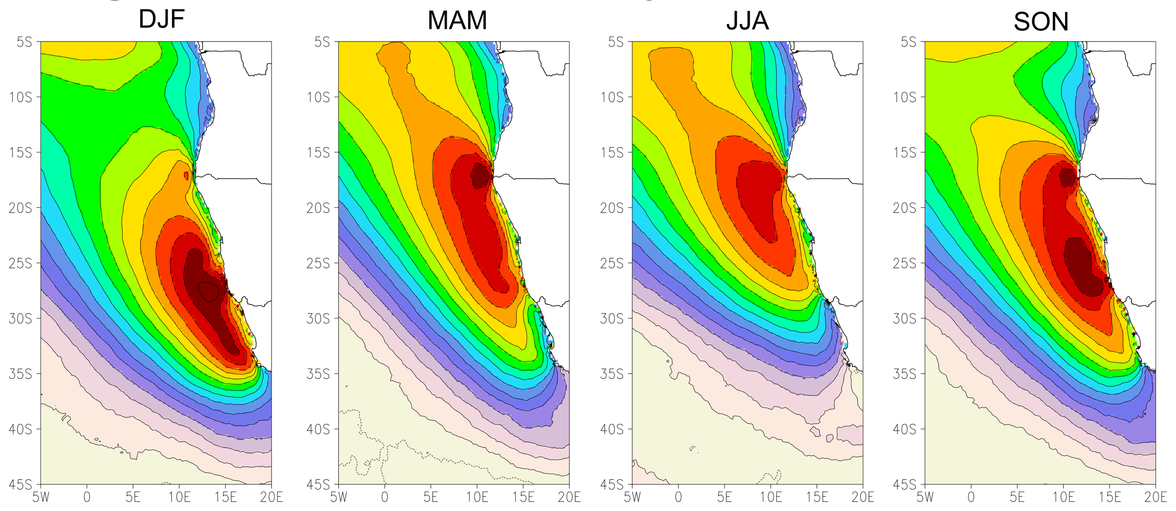
Translating process understanding to improve climate models. GFDL, October 15-16, 2015.

# Upwelling and coastal current biases in climate models (Part 2) – Modelling the atmosphere

Christina Patricola[1], Ping Chang[1], Jaison Kurian[1], R. Justin Small[2], Paquita Zuidema[3], and Brian Medeiros[2]
[1]Texas A&M University, College Station TX; [2]National Center for Atmospheric Research (NCAR), Boulder CO; [3]RSMAS, University of Miami, Miami FL

**Introduction:** The upwelling regions at the eastern edges of the world's subtropical oceans exhibit pronounced SST biases in leading global coupled climate models. In the southeastern tropical Atlantic, the wind-stress curl associated with the Benguela atmospheric low-level coastal jet (LLCJ) plays a major role in determining the spatial distribution of SST. This poster investigates the Benguela LLCJ, including its characteristics and dynamics, the impacts of coastal geometry on jet structure, impacts of jet structure on simulated SST, and the influence of resolution on the jet's representation in models, including the Weather Research and Forecasting (WRF) model, Community Climate System Model (CCSM), and models from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Realistic representation of the detailed structure of the Benguela LLCJ, including both the double core structure and coastal wind drop-off, is critical to reducing the coastal ocean bias in the southeastern tropical Atlantic and is highly dependent on model resolution. The influence of ocean model resolution and errors in Benguela LLCJ representation on SST and upwelling processes is presented in the poster by Small et al. (Part 1).

## Benguela low-level coastal jet: structure and seasonality




The Benguela low-level coastal jet has a maximum wind speed near 975 hPa and is characterized by two seasonally varying cores with preferred locations at 17.5°S near the Angola-Benguela frontal zone and near 28°S.

*Fig 1. Meridional wind (m/s) at 10m from the Cross-Calibrated Multi-Platform (CCMP) Ocean Surface Wind Product averaged 1988-2009.*

## Sensitivity to model resolution and representation in reanalyses

Reanalysis/observational products and models with resolution finer than ~0.25°- 0.5° represent the Benguela LLCJ structure well, while those with resolution of ~2.5° misrepresent the jet as a single broad offshore core.

