On the sensitivity of the sea surface temperature to wind stress in the Benguela upwelling system

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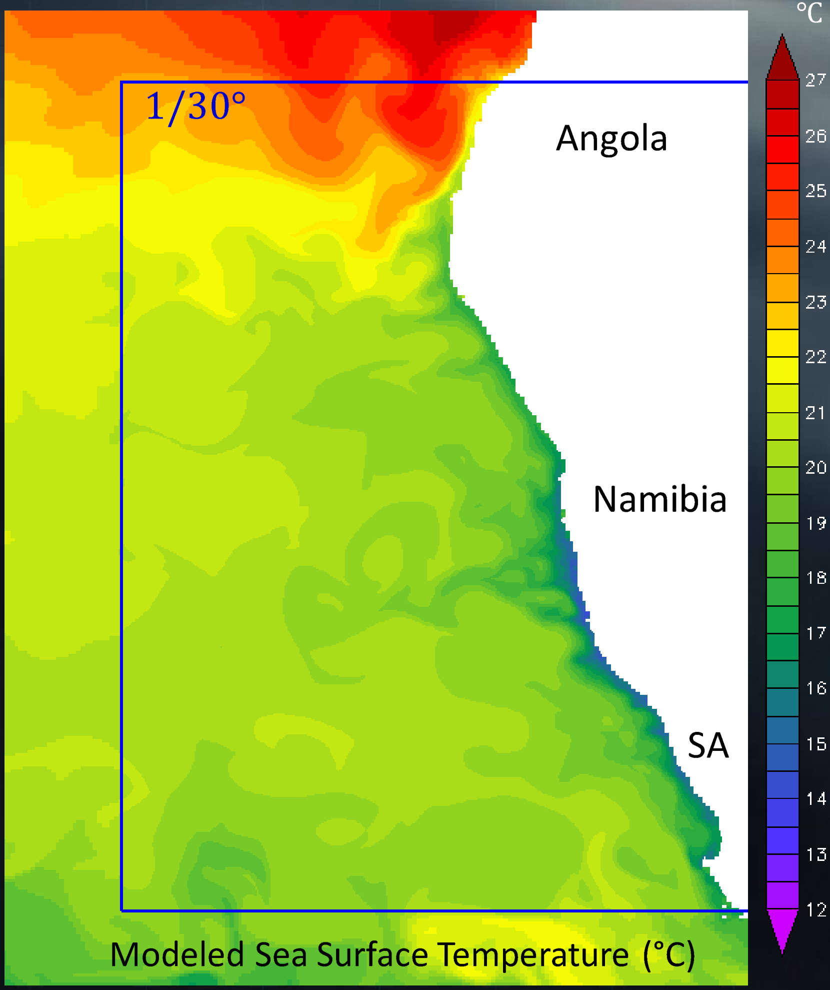
PREFACE



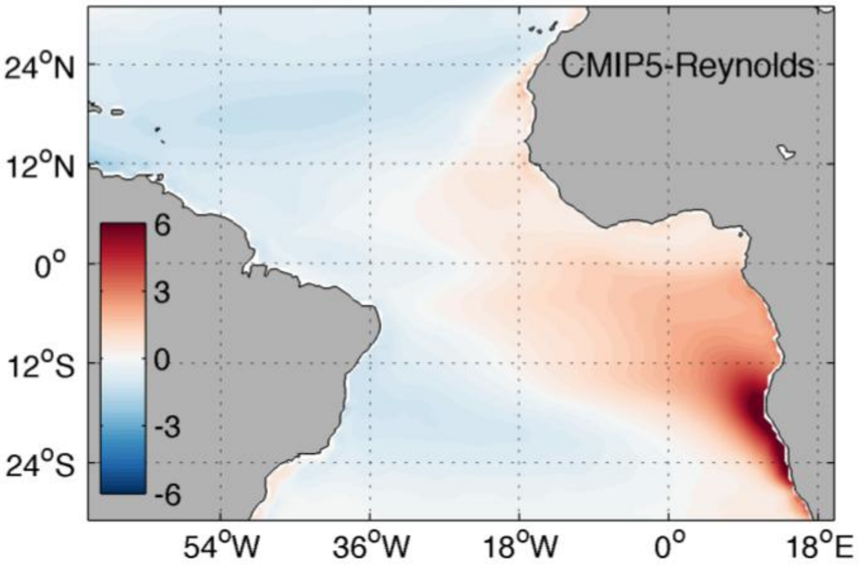
Motivation: SST bias in upwelling systems

Most ocean and coupled models suffer from a warm SST bias in the upwelling systems.

