IOVWST Meeting

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Impact of fine-scale wind stress curl structures on coastal upwelling dynamics : The Benguela system as a case of study.

Fabien Desbiolles[1,2], Bruno Blanke[1], and Abderrahim Bentamy[2]

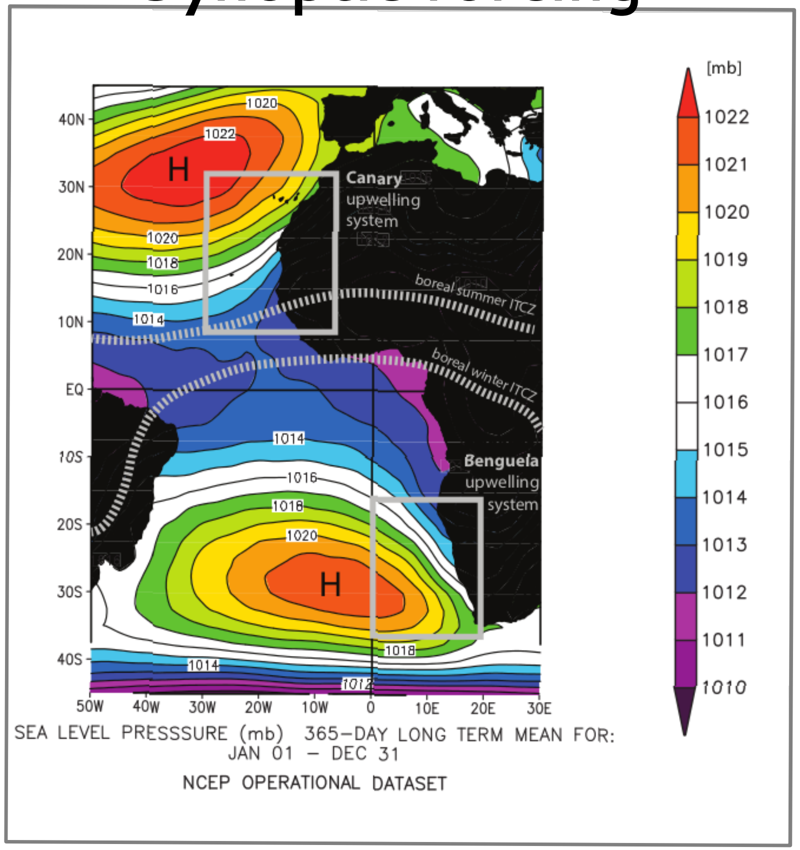
(1) Laboratoire de Physique des Océans – UMR 6523 CNRS–Ifremer–IRD–UBO, Brest, France

(2) Laboratoire d'Océanographie Spatiale – Ifremer, Plouzané, France

Introduction : Upwelling systems

Atmosphere-driven cooling processes

Synoptic forcing



The trade winds variability is controlled by two atmospheric high-pressure systems and drives upwelling seasonality in both Atlantic systems.

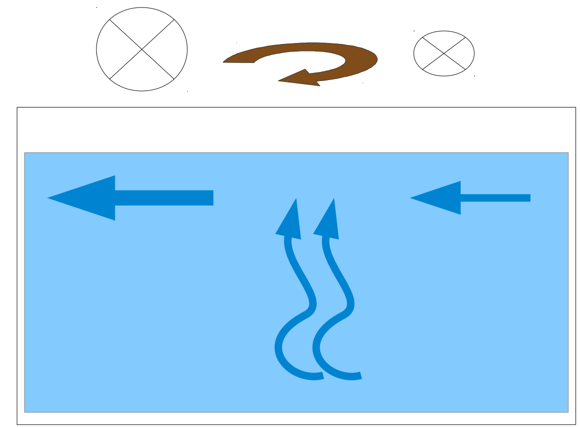
Mechanism: Offshore Ekman Transport

Seaward advection in the upper ocean
==> Compensating upward movement at the coast.

Local forcing

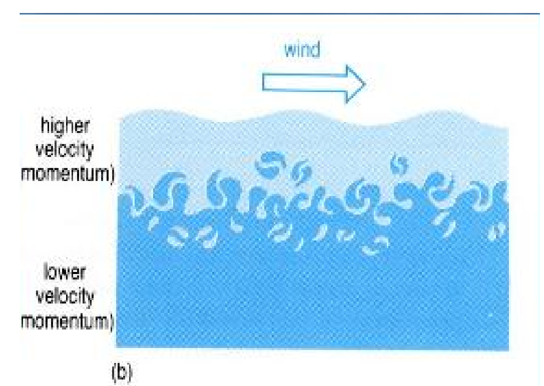
Local horizontal wind shear

Mechanism: Ekman pumping



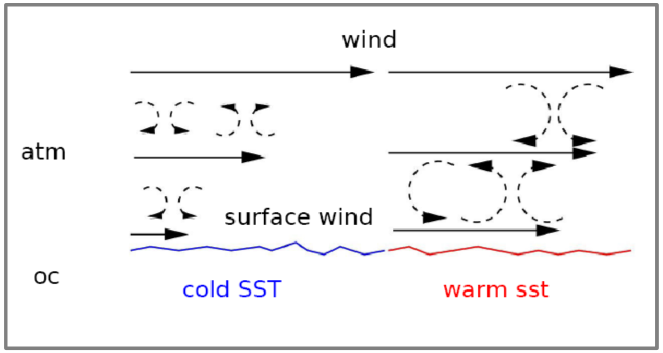
Increase in the momentum fluxes
==> Deepening of the surface mixed layer.

Mechanism: Vertical mixing



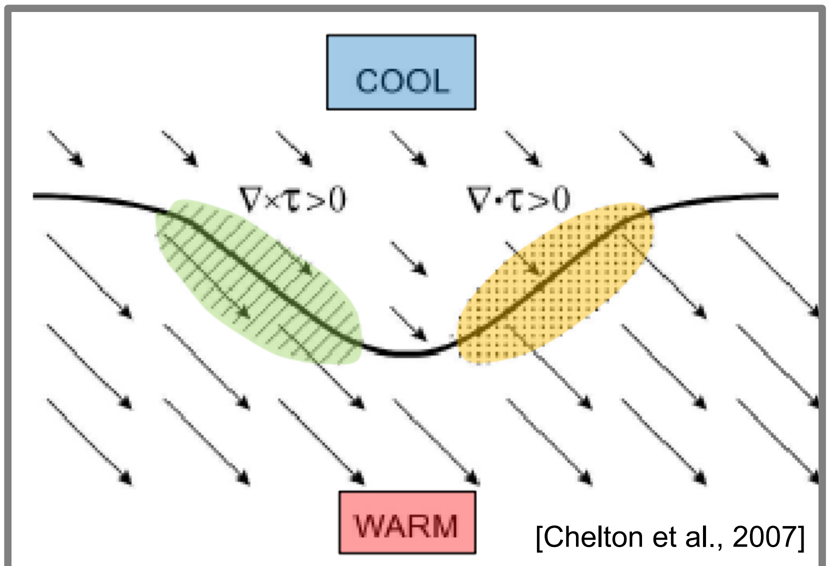
Introduction : Upwelling systems

When the ocean feeds back on the atmospheric flow



The stability of the Marine Atmospheric Boundary Layer (MABL) is modulated by the SST.

Deceleration (acceleration) of the wind over cold (warm) waters.