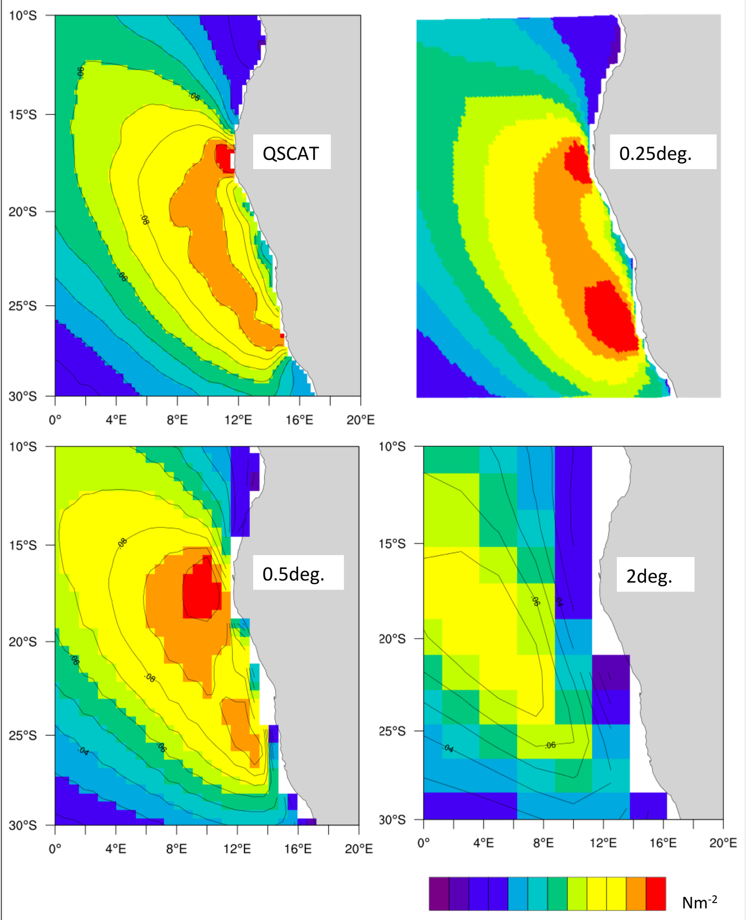



*Fig 2. JJA average of meridional wind stress from CCSM4 with CAM at the resolution labelled. Although the 0.25deg simulation represents the Benguela LLCJ close to the coast, as observed, the wind-stress curl is too large.*

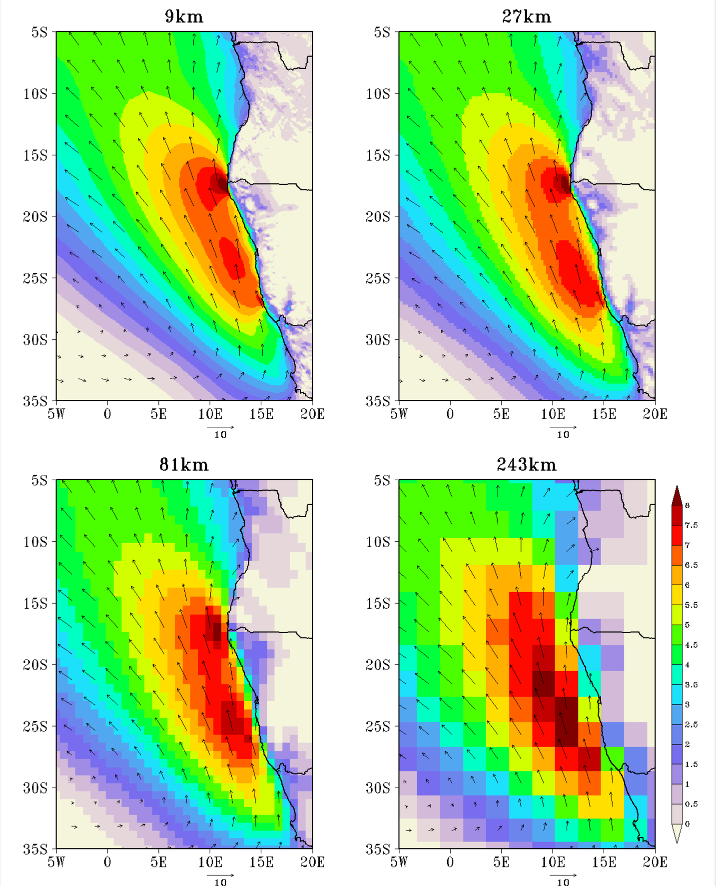



*Fig 3. Meridional wind (shaded; m/s) and wind vector (vector; m/s) at 10m averaged 2005-2008 from the WRF model at 9km, 27km, 81km, and 243 km resolution.*

The SST and ocean circulation of the southeastern tropical Atlantic are heavily impacted by the representation of the Benguela LLCJ's wind-stress curl. (See poster by Small et al. - Part 1)

