Application of the 4D-Variational Data Assimilation Method of the Regional Ocean Modeling System (ROMS) to Simulate Circulation on the Southeast Brazilian Ocean Region

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Introduction

- Use of the Regional Ocean Modeling System (ROMS) in a domain covering Santos, Campos and Espirito Santo (ES) basins at Brazilian southeast coast.
- Focus on Santos Basin due to high interest for the O&G industry
- Main use of model results for currents forecast and project design

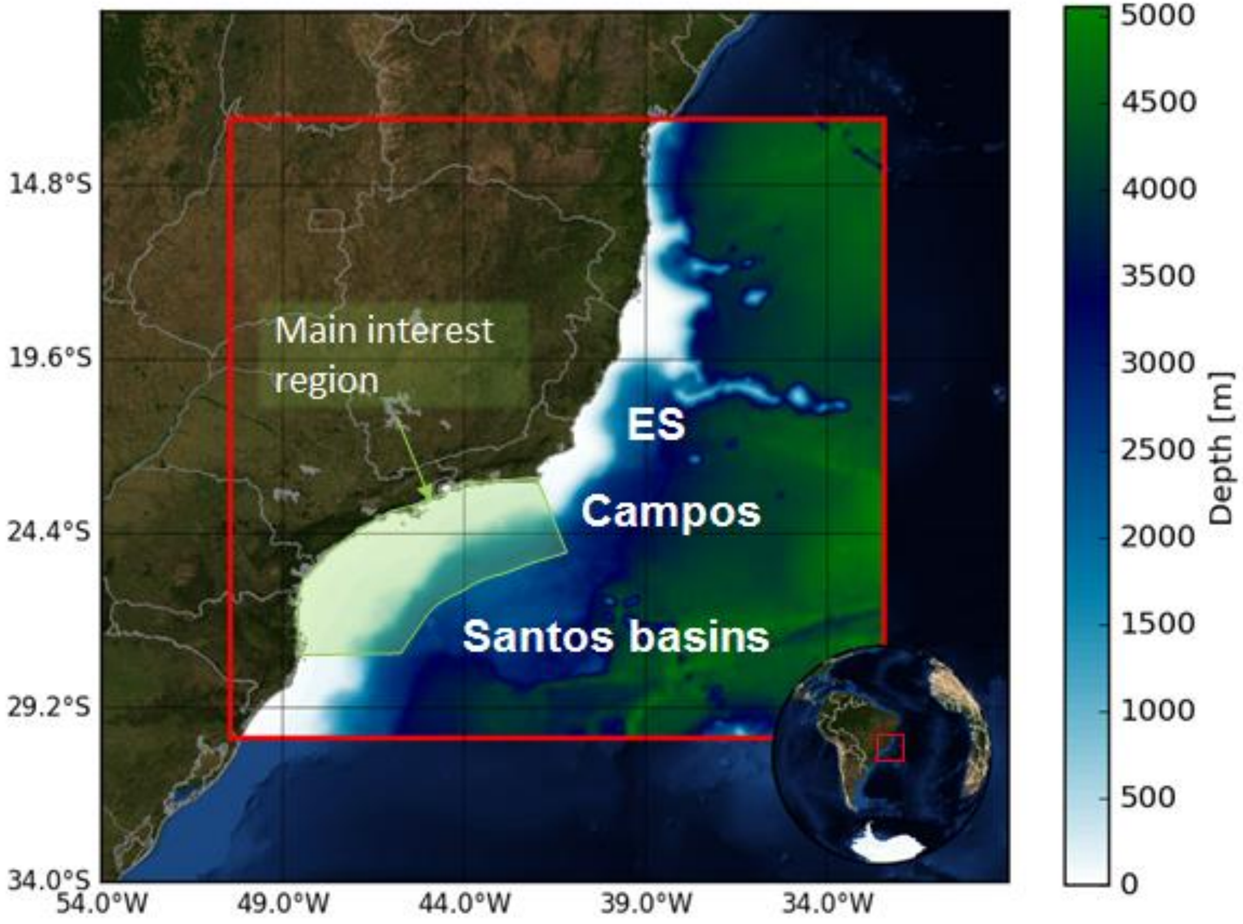


Fig. 1: ROMS grid domain and bathymetry.