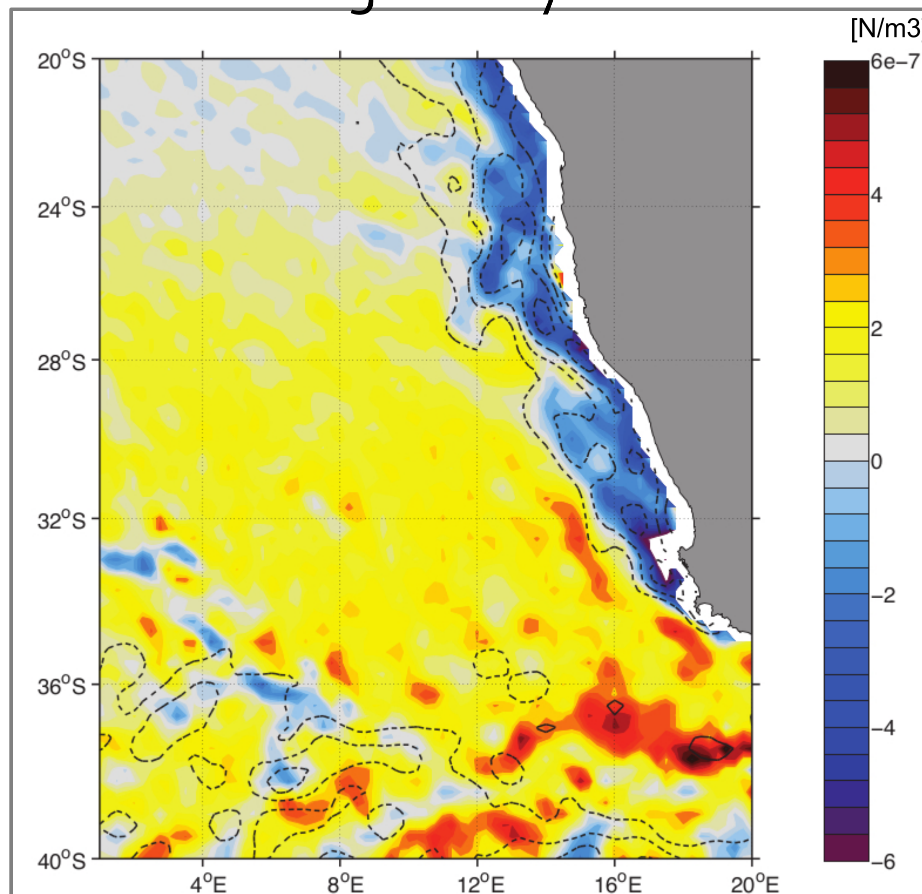


Wind stress curl ~ Crosswind SST gradient

Wind stress divergence ~ Downwind SST gradient

Approximate linear relationships

Benguela system



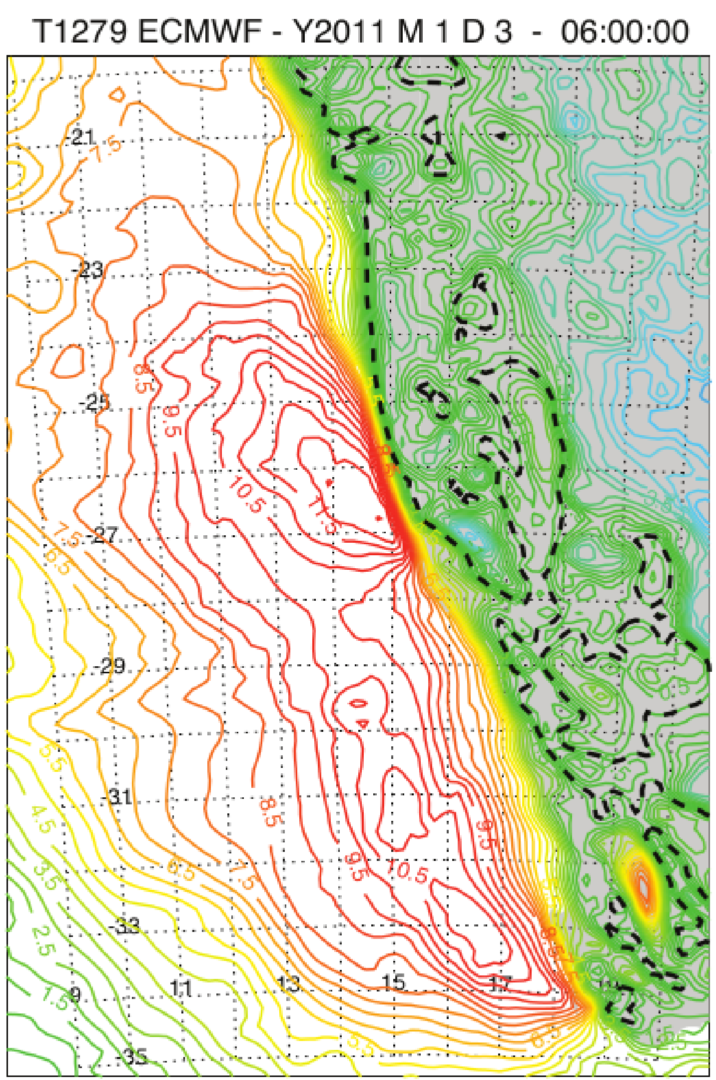
Summertime 2005, mean conditions

Wind stress curl (colors) and crosswind SST gradient (contours, CI=0.3° per 100 km)

Introduction : Upwelling systems

Orographic effect in the coastal band

The wind is constrained by the coast, especially with a rugged coastline or pronounced orography.



Meridional component of the wind on 3 January 2011 at 06:00:00 UTC from the IFS operational ECMWF spectral model. Contour interval : 0.5 m/s

[*Capet et al.*, 2004]

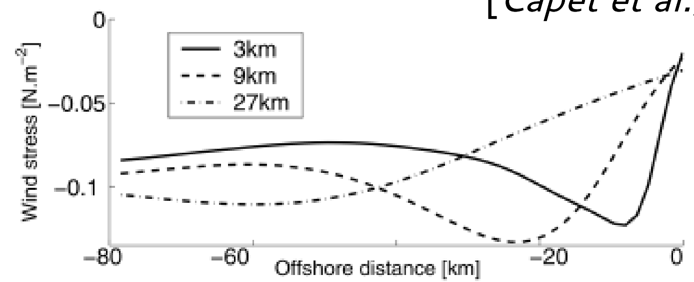
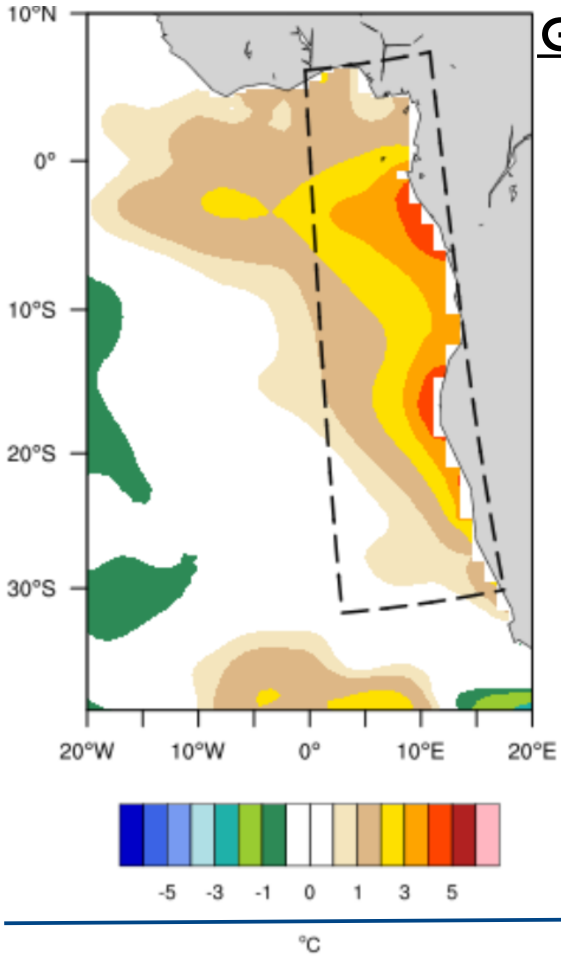


Figure 1. COAMPS alongshore wind stress vs. distance to the coast at 3 different resolutions. The wind is averaged over a 30 km alongshore interval south of Pt. Sur during August 2003.

See also Renault *et al.* [2015]

The whole upwelling dynamics may be affected by the competition between reduced Ekman transport divergence and increased upwelling–favorable wind curl.

Introduction : Motives and purpose



Global Context :

Climate models often show substantial SST warm biases in Eastern Boundary Upwelling Systems (EBUS)

[Small et al., JC submitted]

Regional Context :

Cold biases in modeled SST can be ascribed to poorly resolved wind variability (e.g., Burls and Reason [2008]).
Higher-resolution products must sample mesoscale variability of the wind stress near the coast.