We analyze the sensitivity of this bias to
- horizontal ocean resolution
- wind forcing

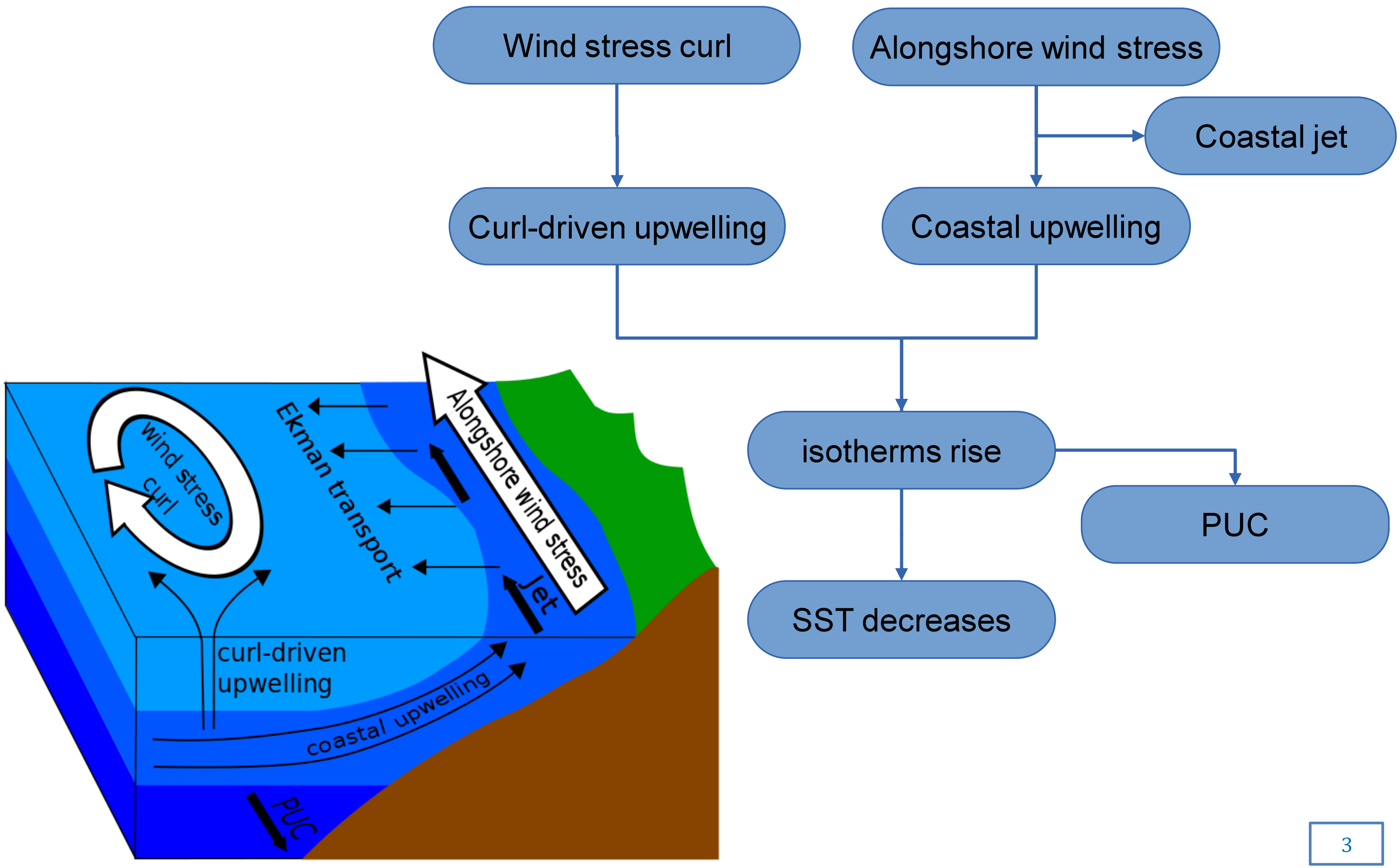
with an eddy-resolving ocean model.

SST bias (°C)



(figure from Xu et al. 2014)

Introduction: Upwelling dynamics



Model description: Different resolutions

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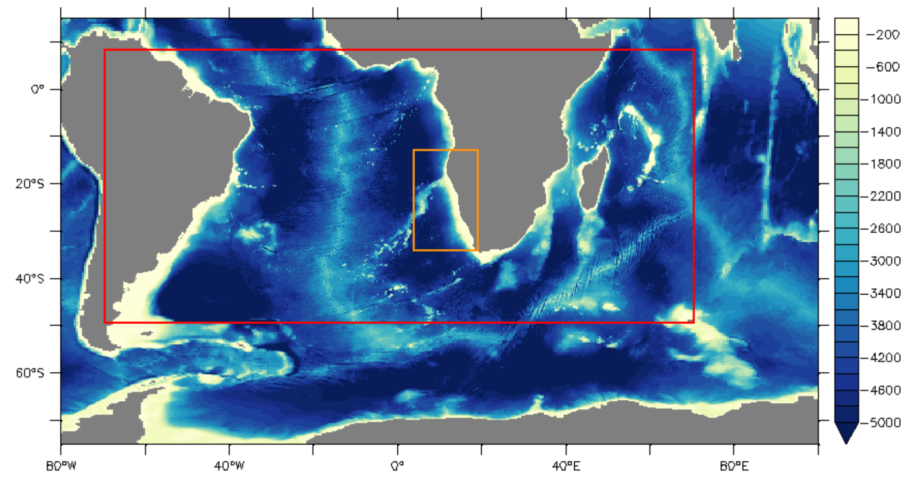
- NEMO 3.1.1
- z-coordinates
- 46 vertical levels
- CORE2 forcing (except wind)