Motivation

- Heterogeneous ocean circulation with remarkable presence of meanders and eddies associated with the Brazil Current System

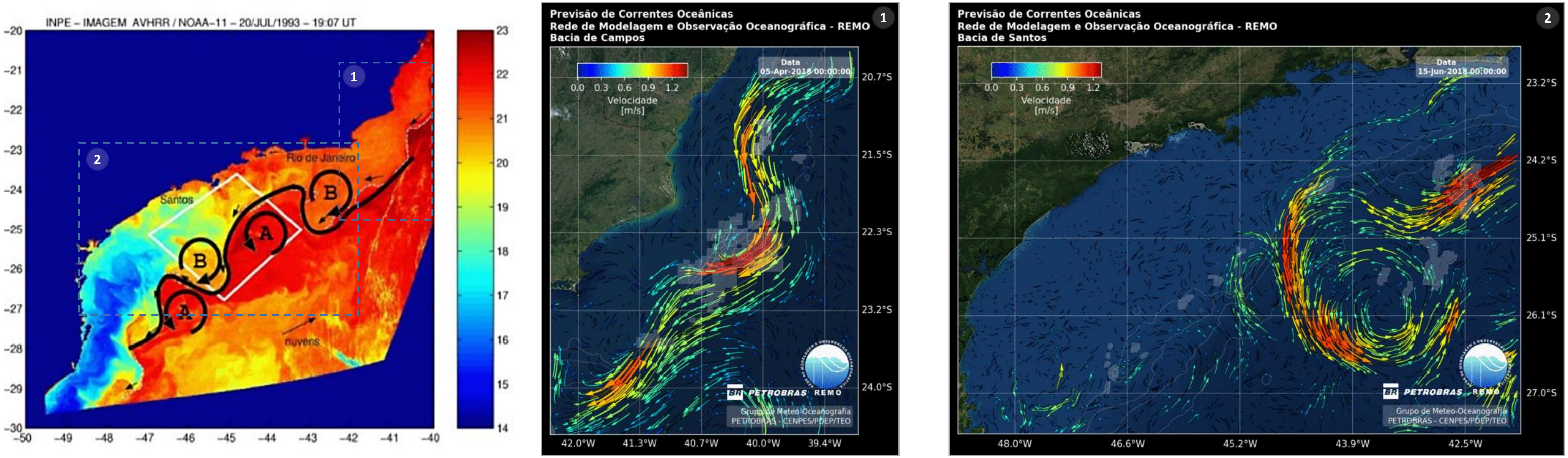


Fig. 2: At left: sketch of the Brazil Current System behavior along Santos and Campos Basin; meanders and eddies are schematically drawn; at middle/right: surface currents at Campos (1) and Santos (2) basins from REMO operational forecast (Silveira, 2006; REMO, 2018).

Motivation

- Difficulty of non-assimilative runs to correctly reproduce mesoscale features (spatial and/or temporal misfit)