What are the wind scales at play in upwelling dynamics and for which processes ?

Twofold purpose :

1. Better document and quantify enhancements to wind stress structures in Southern Benguela dynamics

2. Highlight the short-term upwelling responses to the unique change of momentum fluxes in an hydrodynamic model.

Outline

Recent improvements in the Ifremer/LOS retrieval wind algorithm :
Daily L3 products from QuikSCAT observation: **QS50** (50km) and **QS25** (25km)

Updated results

1. Actual spatial resolution

Cross-correlation calculation to assess the actual spatial resolution :
Local and horizontal coherence of the wind

QS50 vs. QS25

2. Origin of the differences

Fine scale curl patterns in the QuikSCAT product at 0.25° (QS25)

QS50 vs. QS25

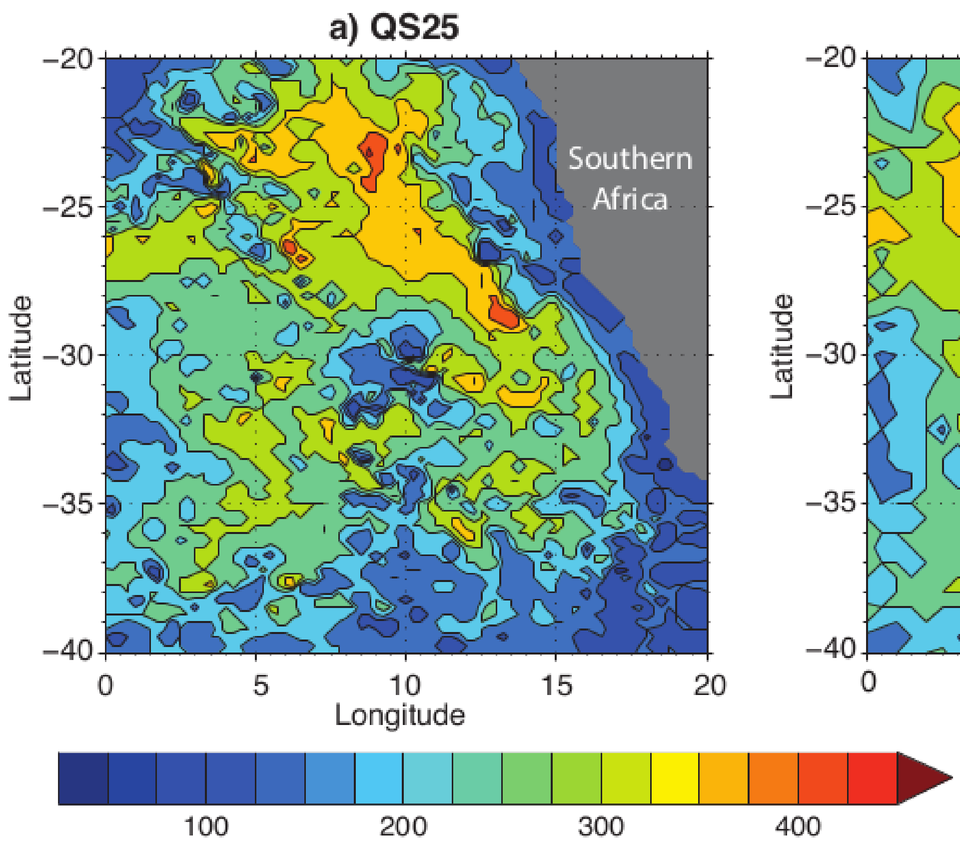
New results

3. Numerical sensitive studies

Upwelling response to fine scales in the wind surface stress :
Focus on SST, dynamical aspects (coastal jet, cross-shore exchange, undercurrent) and vertical velocities.

1. Actual spatial resolution

Intrinsic (given grid) **vs. a<u>ctual</u> spatial resolution :** Local and horizontal coherence of the wind



Desbiolles et al. [JGR, 2014a]

Distance *d* varies according to zones and products:

Large decorrelation distance (>300km) → coherent winds, large-scale patterns.

Finer scales found in QS25 satellite product.

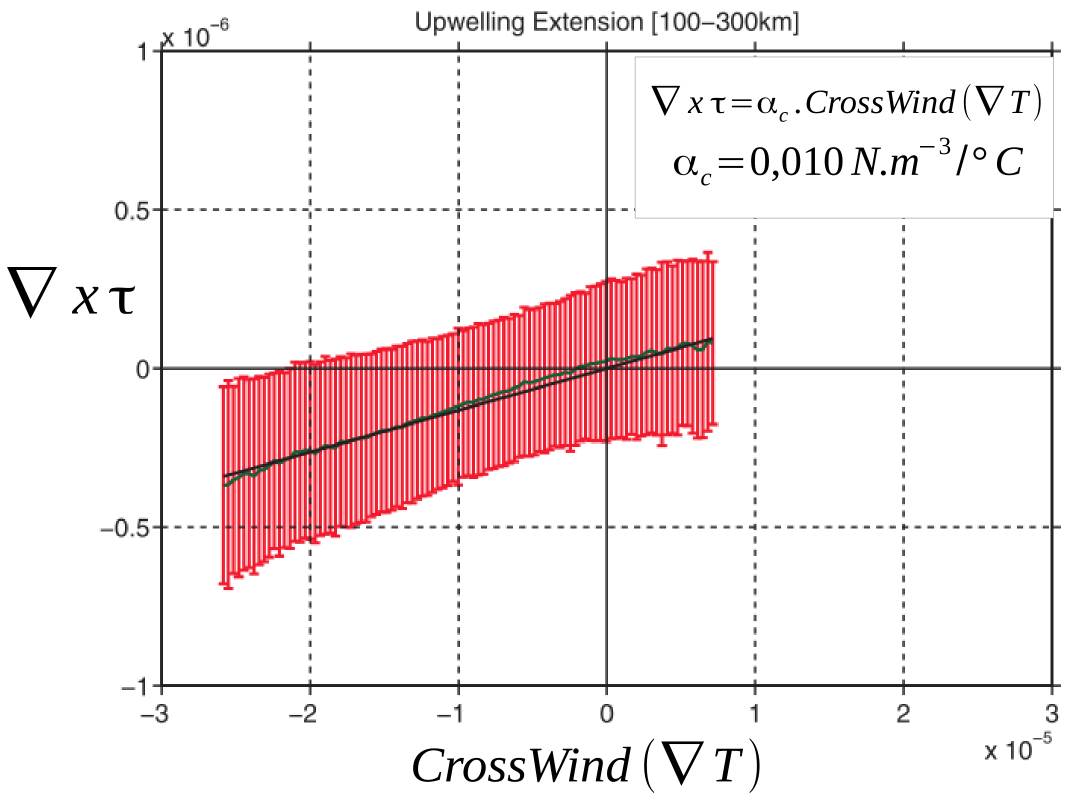
<u>Coastal band</u> characterized by a strong spatial inhomogeneity

→ **Area with strong air-sea-continent interactions.**

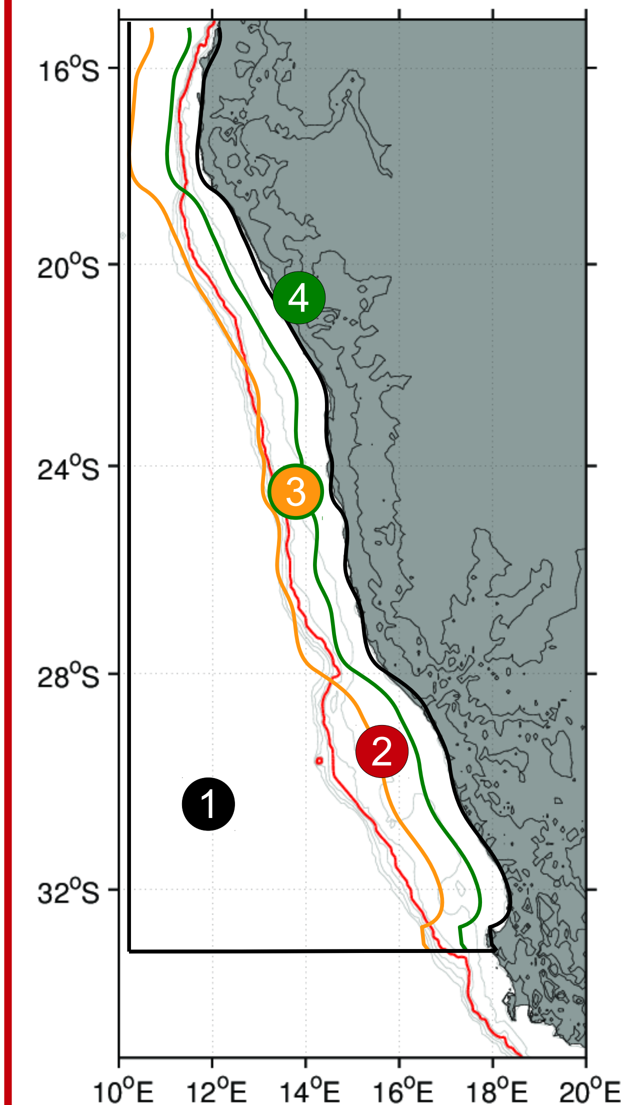
2. Origin of the differences

Evidence for SST feedback in the QS25 wind product.