Bathymetry (m)

Base model "ORCA05"	1/2°	globally
One nest INALT01 (Durgadoo et al. 2013)	1/10°	8°N – 50°S 70°W – 70°E
Nest in nest "REBUS30"	1/30°	13°S – 34°S 4°E – 19°E

1/30°: Resolved coastal upwelling

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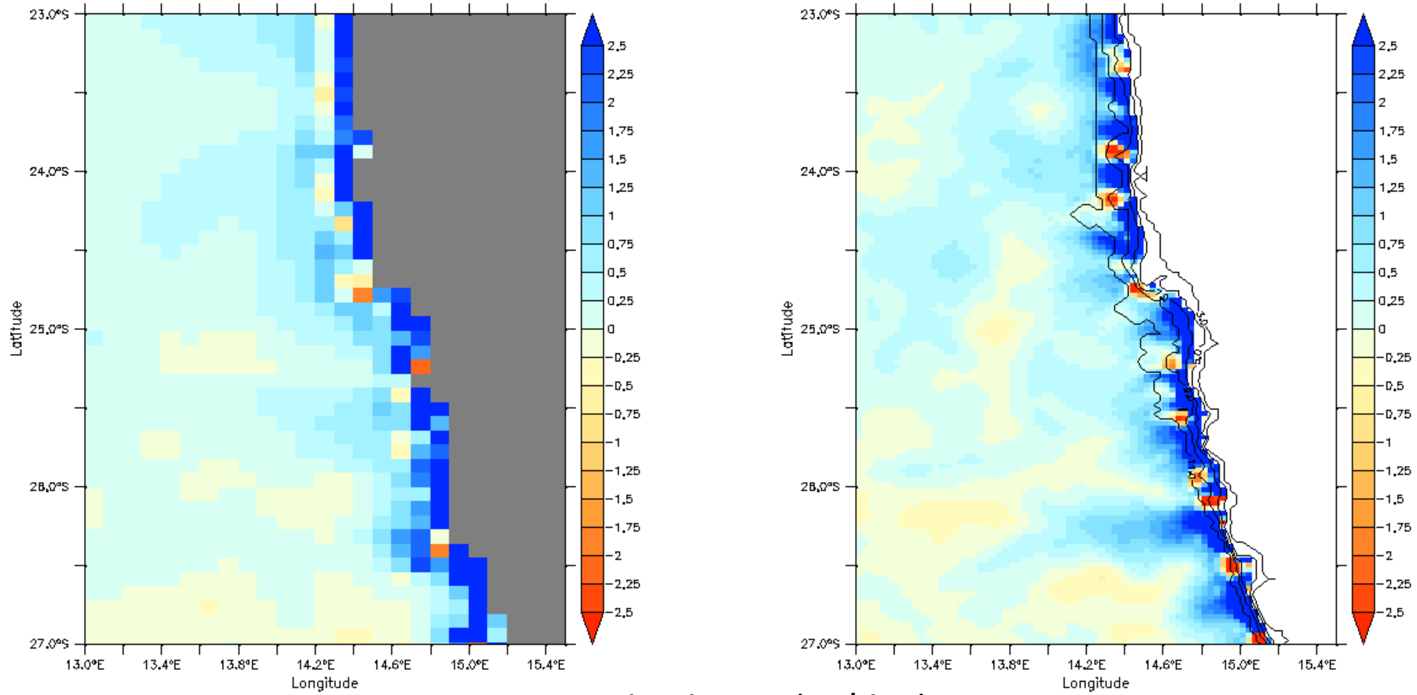
1/10°