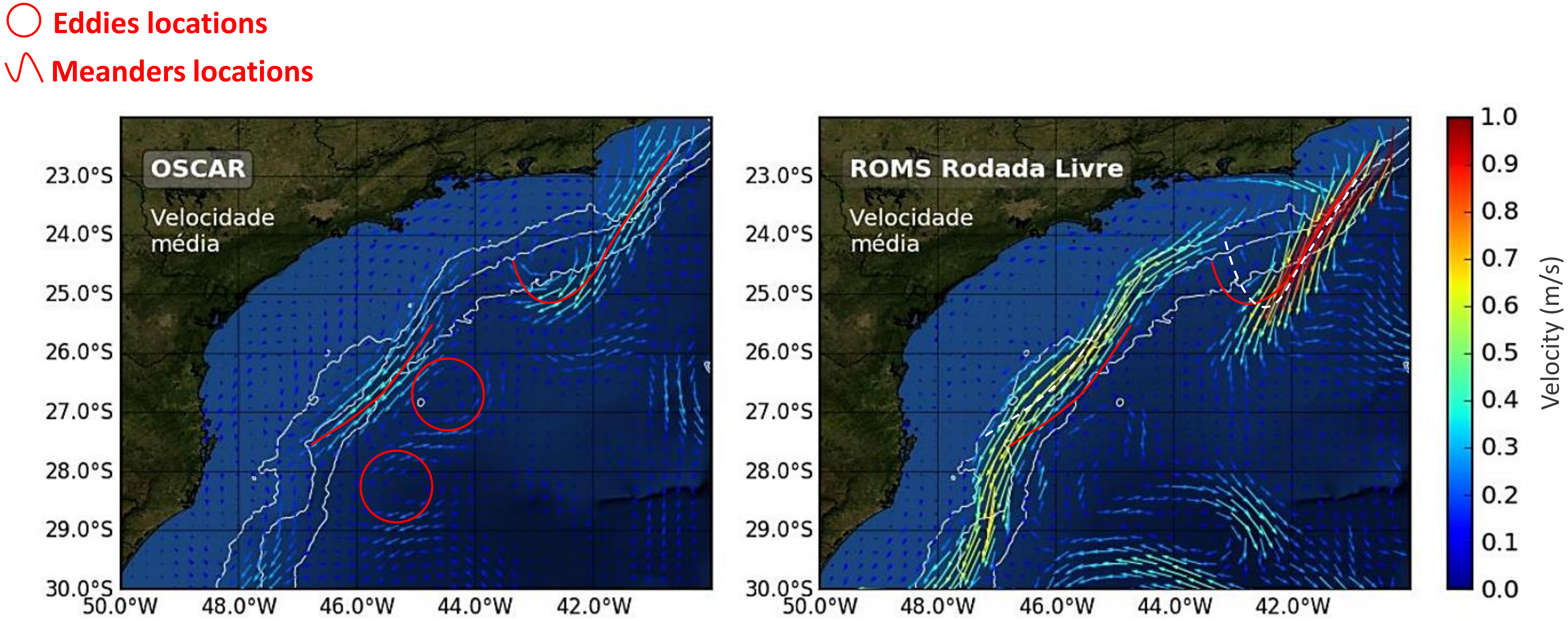
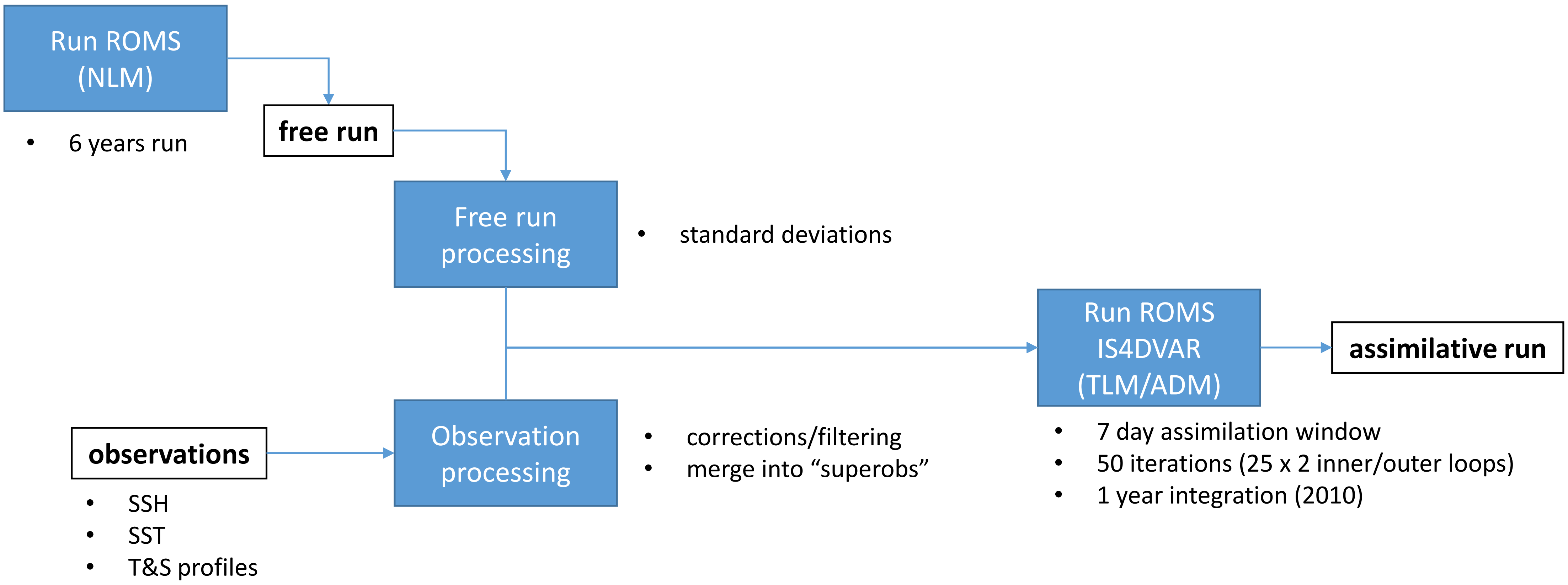