Hypothesis : **Linear relationship** between the wind stress curl and the crosswind SST gradient [Chelton et al., Science 2004] from weekly to seasonal time scales.



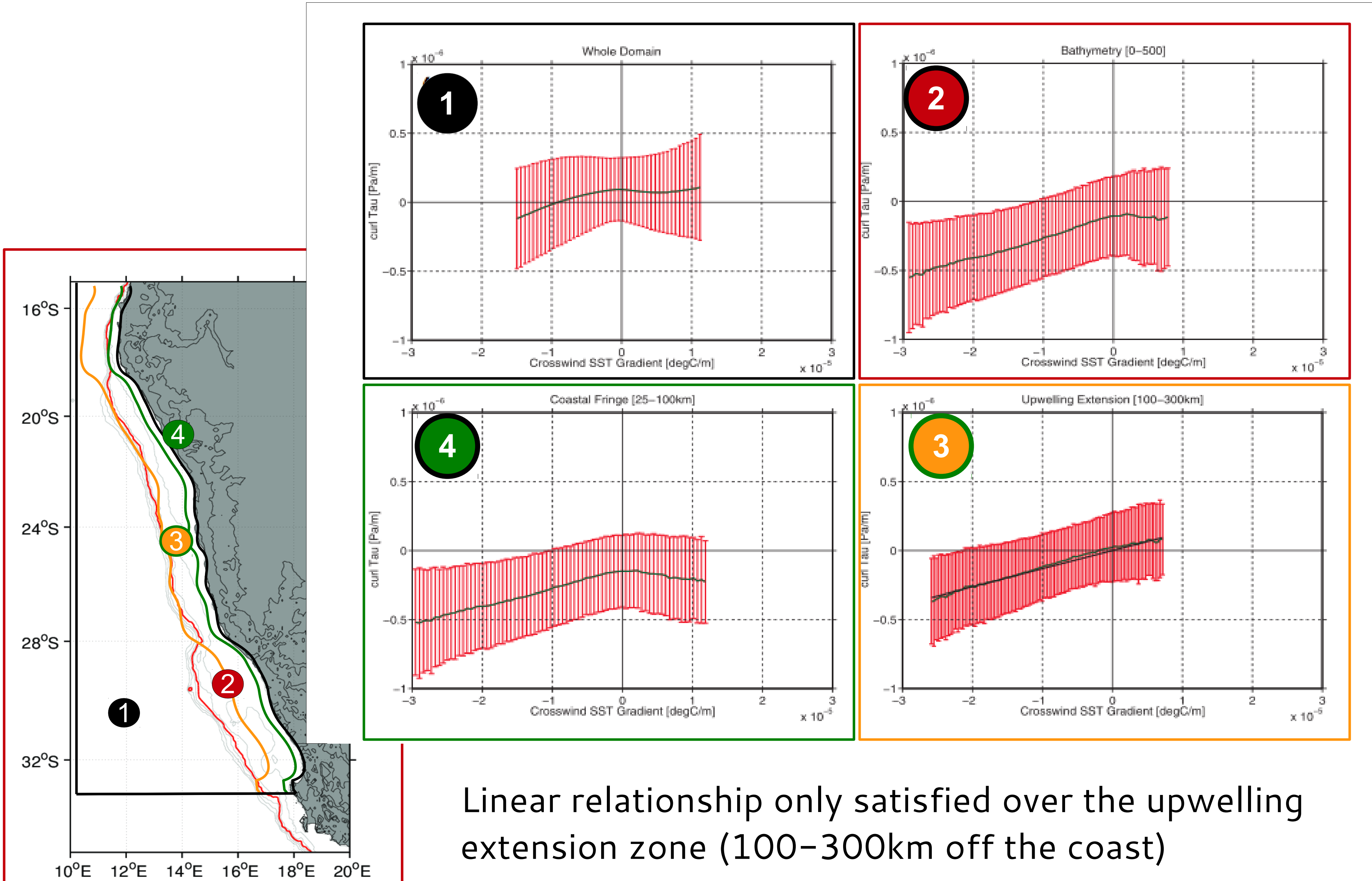
<u>Statistical response</u> studied by bin-averaging weekly averages of QS25 wind stress curl as a function of weekly-averaged crosswind SST gradients over 261 weeks.



Spatial sensitivity ?

2. Origin of the differences

Evidence for SST feedback in the QS25 wind product.

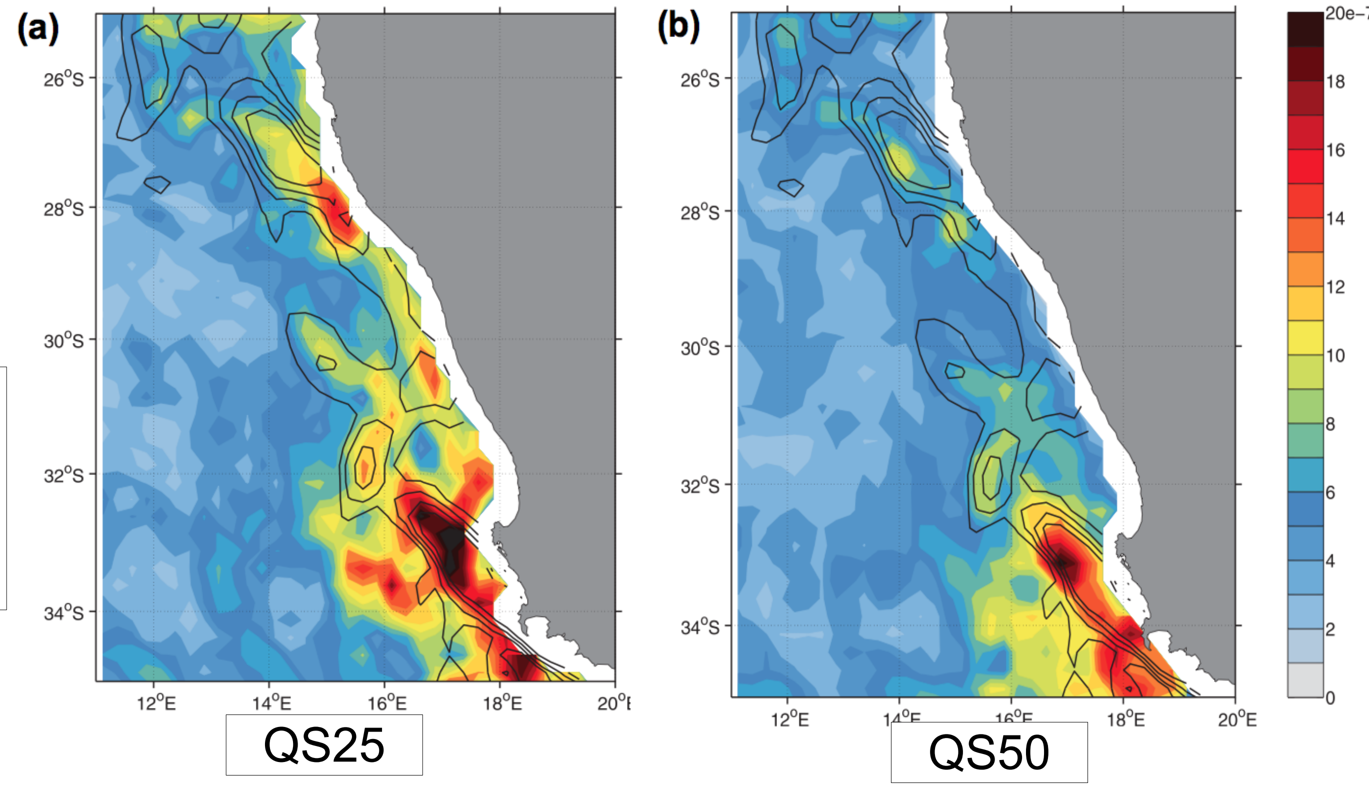


Linear relationship only satisfied over the upwelling extension zone (100-300km off the coast)

2. Origin of the differences

QS50 vs. QS25

An active thermal coupling contributes to wind stress reduction over pronounced SST fronts.