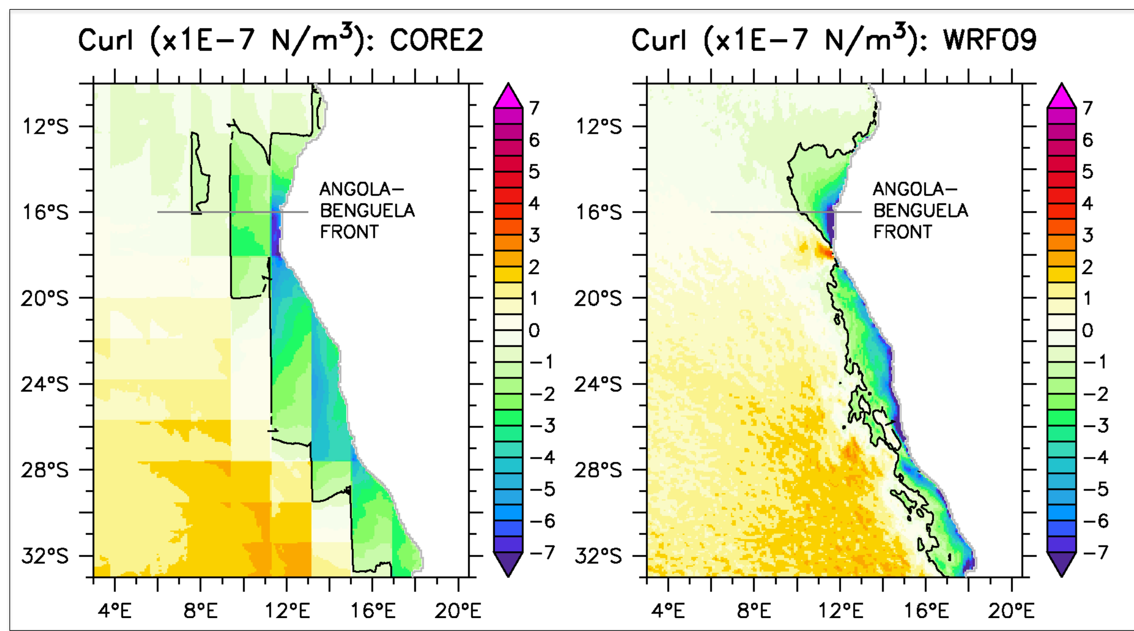



*Fig 4. Wind stress curl (N/m³ *1e-7) prescribed in 9km ROMS simulations from the 2.5°CORE2 product and 9km WRF simulation averaged 2005.*

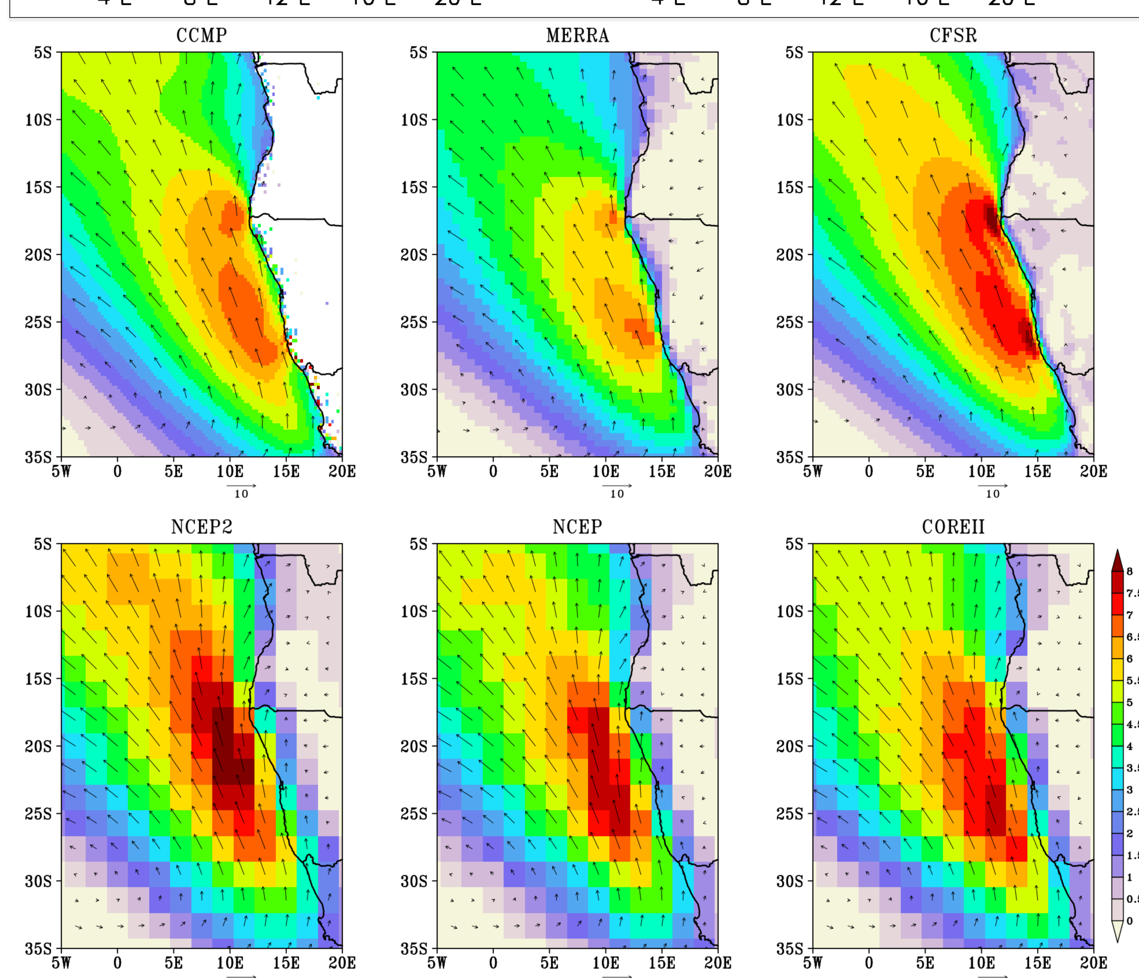
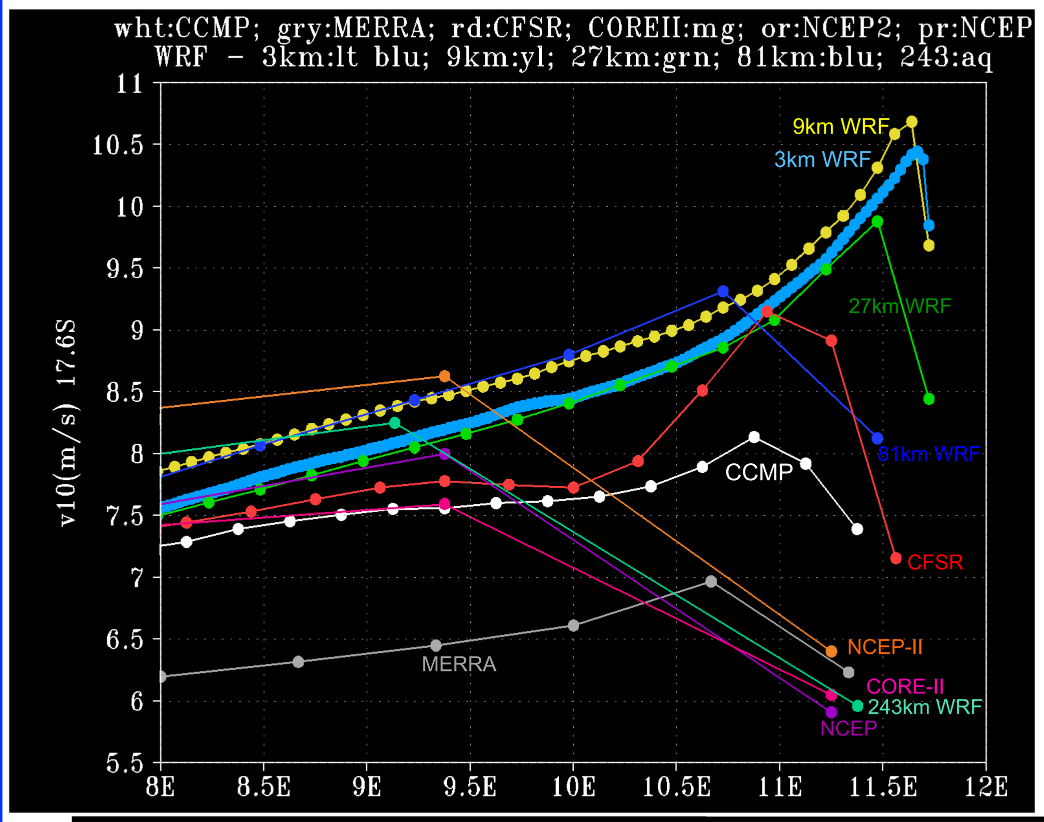