1/30°

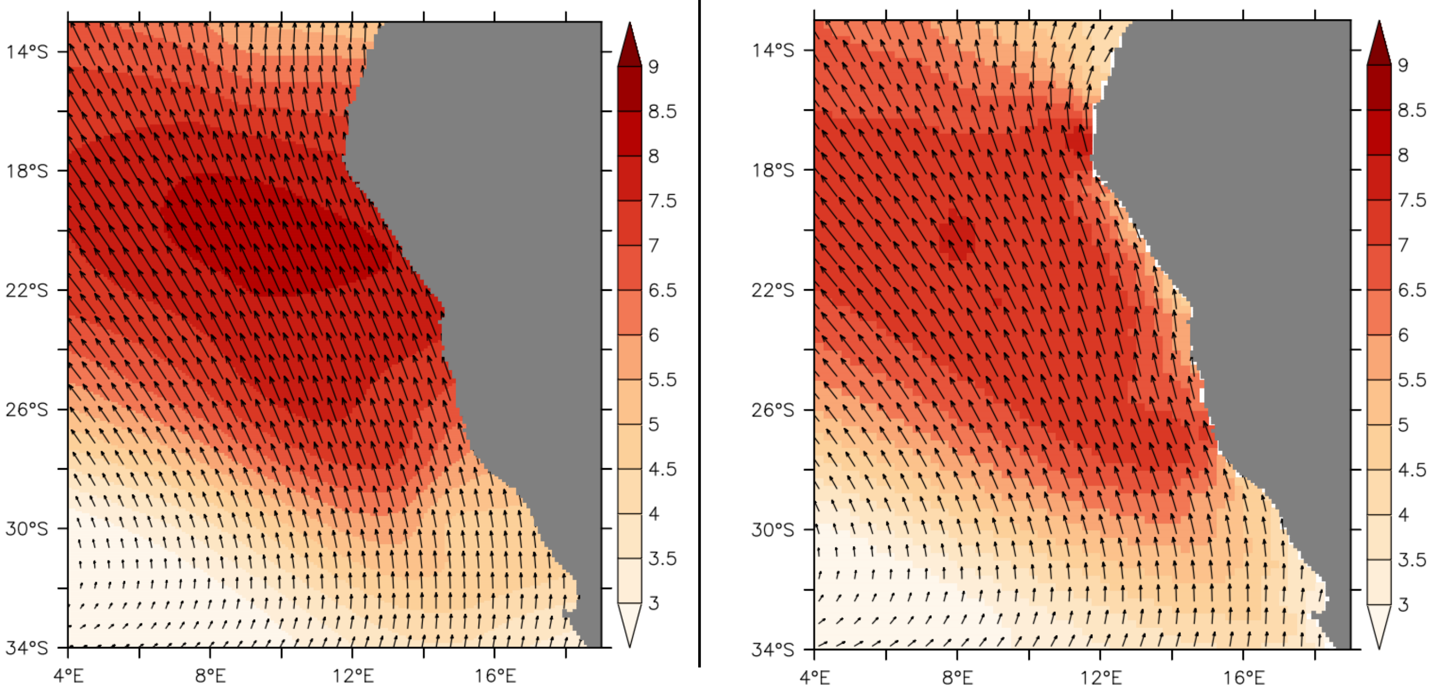


Average vertical velocity (m/day), 2002-2009

- **1/10°:** almost all upwelling is in the last grid cell
- **1/30°**: coastal upwelling now smoothly resolved
- The 1/30° model has still local downwelling cells, which seem to be resolved now

