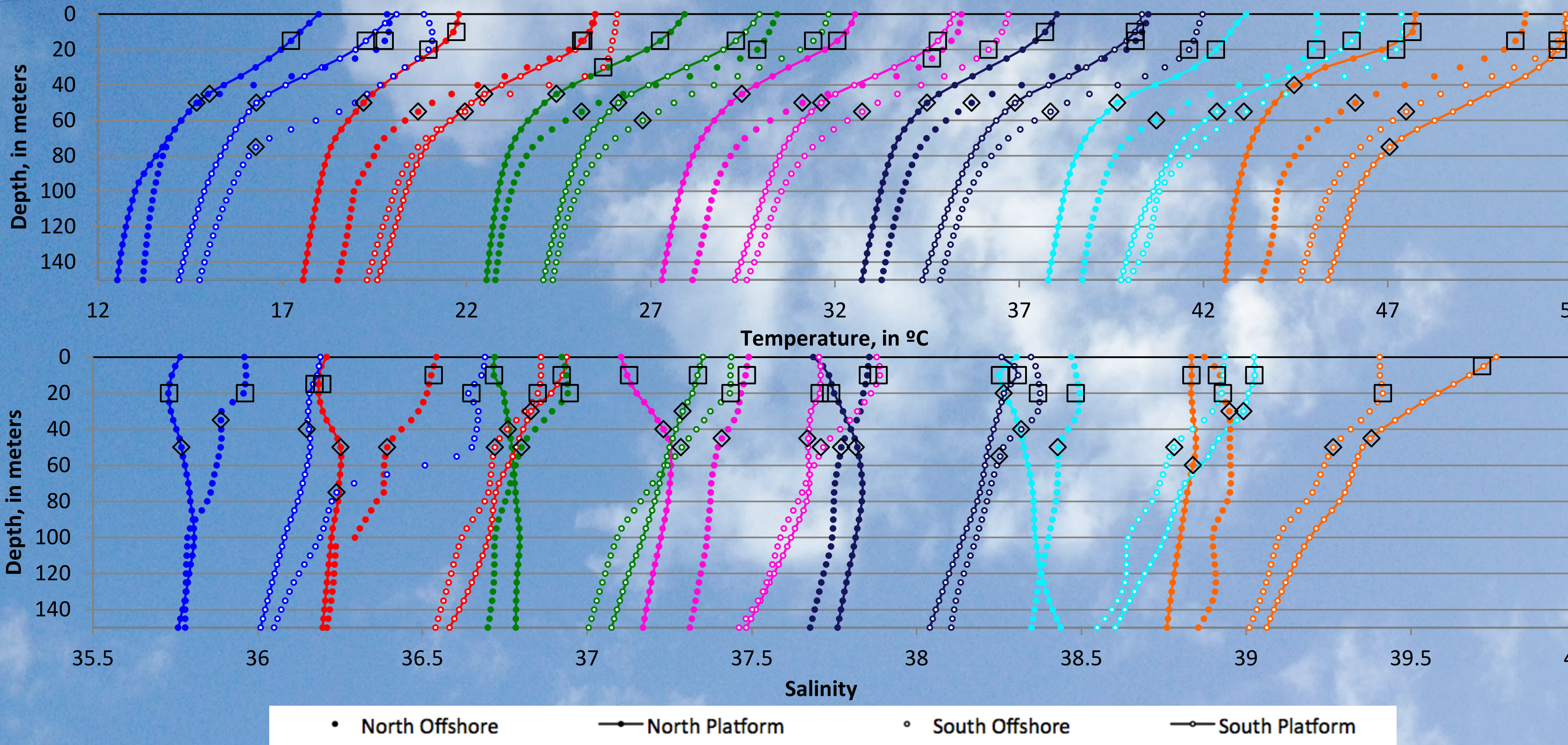



Figure 7 – Temporal evolution of the ocean subsurface (0-150m) temperature seasonal averages (top) and salinity (base). The top and base of the thermocline are both represented with the ■ and ◆ symbols, respectively. The profile colours represent different temporal periods: 1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009 and 2010-2013.