*Fig 5. Meridional wind (shaded; m/s) and wind vector (vector; m/s) at 10m averaged 1988-2009 from the CCMP data set, MERRA reanalysis, NCEP CFSR, NCEP2 reanalysis, NCEP reanalysis, and CORE-II data set. White indicates no data.*

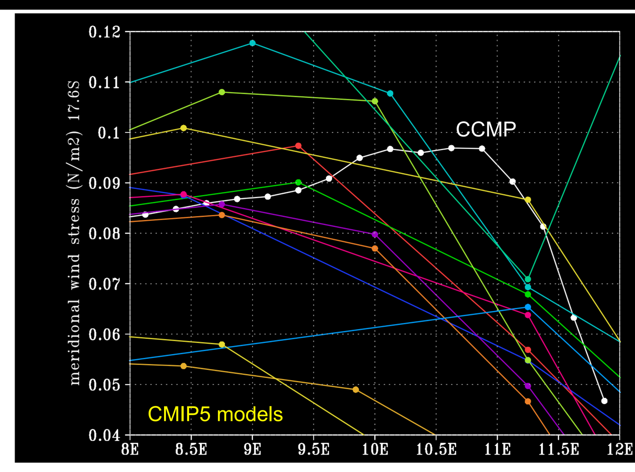
**Acknowledgements**: This research was supported by National Science Foundation Awards OCE-1334707 and 0961545 and the Extreme Science and Engineering Discovery Environment (XSEDE), which is supported by NSF grant number ACI-1053575. We thank the US CLIVAR Eastern Tropical Oceans Synthesis (ETOS) WG for their intellectual support; and their recommendation for a continuing focus on understanding and representing the processes establishing the S.E. Atlantic SST. The Texas Advanced Computing Center (TACC) at The University of Texas at Austin and the Texas A&M Supercomputing Center provided HPC resources.

## Resolving coastal wind drop-off




Reanalysis/observational products and regional model simulations with varying resolutions represent a wide range of locations of the Benguela LLCJ maximum relative to the coast. The simulated longitudinal wind structure appears to converge for resolutions between 3km and 9km.