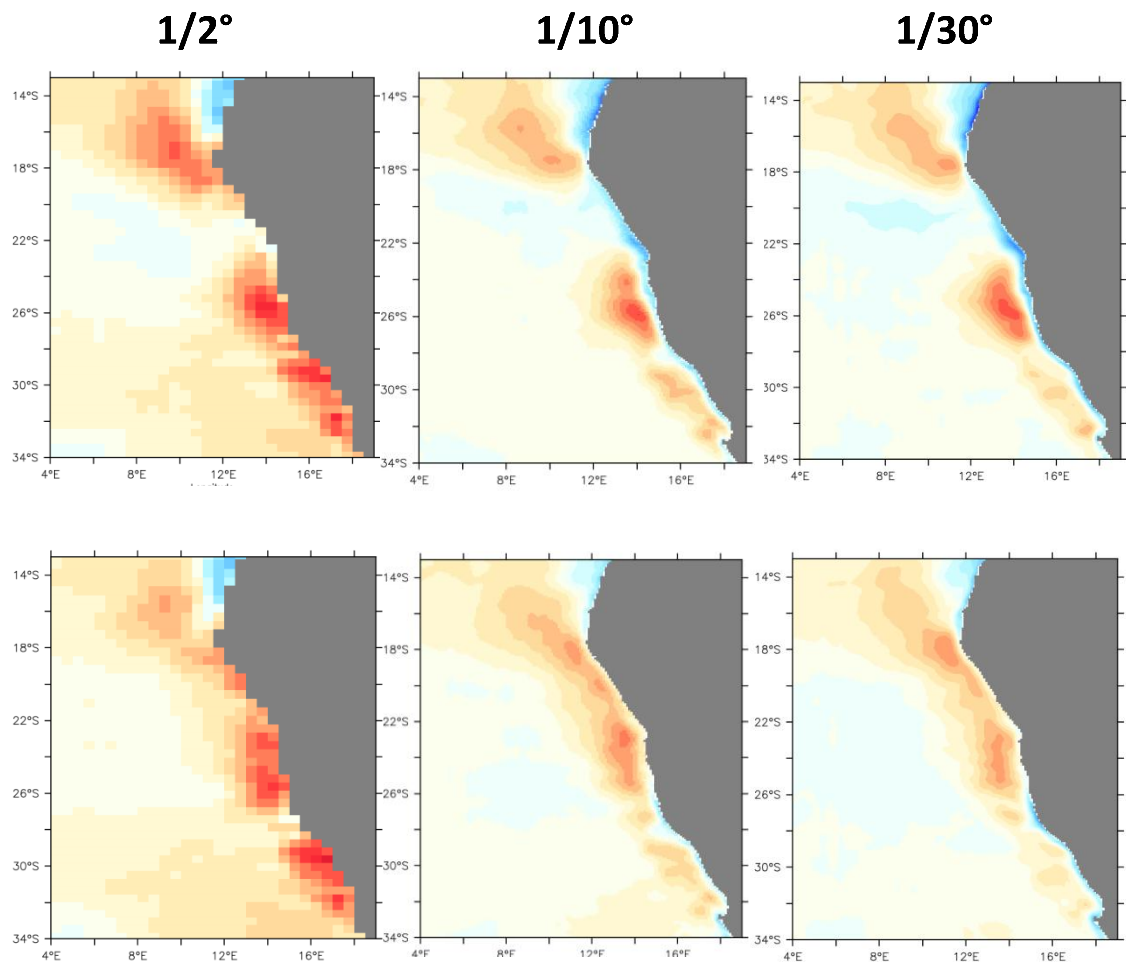
Model forcing: Different wind products

CORE2 (coherent forcing dataset)	QuikSCAT mean + CCMP variability
2°, 6-hourly	1/4°, 6-hourly



Wind speed (m/s)

SST bias: Comparison of model results



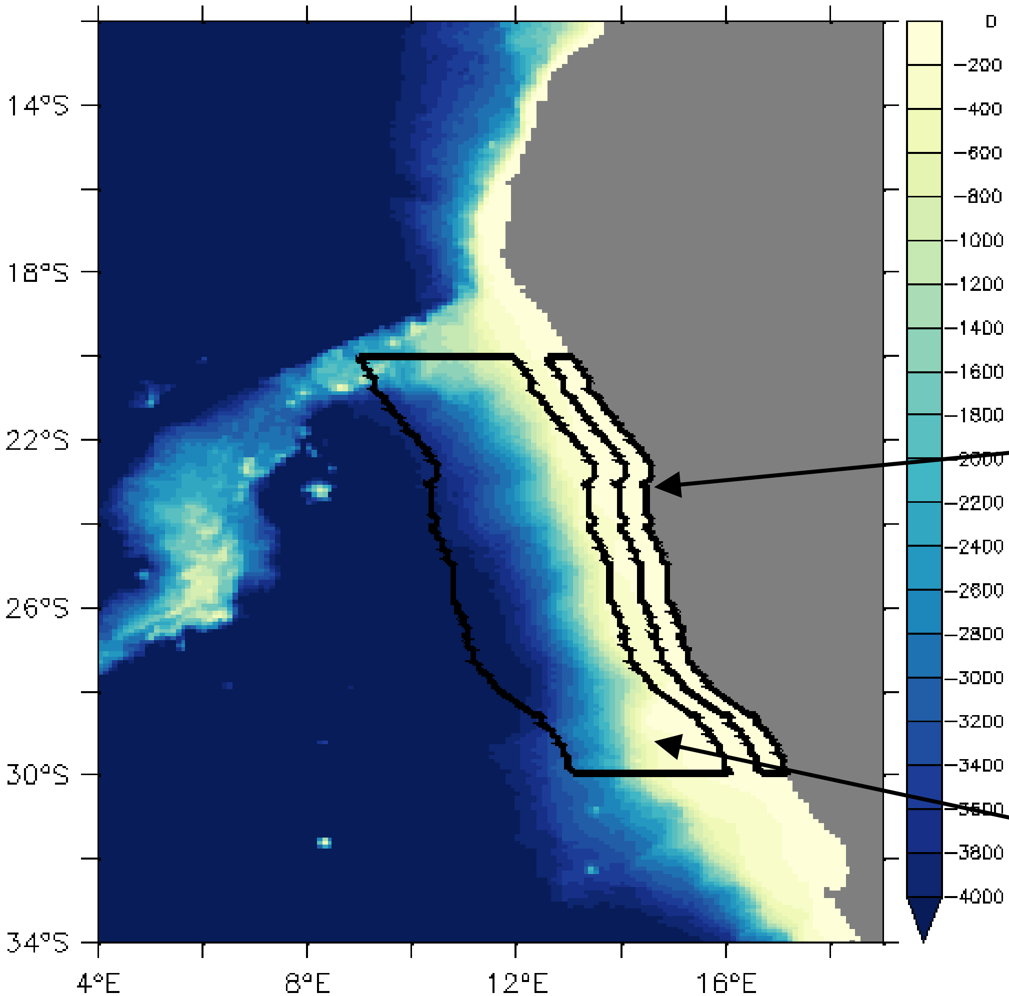
SST difference (°C) to MUR satellite product (2003 - 2009)