# IPUS temporal evolution

## Density and Spiciness

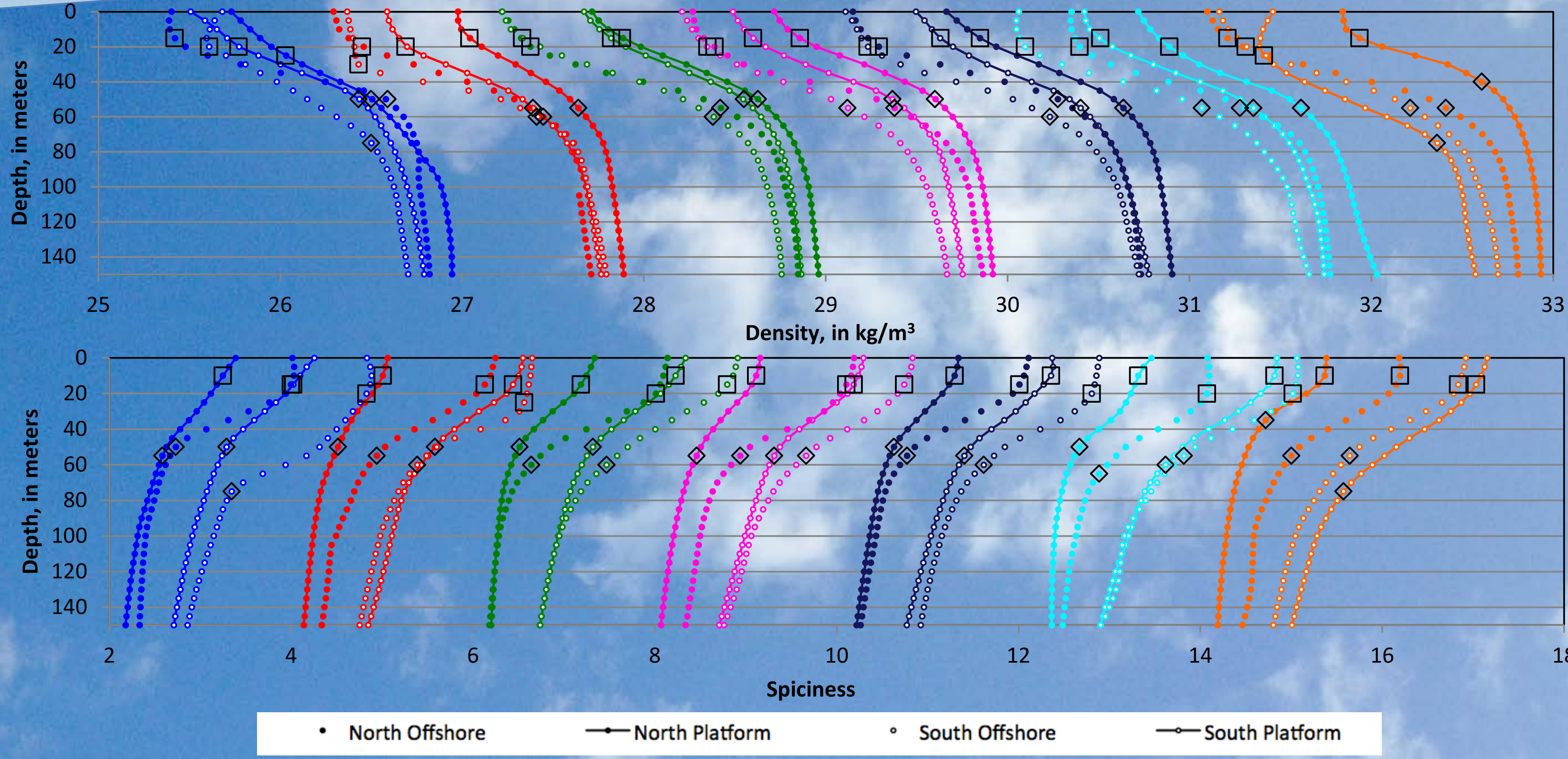



Figure 8 – Temporal evolution of the ocean subsurface (0-150m) density seasonal averages (top) and spiciness (base). The top and base of the thermocline are both represented with the ■ and ◆ symbols, respectively. The profile colours represent different temporal periods: 1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009 and 2010-2013.

## Subsurface study
Preliminary results

north subarea
between **1970 - 1989**

south subarea
between **1960 - 1969**

**Upwelling season:**

Intensification since **1950**

Relaxation since **1990**, more intense in south subarea

- Shown by homogenization within coastal and offshore superficial waters and more similarity between coast and offshore waters.

- North area of IPUS → higher difference between coastal and offshore superficial waters → **Upwelling intensification?**

**South area of IPUS temporal evolution:**

With the relaxation process of upwelling described above is observed that the surface layer of coastal areas is currently **warmer** than in previous decades.