Mean of the wind stress gradient (colors) and SST gradient (contours) over the upwelling season

QS25 gradients and SST gradients are coupled.
QS50 winds are less statistically related to the SST field than QS25 winds.
==> QS25 data include spatial scales that are coherent with the scales of coupled thermodynamical processes.

Coupling coefficient and corresponding R^2 coefficient

	α_c	R^2
QS25	0.013	0.89
QS50	0.012	0.62

Desbiolles et al. [JGR, 2014b]

3. Numerical sensitivity studies

Regional Ocean Modeling System (ROMS)

<u>Horizontal resolution 1/12°</u>

32 vertical levels

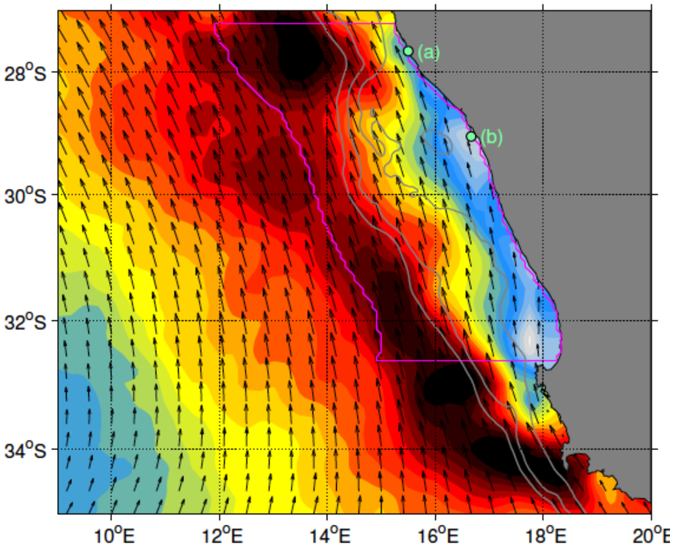
<u>Atmospheric forcing:</u>

Wind stress : QS50 / QS25 / Blended QS25-ECMWF

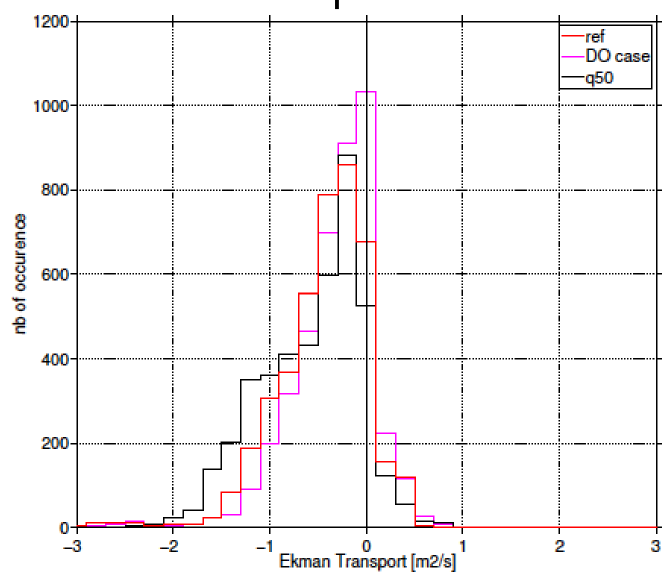
<u>Set of experiments</u> :

Same initial condition → **QS25**, **QS50**, **Blended QS25-ECMWF**

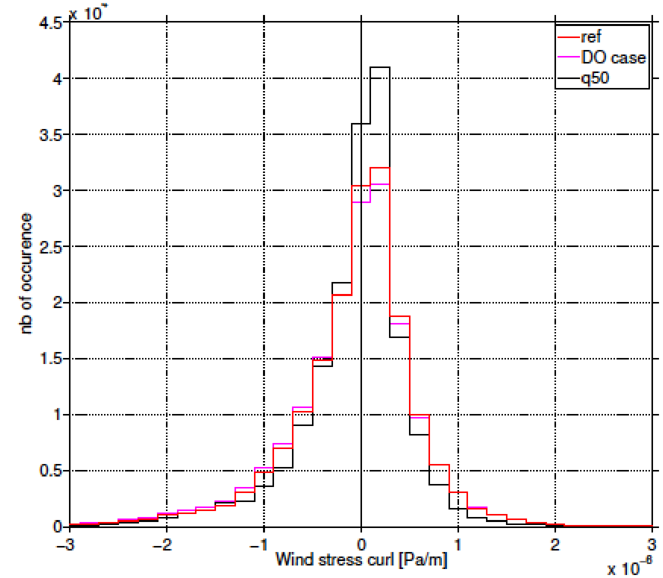
QS25 January-February 2005
Wind stress mean conditions



Ekman Transport distribution



Wind stress curl distribution

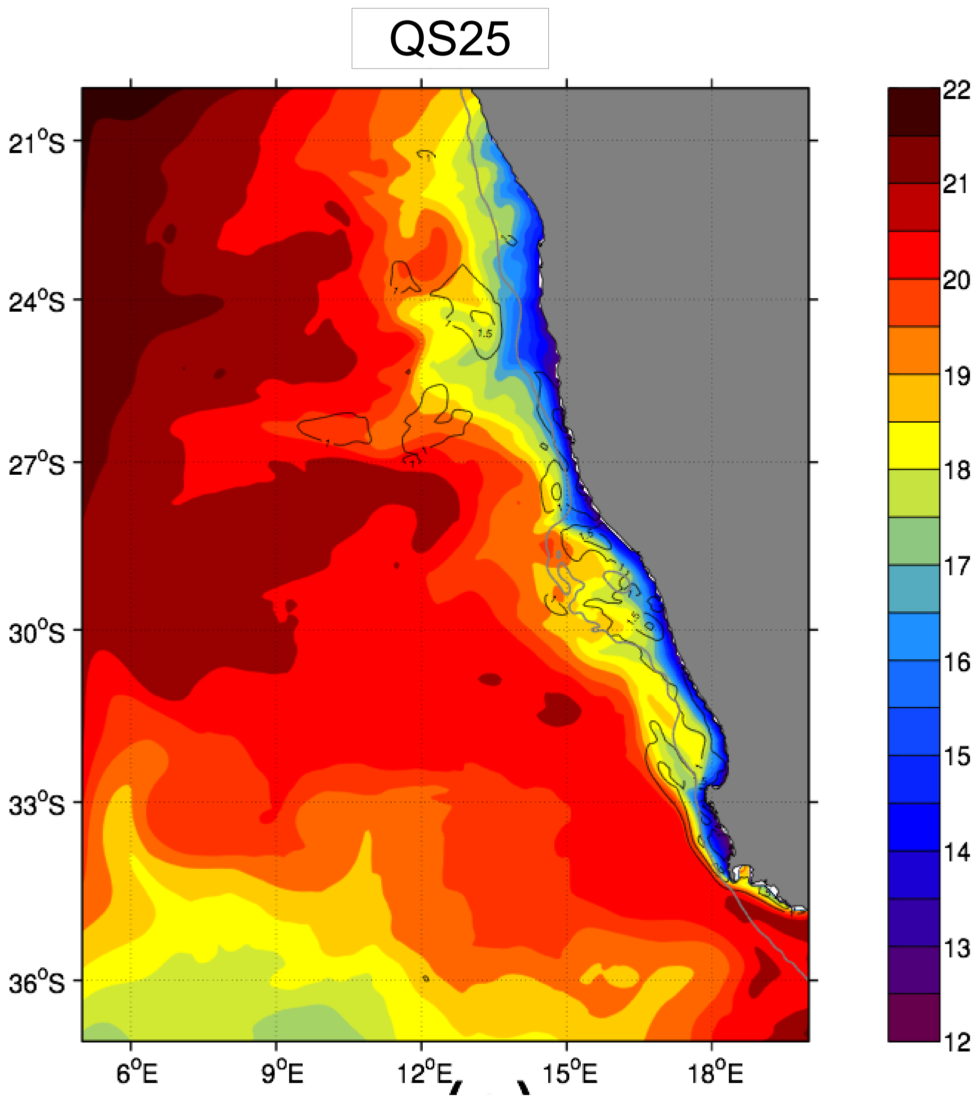


QS25 (red), QS50 (black) and Blended QS25-ECMWF (pink)