1/2°: Similar amount of warm bias with CORE and QuikSCAT, up to 2.5°C

1/10°: CORE: cold bias at coast, still 2.0°C warm bias offshore
QSCAT: warm bias up to 1.5°C

1/30°: almost no changes, same patterns

Upwelling: Evaluation of Transport



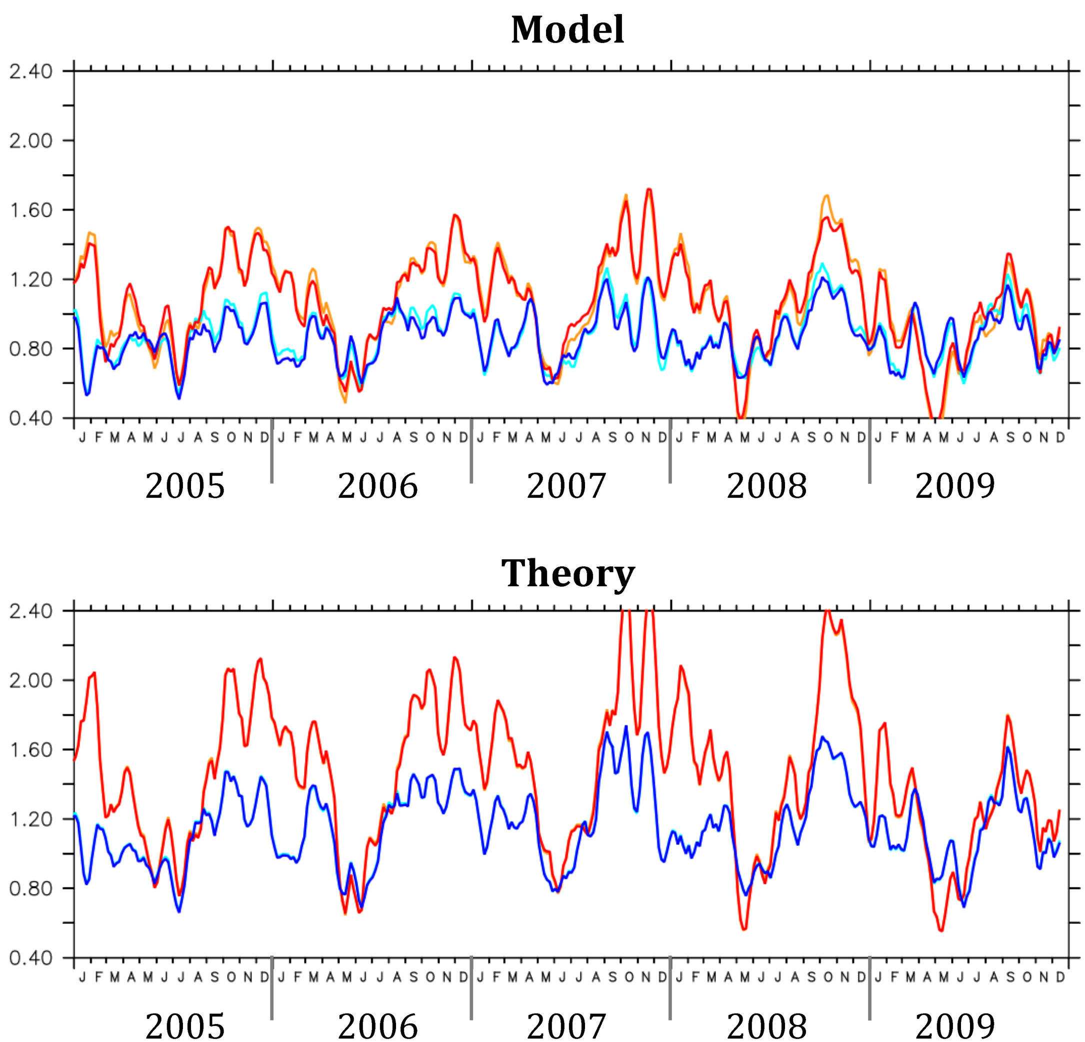
Bathymetry (m)

We calculate the upwelling transport by integrating the vertical velocity in two regions:

Coastal upwelling:
20°S-30°S; coast to 0.5° offshore
Depth: 32m(~ level of transport maximum ~ Ekman depth)

Curl-driven offshore upwelling:
20°S-30°S; 4° to 1° off the coast
Depth: 112m (~ level of transport maximum ~ Ekman depth)

Coastal upwelling: Model vs. theory



- 1/10°, CORE
- 1/30°, CORE
- 1/10°, QuikSCAT
- 1/30°, QuikSCAT

Theoretical transport:

$$\approx 1.1 \int \frac{\tau_{\text{along}}}{f \rho_0} \mathrm{d}y$$

(Estrade et al., 2008)

- Very high correlation (97%) to alongshore wind stress
- More coastal upwelling with CORE
- No differences 1/10° - 1/30°
- Model: ~ 0.9Sv
- Theory: ~ 1.2Sv