*Fig 6. Meridional wind (m/s) at 10m and at the grid point closest to 17.6°S in April from reanalysis/ observational products and regional climate model (WRF) simulations at 3km, 9km, 27km, 81km, and 243km resolution. All are 2005-2008, except the 3km simulation, which is 2011.*




Most CMIP5 models have large errors in simulated coastal wind stress drop-off.

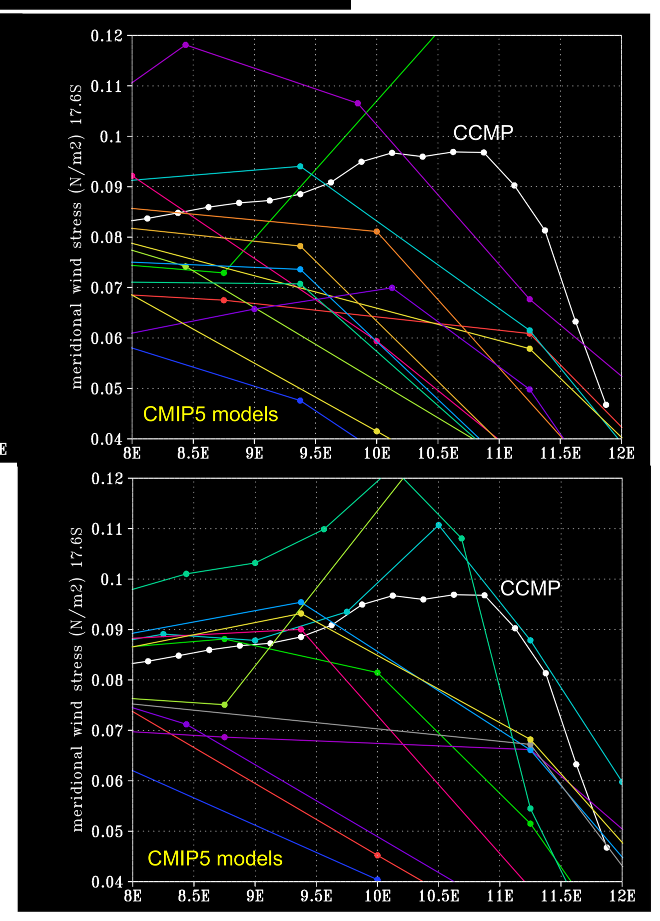



*Fig 7. Surface meridional wind stress (N/m²) at the grid point closest to 17.6°S in April from CCMP (white) and CMIP5 models (colors) averaged 1988-2009. Each color line is one model. Multiple panels are used for clarity, and the specific model selections in each panel have no meaning.*

## Jet dynamics

The simulated climatological Benguela LLCJ strength is proportional to the zonal pressure gradient force (PGF). The model resolves two maxima in the zonal PGF, which support the two Benguela jet cores, at resolutions of 9km, 27km, and 81km. At 243km resolution the zonal PGF and Benguela jet are represented as a single broad maximum.

### Zonal momentum budget

$$\underbrace{\frac{\partial U}{\partial t}}_{\text{local time change}} = \underbrace{-U\frac{\partial U}{\partial x} - V\frac{\partial U}{\partial y} - W\frac{\partial U}{\partial z}}_{\text{advection}} \underbrace{-\frac{1}{\rho}\frac{\partial P}{\partial x}}_{\text{PGF}} + \underbrace{fV}_{\text{Coriolis}} + \underbrace{U_m}_{\text{mixing}}$$

### Meridional momentum budget

$$\underbrace{\frac{\partial V}{\partial t}}_{\text{local time change}} = \underbrace{-U\frac{\partial V}{\partial x} - V\frac{\partial V}{\partial y} - W\frac{\partial V}{\partial z}}_{\text{advection}} \underbrace{-\frac{1}{\rho}\frac{\partial P}{\partial y}}_{\text{PGF}} \underbrace{-fU}_{\text{Coriolis}} + \underbrace{V_m}_{\text{mixing}}$$