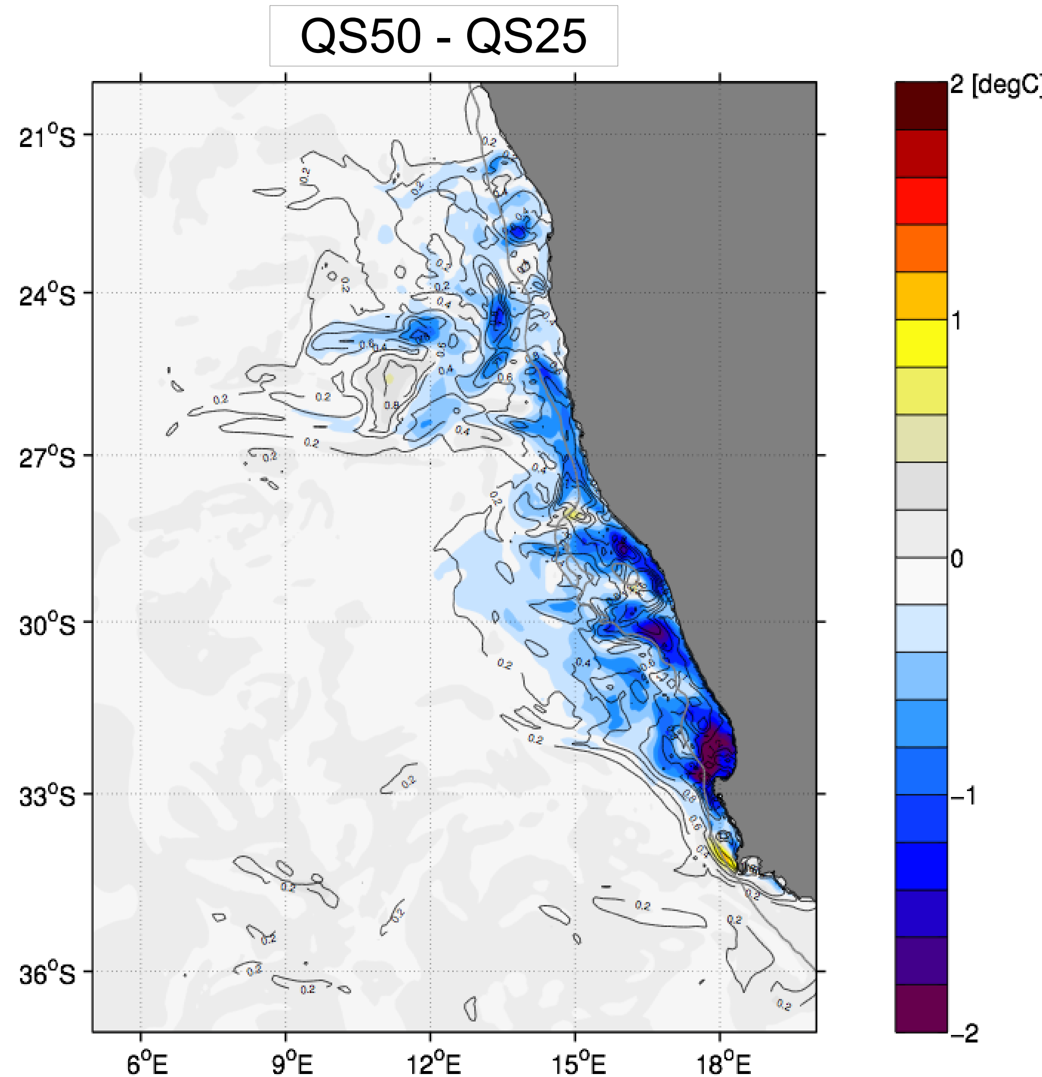
1. QS50 vs. QS25
2. Wind profile : QS25 vs. Blended QS25-ECMWF

3. Numerical sensitivity studies

QS50 vs. QS25



Mean (colors, °C) and RMS (contours, °C) of the SST forced by QS25 over January–February 2005.



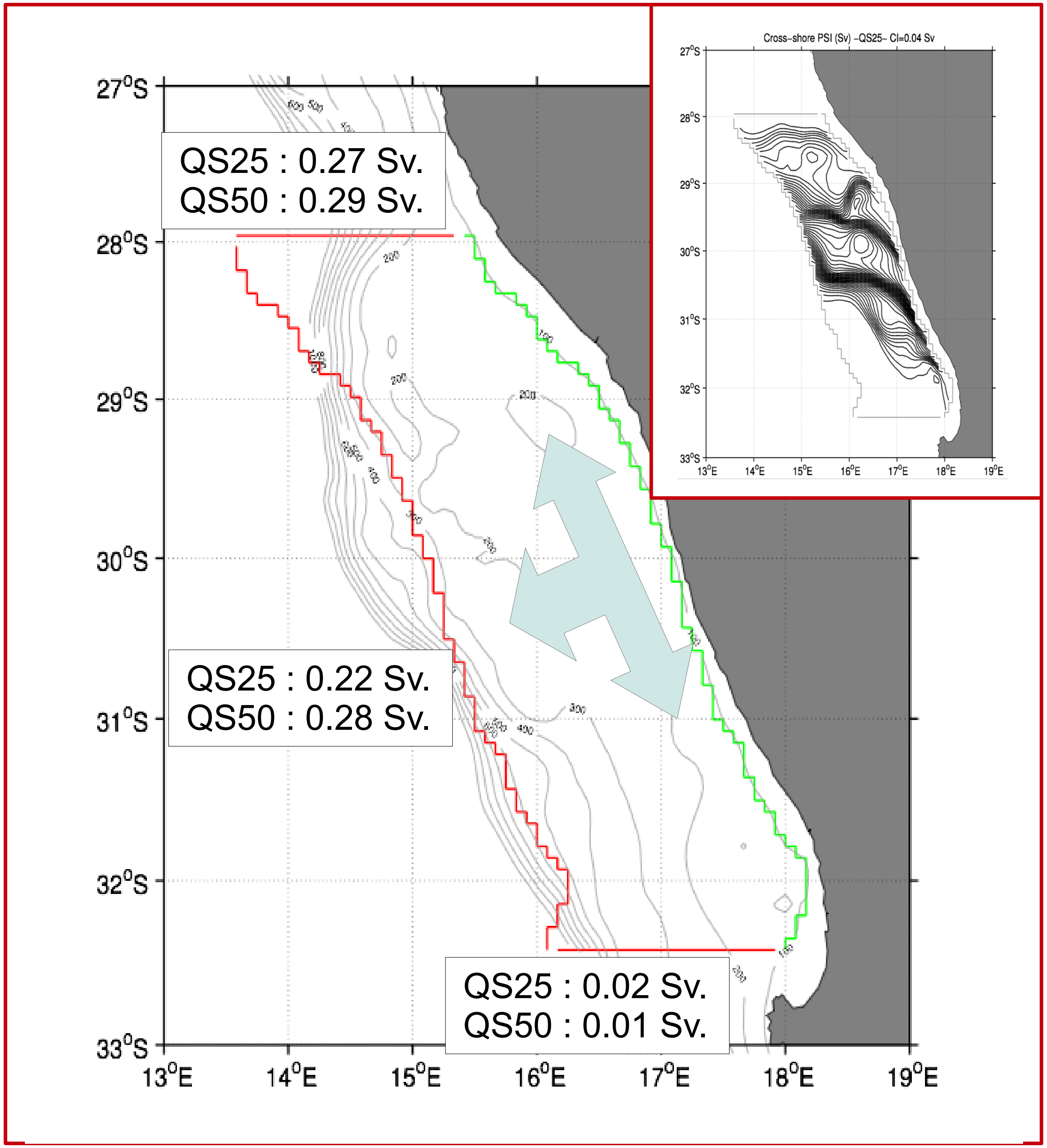
Mean biases (colors, °C) and RMS difference for the SST forced by QS50 and QS25.