Fig. 3: Surface mean currents (m/s) for January, 2010: at left, OSCAR model; at right: non assimilative run. Features of surface circulation are shifted or absent in the non assimilative run.

Objectives

- To improve model skills in reproducing mesoscale features of Santos Basin surface circulation
  - Setup and run a 1 year assimilative experiment using ROMS 4D-VAR module
  - Compare with free run, reference models and observational data

Methodology



Model setup

- Model resolution: 1/12 degrees, with 40 layers and 222x217 horizontal grid points
- Bathymetry: ETOPO 1
- Boundary, initial fields and climatology: Global HYCOM NCODA Analysis 1/12 daily fields
- Surface forcing: Global NOAA CFSR 1/3 (Climate Forecast System Reanalysis) hourly fields
- Nudging to HYCOM climatology (T&S only): 360/30 days (above/under 800 m)

Assimilation setup

Table 1. Summary of observed data assimilated in ROMS 4D-VAR.

Variable	Source	Resolution	Frequency	Obs. Error[b]
SST	OSTIA	6 km	daily	0.4°C
SSH	AVISO (ATOBA product)	9 km	weekly	0.02 m
T&S profiles	ARGO, CTD/XBT[a]	-	-	0.1°C / 0.05

[a] ARGO floats kindly processed by UFBA and Brazilian Navy; CTD and XBT from Petrobras database.

Table 2. Decorrelation length scales for different state variables.

Variables	Horizontal Decorrelation Length (L_h)[1]	Vertical Decorrelation Length (L_v)[1]
T, S, ζ	100 km	100 m
u, v	60 km	100 m

[b] values estimated following Fragoso et al. (2016), Zavala-Garay & Wilkin (2013), Powell et al. (2009), Zhang et al. (2010) and Broquet et al. (2009), semivariogram analyses and experimentation.