# IPUS geographical divergence

## Maximum gradient thickness

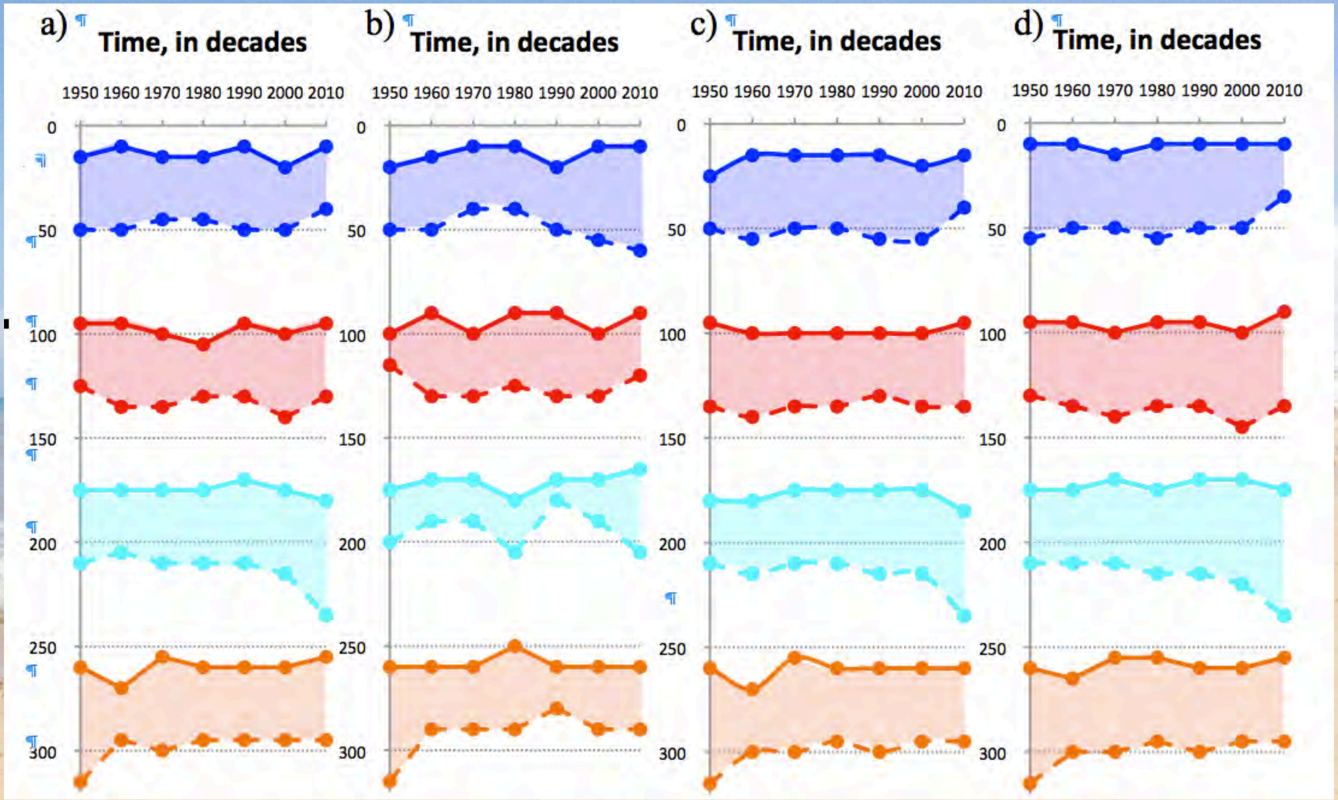



Figure 9 – Maximum gradient thickness variation in time of temperature (a), salinity (b), density (c) and spiciness (d). Each colour represent a different area: **blue – North platform**, **red – North offshore**, **cyan – South platform** and **orange – South offshore**. The vertical scale, depth, is represented by the dotted grey lines spaced 50m (Please note that each area is shifted vertically 80m).