3. Numerical sensitivity studies

QS50 vs. QS25

Fate of costal particles in the Southern Benguela upwelling:

Calculation with the offline Langrangian tool ARIANE [Blanke and Raynaud, 1997]



Alongshore component of the QS50 wind stress is more important than QS25.

Consequences :

- Larger cross-shore export by Ekman transport
- More intense oceanic coastal jet (geostrophic balance of the SST front)

QS25 wind stress curl more important over the whole coastal band.

Consequence:

Intensification of the poleward undercurrent at basin-scale through Sverdrup balance

3. Numerical sensitivity studies

Coastal wind drop-off

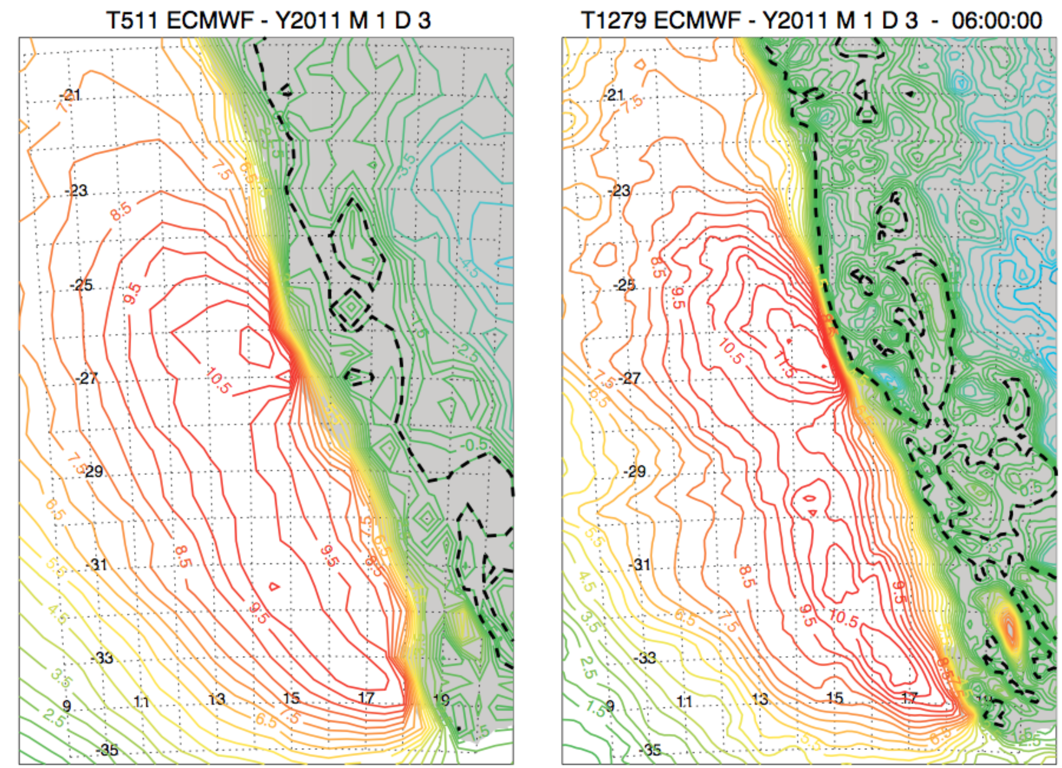
The wind profile in the satellite blind zone (about 30km) remains unknown :

Blended QS25-ECMWF

Sensitivity tests

The whole upwelling dynamics and especially the vertical velocity field may be affected

Competition between reduction of coastal upwelling (Ekman transport) and
Increase of Ekman pumping.



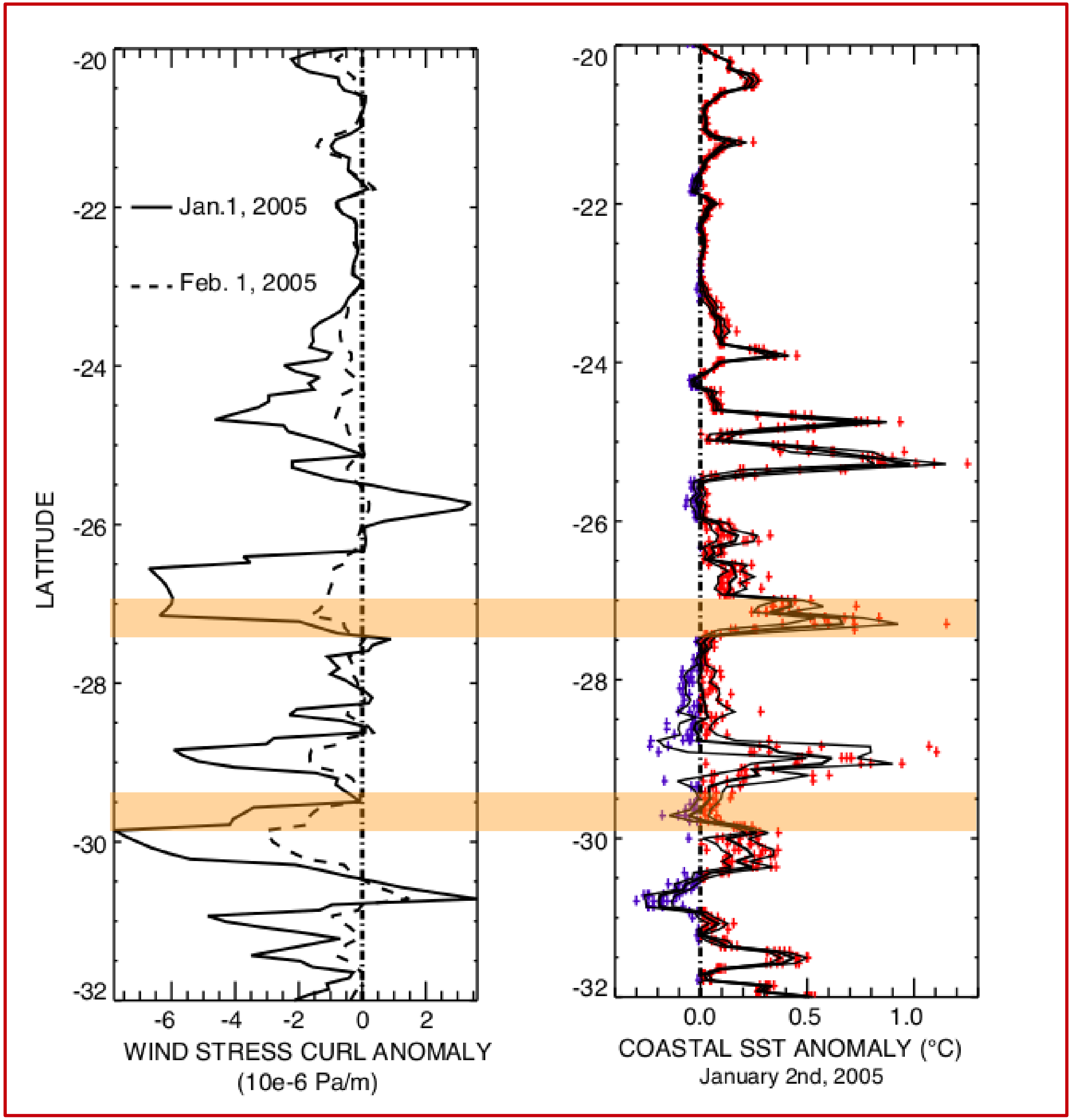
Meridional component of the wind on 3 January 2011 at 06:00:00 UTC from the IFS operational ECMWF spectral model at 2 horizontal resolutions. Contour interval : 0.5 m/s