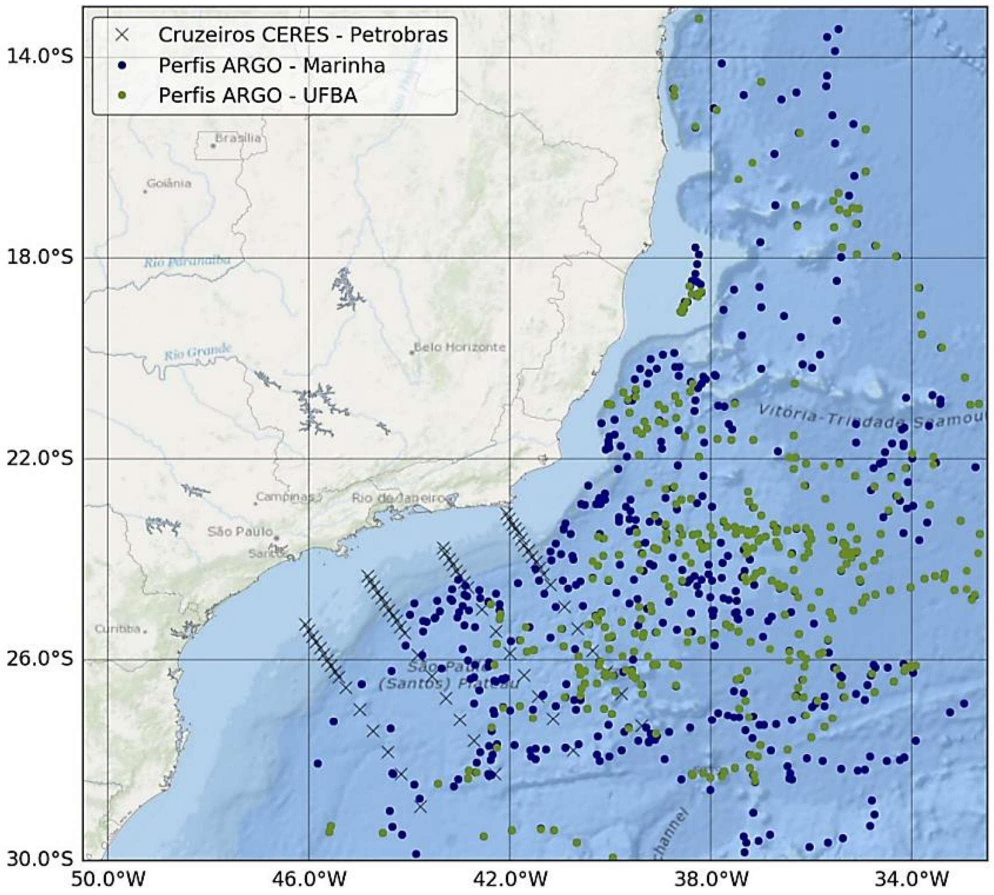


Fig. 5: T&S profiles assimilated in ROMS: circles are ARGO floats and crosses are CTD/XBT data from Petrobras. Total number of profiles: 1147.

Results

- Sea Surface Temperature (RMSD)