Curl-driven upwelling: Model vs. theory

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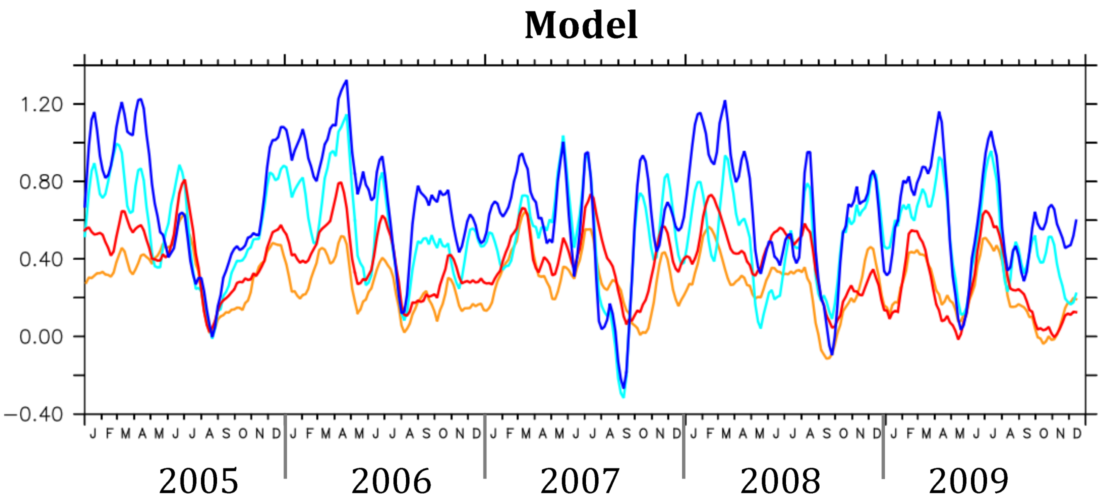

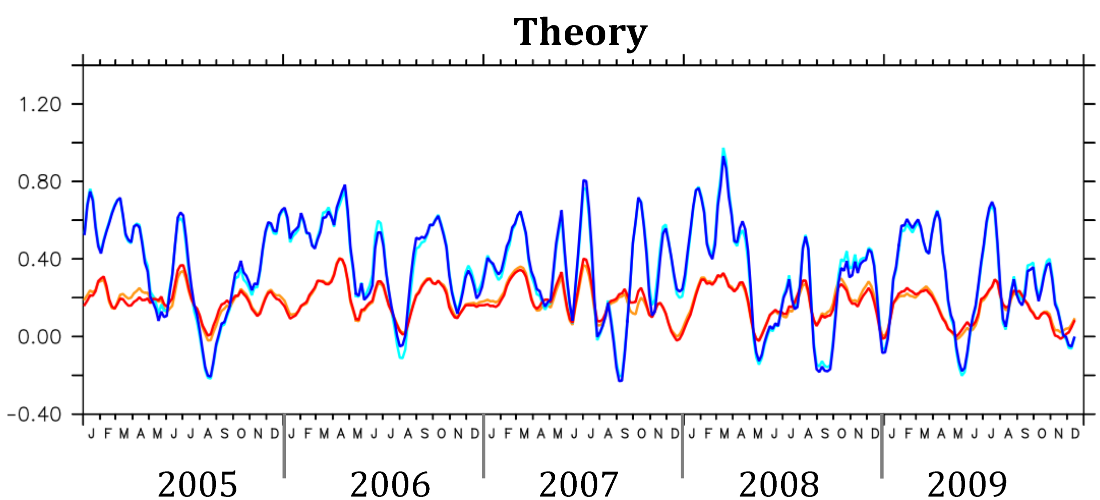

- 1/10°, CORE
- 1/30°, CORE
- 1/10°, QuikSCAT
- 1/30°, QuikSCAT

Ekman pumping

$$\frac{\nabla \times \tau}{f \rho_0}$$

- Again a good correlation
- More curl-driven upwelling with QuikSCAT
- Small increase in 1/30° compared to 1/10°C
- Model: ~ 0.6Sv
- Theory: ~ 0.4Sv