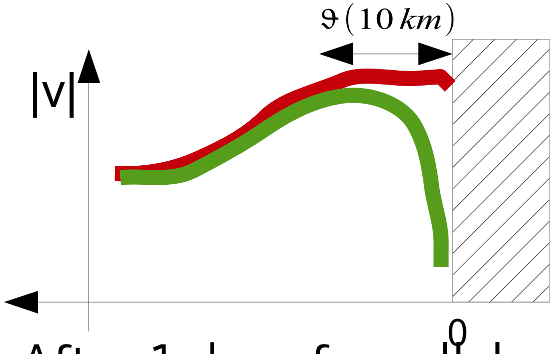
Characteristic length scales :

- Coastal upwelling L_{CU} → $\neq R_d$
- Wind drop-off L_{Drop} → Here, the drop-off length scale is imposed by the width of the satellite blind zone (15-30km according to latitude)

3. Numerical sensitivity studies

Coastal wind drop-off



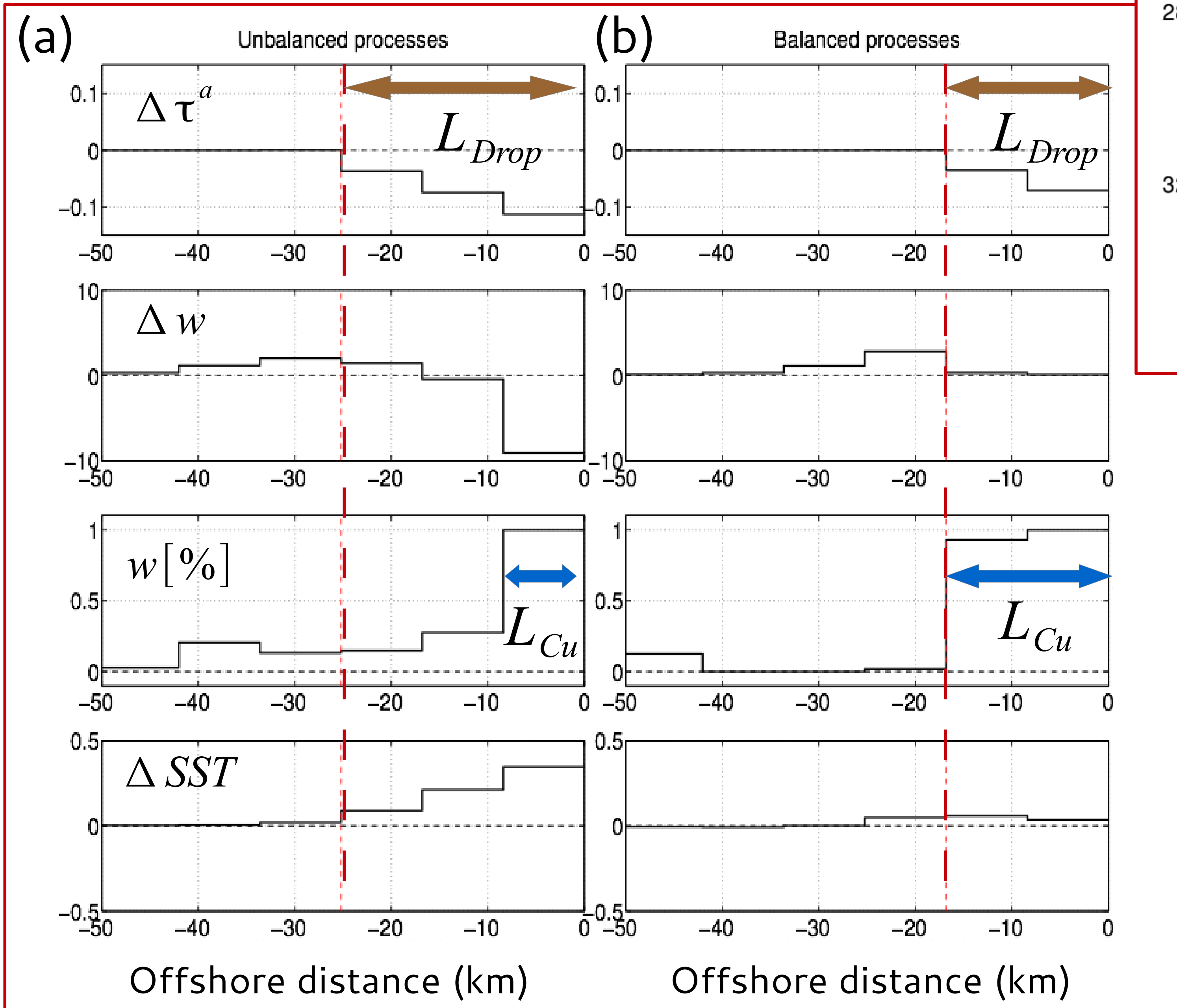


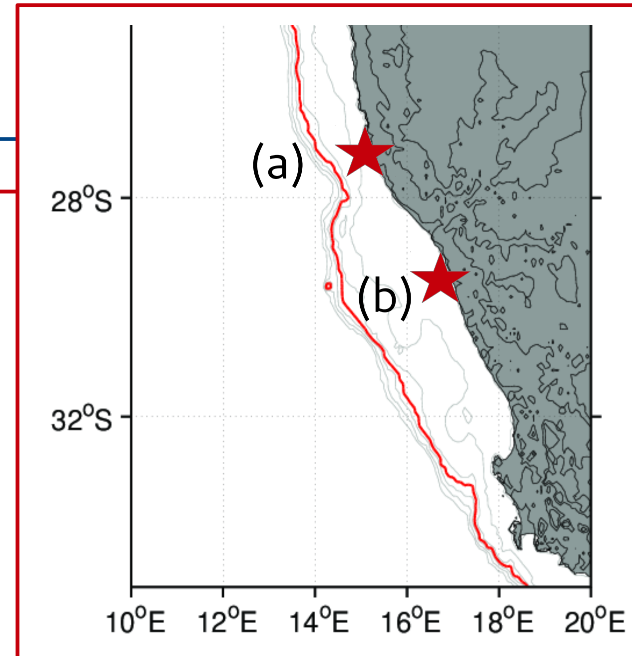
After 1 day of parallel integration

Coastal SST is warmer (colder) with the introduction of a wind deceleration (acceleration)

Overall, there is imbalance between Ekman transport and Ekman pumping : The wind drop-off, partially induced by orography, tends to reduce coastal SST cooling.
BUT, the oceanic response is not linearly dependent on the wind reduction applied at the coast.

3. Numerical sensitivity studies





(a) $L_{Cu} < L_{Drop}$

Different length scales :
==> Imbalance between Ekman transport and Ekman pumping

(b) $L_{Cu} \sim L_{Drop}$

The 2 processes are balanced : neither SST or vertical velocity anomaly.

3. Conclusions

- The QS25 product is a relevant dataset to capture wind variability in the nearshore region : Good representation of SST/wind interactions in the upwelling extension zone

SST-driven curl can be locally (upwelling extension zone) the main contributor (70%) of the WSC variability and magnitude. (Desbiolles et al. [JGR, 2014b])

Still impotant issues : sign of the ocean feedback during an upwelling event?

- Numerical studies show that upwelling dynamics are sensitive to both mesoscale (thermal coupling, O(100km)) AND submesoscale (wind drop-off, O(10km)) wind variability.

Higher-resolution products need for realistic upwelling responses !!

Thanks for your attention

Recommended papers:

Capet, X. J. et al. [2004, Grl] Upwelling response to coastal wind profiles.

Chelton, D.B. Et al. [2007, JPO] Summertime coupling between sea surface temperature and wind stress in the California Current System.

Renault, L. et al. [2015, submitted JC] Orographic Shaping of U.S. West Coast Wind Profiles During the Upwelling Season

Small, R. J. et al. [2015, submitted JC]. The Benguela upwelling system: quantifying the sensitivity to resolution and coastal wind representation in a global climate model