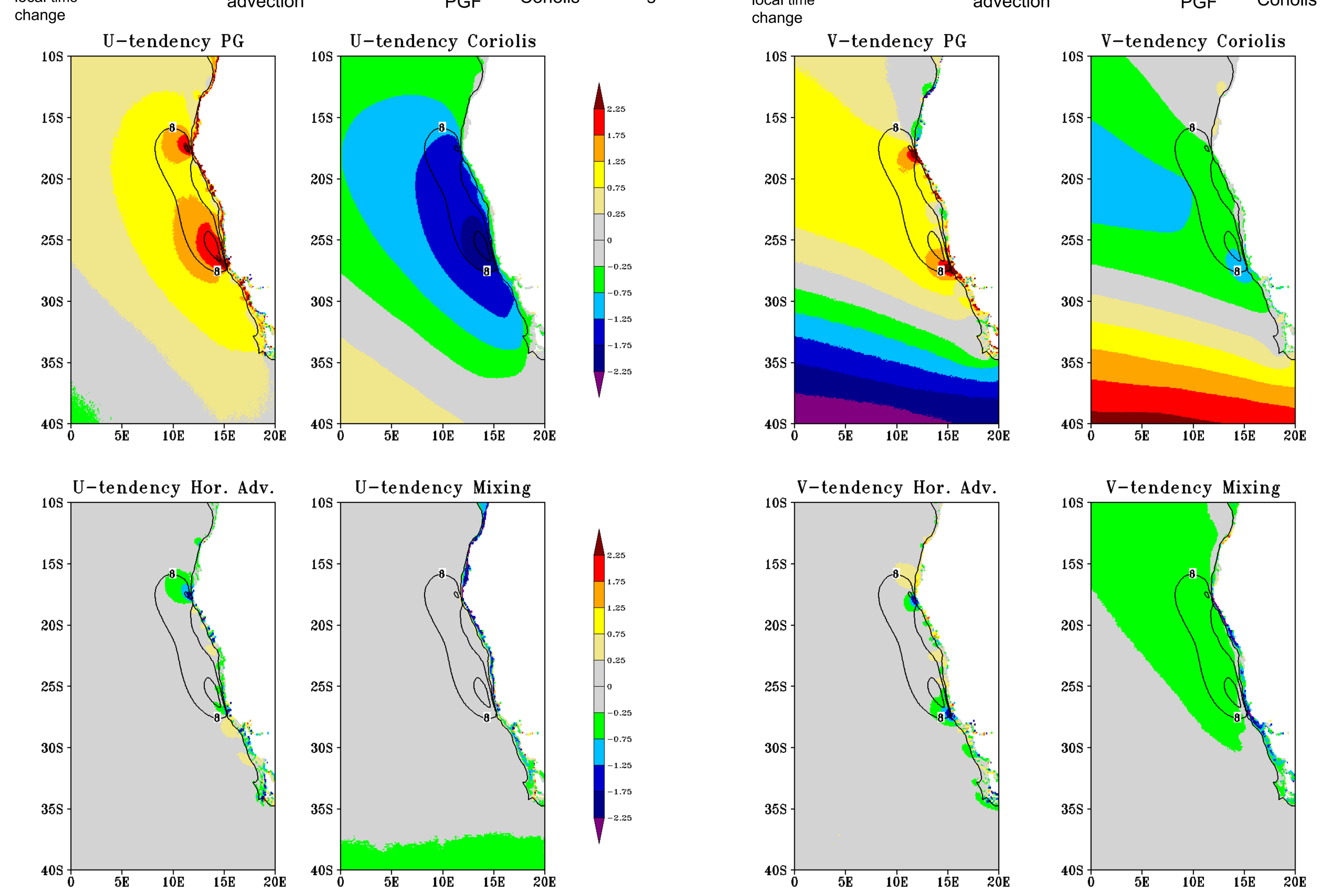



*Fig 8. Zonal (left) and meridional (right) momentum budget terms (shaded; m/s h⁻¹) and meridional wind exceeding 8m/s (contour; m/s) at 975 hPa averaged 2005-2009 from a 9km regional model (WRF) simulation.*

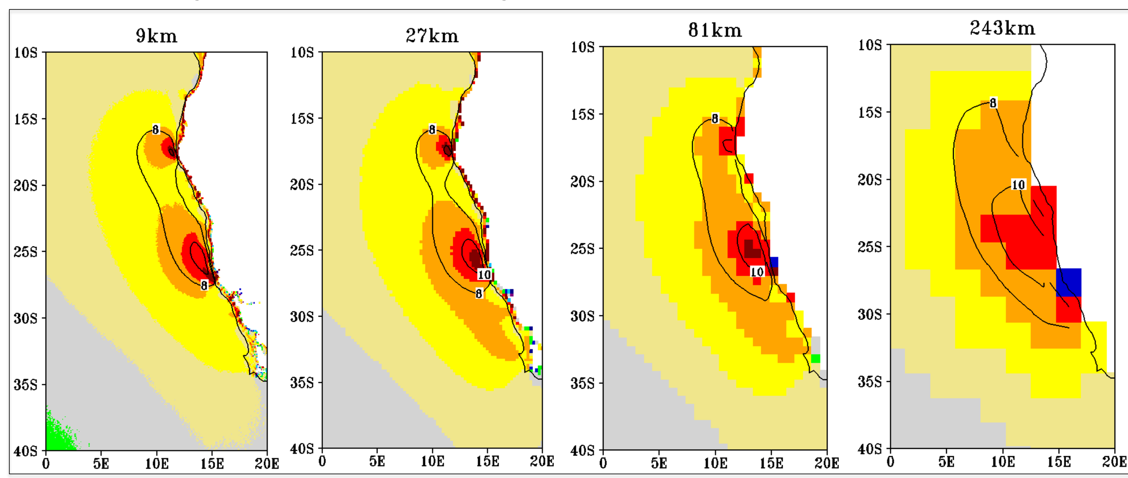



*Fig 9. Zonal pressure gradient term (shaded; m/s h⁻¹) and meridional wind exceeding 8m/s (contour; m/s) at 975 hPa averaged 2005-2009 from regional model (WRF) simulations at 9km, 27km, 81km, and 243km resolution.*

## Coastal geometry and LLCJ structure

The existence of the northern core of the Benguela LLCJ is supported by the convex coastline at 17.5°S. This jet maximum is characterized by a hydraulic expansion fan, in which flow spreads laterally and the marine boundary layer becomes shallow, leading to enhanced wind speed.