# IPUS geographical divergence

## Amplitude of the maximum gradient zone

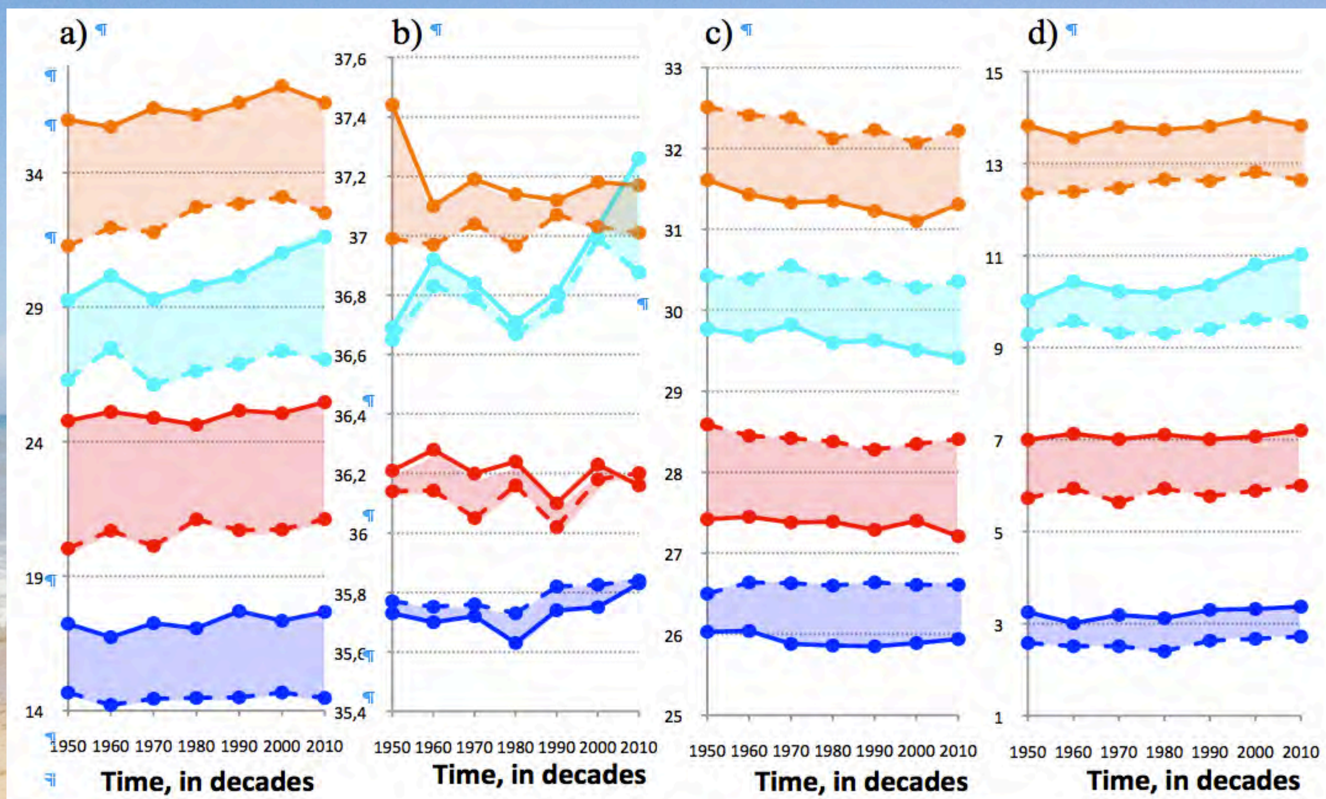



Figure 10 – Temperature (a), salinity (b), density (c) and spiciness (d) maximum gradient variation in time. Each colour represent a different area: **blue – North platform**, **red – North offshore**, **cyan – South platform** and **orange – South offshore**. The vertical scale is the correspondent variable where the dotted grey lines are spaced 5ºC, 0,2 psu, 1 kg/m$^3$ and 2 unit, respectively (Please note that each area is shifted vertically 5ºC, 0,25 psu, 2 kg/m$^3$ and 3 unit).

# IPUS geographical divergence

Results

Clear discrepancy between the north and south study areas of the IUS:
-the south waters are warmer, saltier and consecutive denser than the north waters.

**TEMPERATURE**

South coastal waters thermocline → deepener of the lower limit → bigger thickness
Coastal waters thermocline → similar temperature gradient with offshore waters.
Increasing of thermocline gradient → more perceptible in the south area of the IUS
Offshore waters thermocline → Higher gradient and a tendency for the upper limit to get shallower

**SALINITY**

Halocline → smaller gradient and depth in all area of IUS
All IUS area excepting the north coastal area → almost vertical but still inverted halocline
Coastal waters → bottom of the halocline is getting deeper in time → higher thickness and gradient in recent years
Offshore waters → halocline thickness very stable and its gradient is getting smaller but of same salinities values

**DENSITY and SPICINESS**

Maximum gradient thickness → similar pattern with temperature
Offshore waters → great density gradient
Platform waters → small density gradient
Spiciness maximum gradient zone → directly correlated with the temperature distribution

**Subsurface study**

Conclusion

*Possible strengthening of the upwelling process in recent years?*

pycnocline → shallow and small thickness
homogeneous water column

Subsurface of the Iberian Margin coastal waters

**Generalized warming**

Minor extension in the **north coastal** area of the Iberian Margin

Increasing of the thermocline gradient

**Higher stratification**

Sinking of the thermocline lower limit?

Rising of the mixed layer depth?