SST: Sensitivity to wind forcing

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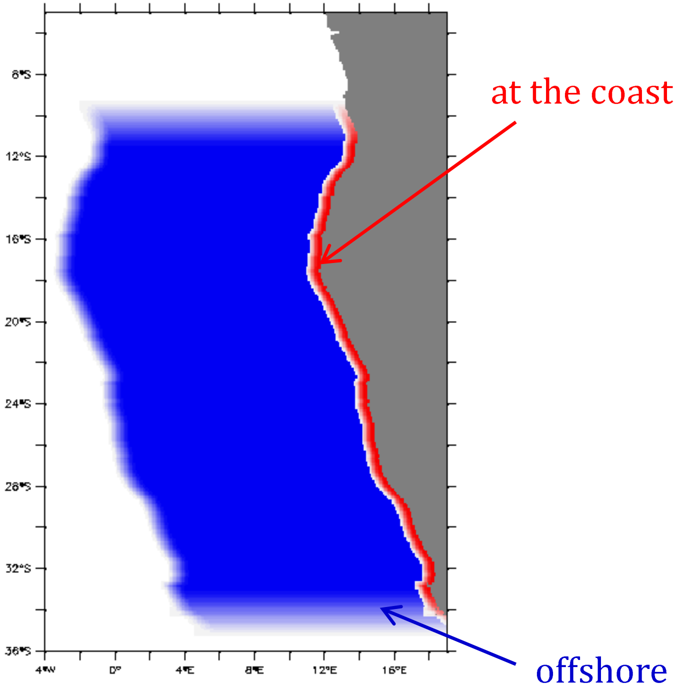
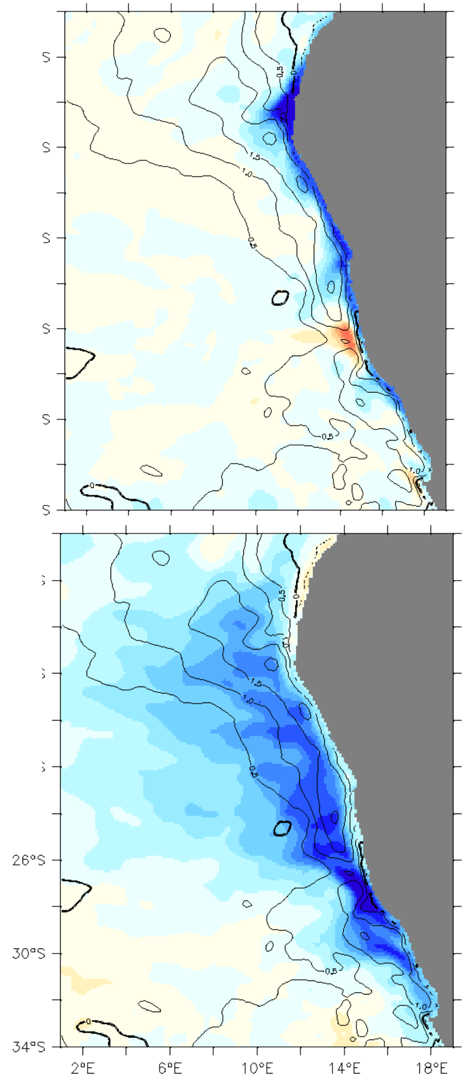
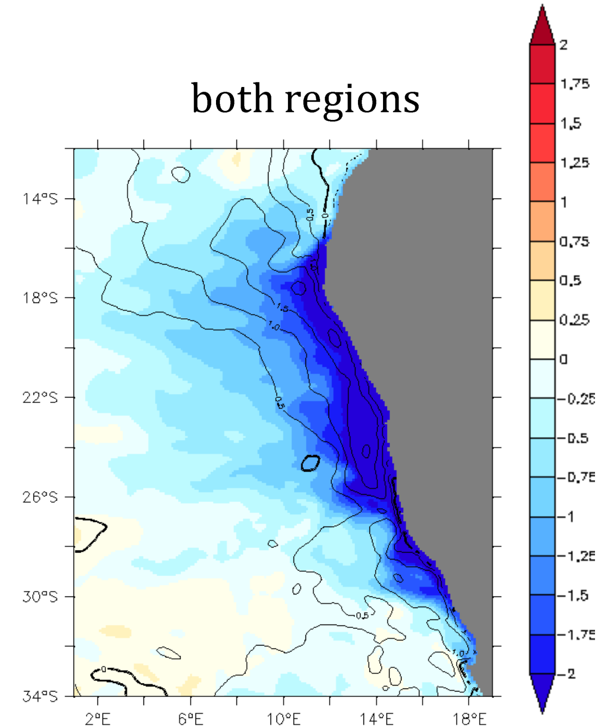
Artificial change of mean wind by +40%





both regions



SST difference (°C) to model without wind manipulation

- Wind manipulation has only local SST effects, despite filaments etc.
- ABFZ still at the same position
- Only offshore, curl-driven upwelling affects the region of highest SST bias

Conclusion: Ingredients for modeling the SST

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high

Importance

low

Ocean resolution higher than 1/2°

Mean alongshore wind stress

Wind stress curl (i.e. gradient of the wind stress)

Spatial resolution of wind forcing (1/4° ↔ 2°)

Temporal resolution of wind forcing (6-hourly ↔ daily)

Ocean resolution higher than 1/10°

Wind variability (for mean SST)

Conclusion: Reasons for the warm bias

The warm bias was reduced by

- using more realistic **wind forcing**
- increasing the **ocean resolution** to 1/10°

The remaining warm bias (~1.5°C) in the Benguela upwelling system is

- **not** because of **unresolved mesoscale effects** (eddies, filaments, ...)
- **not only** because of missing **coastal upwelling**
- **maybe** because of missing or inefficient **offshore curl-driven upwelling**