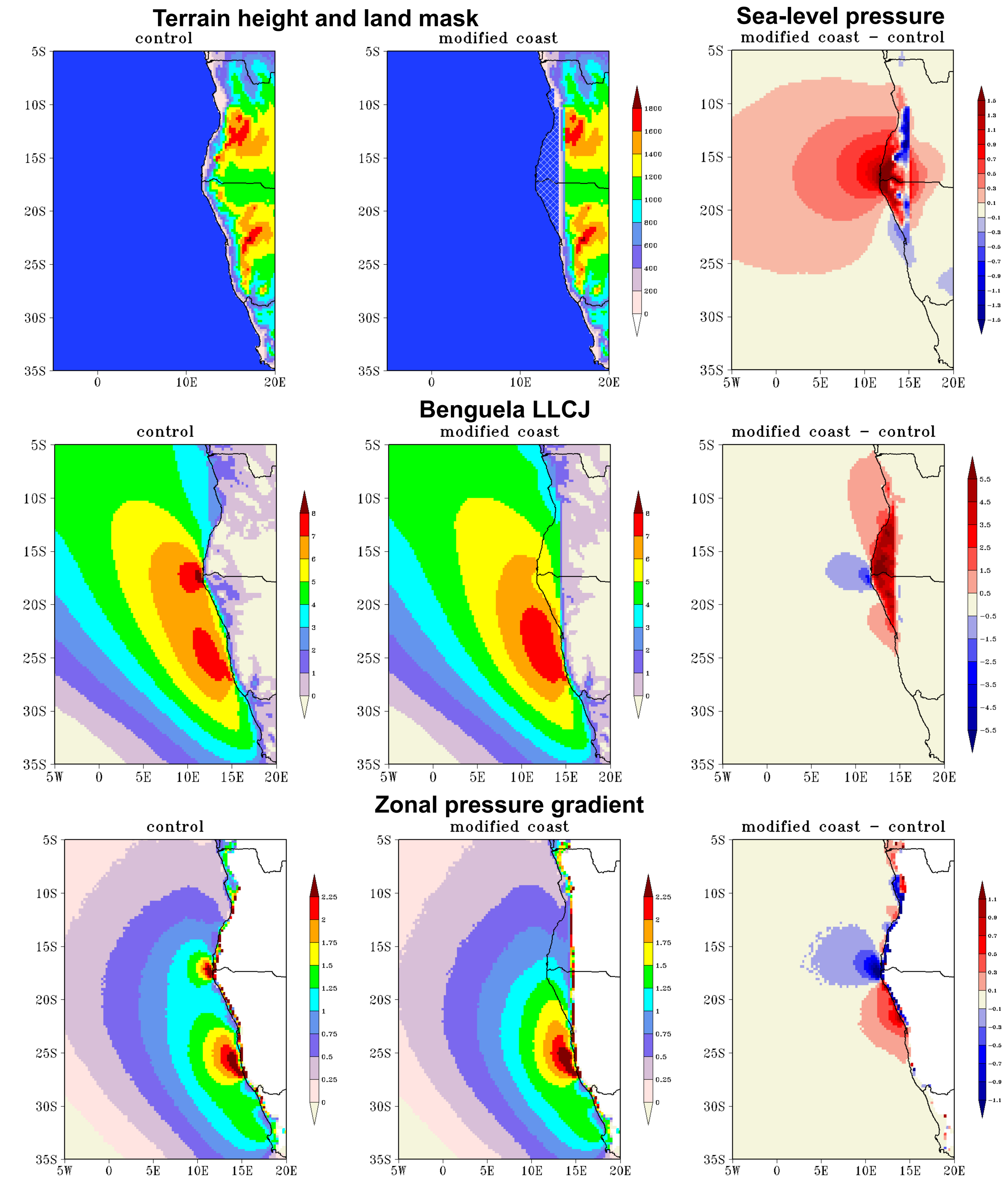



*Fig 10. (row 1, left and center) terrain height (m), ocean mask (blue), and modified land (white hatching), (row 1, right) sea-level pressure (hPa), (row 2) meridional wind (m/s) at 10m, and (row 3) zonal pressure gradient term (m/s h⁻¹) at 975 hPa from 27km WRF simulations with original and modified coastline and the difference, averaged 2005-2009.*

## Impact of jet structure and wind-stress curl on SST

While errors in Benguela LLCJ structure enhance SST bias, the bias is further worsened by deficient coastal wind-stress curl near the Angola-Benguela frontal zone.