Oceanic area offshore the Iberian Margin

climate variability patterns Influence

Warming less intense

**mixed layer** getting warmer over the years

**Lower stratification**

# Acknowledgments

**3rd Climate Change Symposium Travel Grant financed by:**

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

**PhD financed by:**

PD F

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

# Bibliographic references

## Methodology


- **Atkinson**, L. P.; Huthnance, J.; Blanco, J. L. (2005). *Circulation, mixing and the distribution of remineralized nutrients*. In: Robinson, Allan R.; Brink, Kenneth H., (eds.) The global coastal ocean: multiscale interdisciplinary processes. Cambridge, Massachusetts, Harvard University Press, 227-267, 1033pp. (The Sea, Vol. 13).
- **de Boyer Montégut**, C.; Madec, G.; Fischer, A. S.; Lazar, A.; Iudicone, D. (2004). *Mixed layer depth over the global ocean: An examination of profile data and a profile-based climatology*. J. Geophys. Res. 109, C12003.
- **Dong**, S., J. Sprintall, S. T. Gille, and L. Talley (2008). *Southern Ocean mixed-layer depth from Argo float profiles.* J. Geo- phys. Res., 113, C06013, doi:10.1029/2006JC004051.
- **Flament**, P (2002). *A state variable for characterizing water masses and their diffusive stability: spiciness.* Progress in Oceanography. Volume 54, 2002, Pages 493-501. University of Hawaii at Manoa, Honolulu, HI 96822, USA.
- **Fritsch**, F.N.; Carlson, R.E. (1980). *Monotone Piecewise Cubic Interpolation*. Society for Industrial and Applied Mathematics (SIAM) J. Numer. Anal. Vol. 17, No. 2, April 1980.
- **Holte**, J.; Talley, L. (2008). *A new algorithm for finding mixed layer depths with applications to Argo data and Subantartic Mode Water Formation*. Journal of Atmospheric and Oceanic Technology, Volume 26, 1920-1939 pp.
- **IOC, SCOR and IAPSO** (2010). *The international thermodynamic equation of seawater - 2010: Calculation and use of thermodynamic properties*. Intergovernmental Oceanographic Commission, Manuals and Guides No. 56, UNESCO (English), 196 pp.
- **Lukas**, R., and E. Lindstrom, 1991: The mixed layer of the western equatorial Pacific Ocean. J. Geophys. Res., 96, 3343–3358.

# Bibliographic references

## Coastal upwelling


- **Barton**, E.D.; Field, D.B.; Roy, C. (2013). *Canary current upwelling: More or less?* Progress in Oceanography 116, 167-178.
- **Belkin**, I.M. (2009). *Rapid warming of large marine ecosystems.* Progress in Oceanography 81, 207-213.
- **Lavín**, A., G. Díaz del Río, J. M. Cabanas y G. Casas. 2000. *Afloramiento en el noroeste de la península Ibérica. Índices de afloramiento para el punto 43ºN 11º W. Periodo 1990-1999.* Datos y resúmenes Instituto Español de Oceanografia. Nº 15, 25 pp.
- **Lemos**, R. T. and Pires, H. O. (2004). *The upwelling regime off the West Portuguese Coast*, 1941–2000. Int. J. Climatol., 24: 511–524.
- **Lemos**, R. T. and Sansó, B. (2006). *Spatio-temporal variability of ocean temperature in the Portugal Current System.* Journal of Geophysical Research, 111, C04010.
- **McGregor**, H.V., Dima, M., Fischer, H.W. and Mulitza, S. 2007. *Rapid 20th-century increase in coastal upwelling off northwest Africa.* Science 315: 637-639.
- **Narayan**, N.; Paul, A.; Mulitza, S.; Shulz, M. (2010). *Trends in coastal upwelling intensity during the late 20th century.* Ocean Sciences 6, 815-823.
- **Pardo**, P.D.; Padín, X.A.; Gilcoto, M.; Farina-Busto, L.; Pérez, F.F. (2011). *Evolution of upwelling systems coupled to the long-therm variability in sea surface temperature and Ekman transport.* Climate Research 48, 231-246.
- **Santos**, A.M.P., A.S. Kazmin, A. Peliz (2005). *Decadal Changes in the Canary Upwelling System as Revealed in Satellite Observations and its Impact upon Bioproductivity.* Journal of Marine. Res., 63, 359-379.
- **Sherman**, K.; Belkin, I.; Friedland, K.; O'Reilly, J.; Hyde, K. (2009). *Accelerated warming and emergent trends in fisheries biomass yields of the world's large marine ecosystems.* Ambio 38 (4), 215-224.