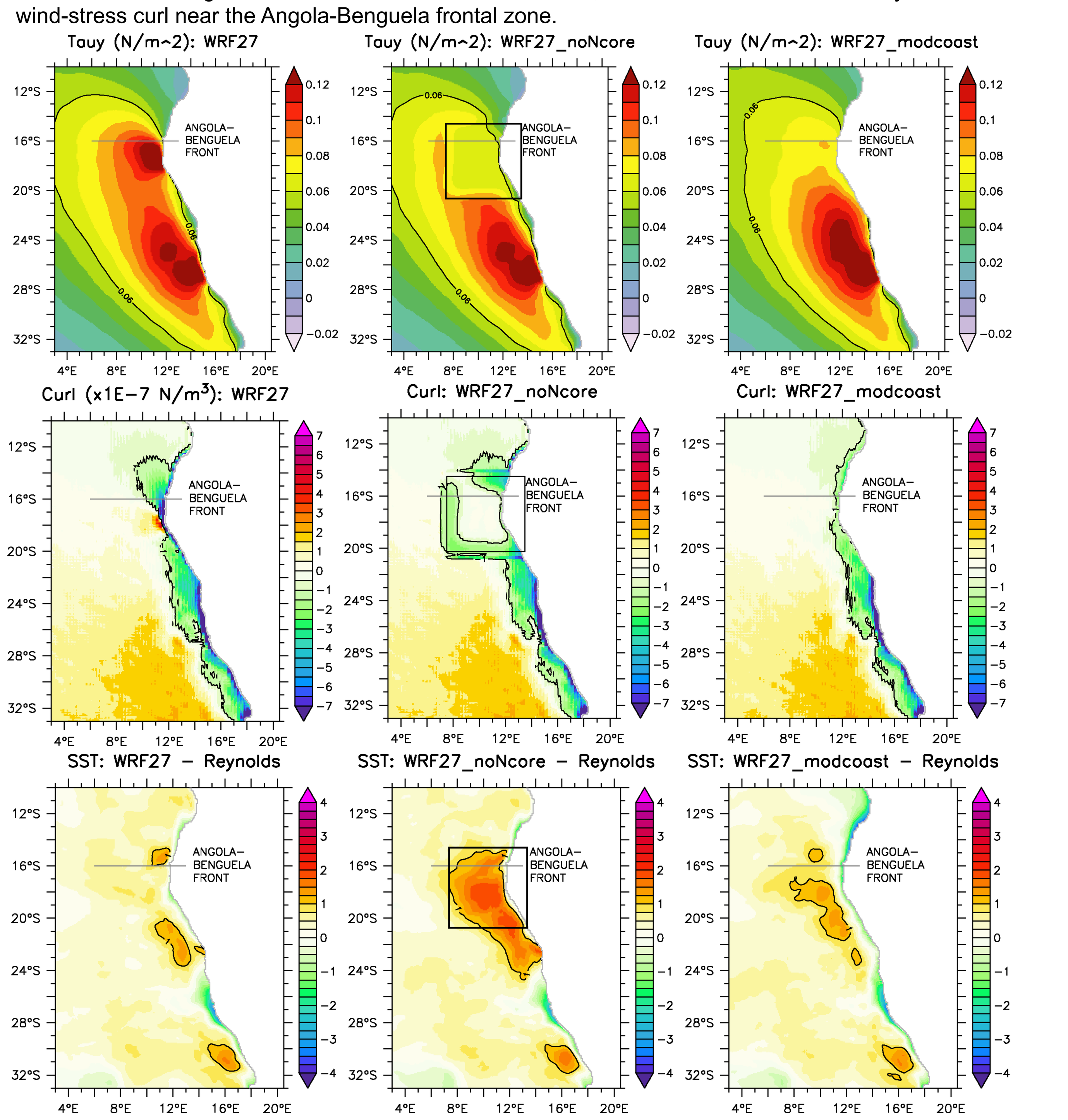



*Fig 11. Meridional wind stress (N/m²), wind stress curl (N/m³ *1e⁻⁷), and SST bias relative to Reynolds SST averaged 2005 from 9 km ROMS (Regional Ocean Modeling System) forced with the atmosphere of the 27km WRF simulation, 27 km WRF simulation with the northern Benguela jet core artificially removed and wind stress curl set to zero in the marked box, and 27km WRF simulation with modified coastal geometry as in Fig. 10.*

## Summary

- Realistic representation of the detailed structure of the Benguela LLCJ, including both the double core and coastal wind drop-off, is critical to reducing the coastal ocean bias in the southeastern tropical Atlantic. (See also poster by Small et al. – Part 1)
- Atmospheric models need a resolution of at least ~0.25°–0.5° in order to simulate the double core jet structure, which is supported by strong pressure gradient forces arising from the convex coastal geometry near 17.5°S and coastal terrain.
- The simulated coastal wind drop-off pattern converges between 3km and 9km resolution. There is a disparity of several degrees of longitude in the wind maximum location in models and data products ranging from 3km to 2.5° resolution. There is uncertainty in the actual coastal wind drop-off pattern due to lack of observations near the coast, where satellite products are less reliable.