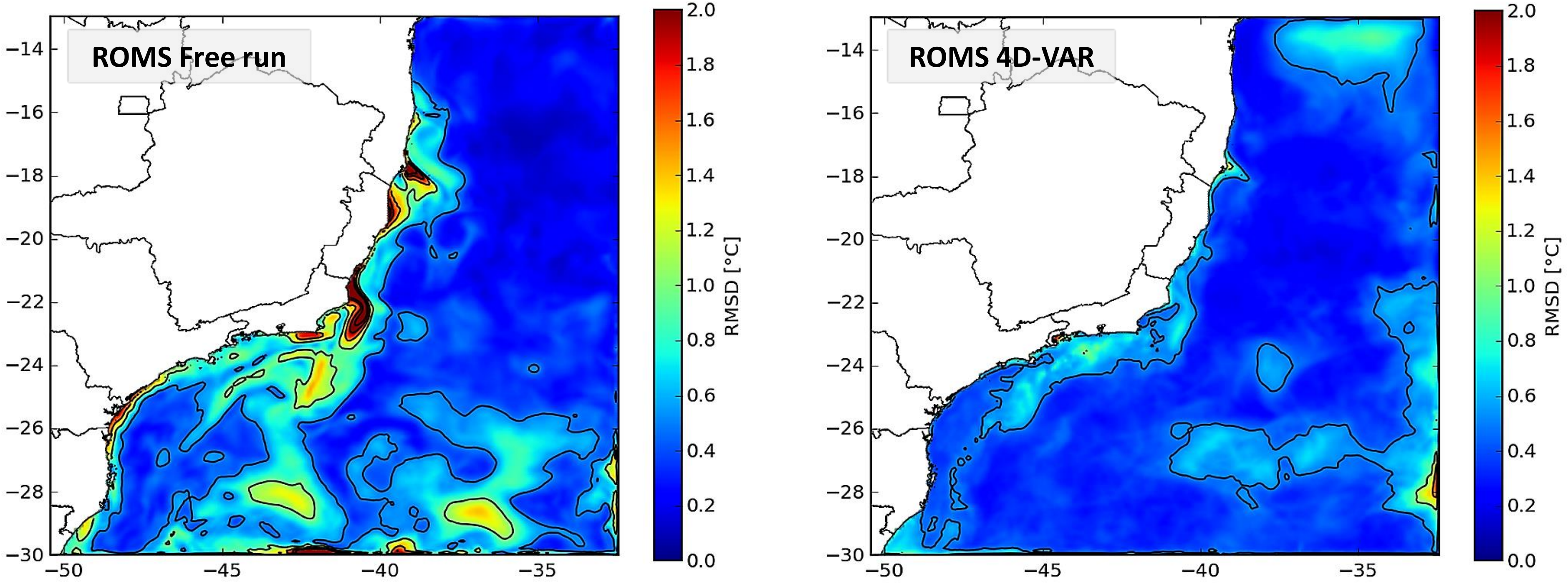


Fig. 8: Root Mean Square Deviation (RMSD) between assimilated OSTIA fields and free run (at left) and assimilative run (at right)

Results

- Sea Surface Height (RMSD)

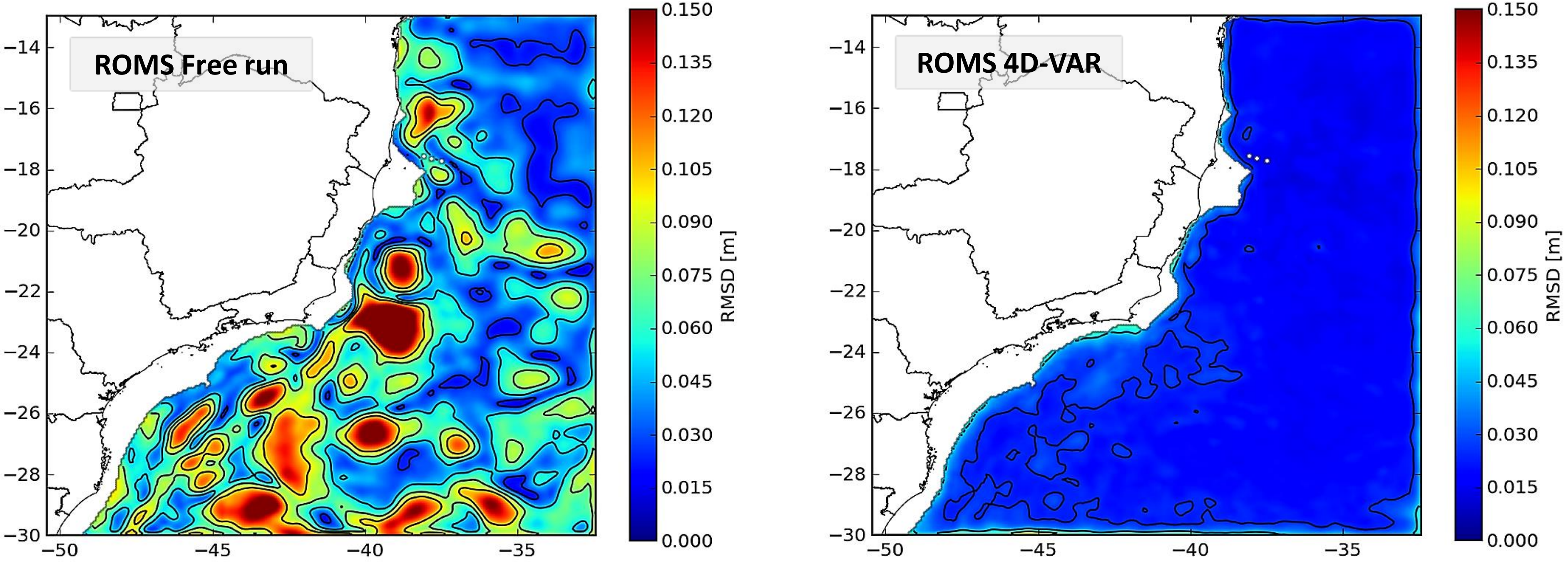


Fig. 9: Root Mean Square Deviation (RMSD) between assimilated AVISO fields and free run (at left) and assimilative run (at right)

Results

- Vertical T&S profiles (RMSD/error bias)

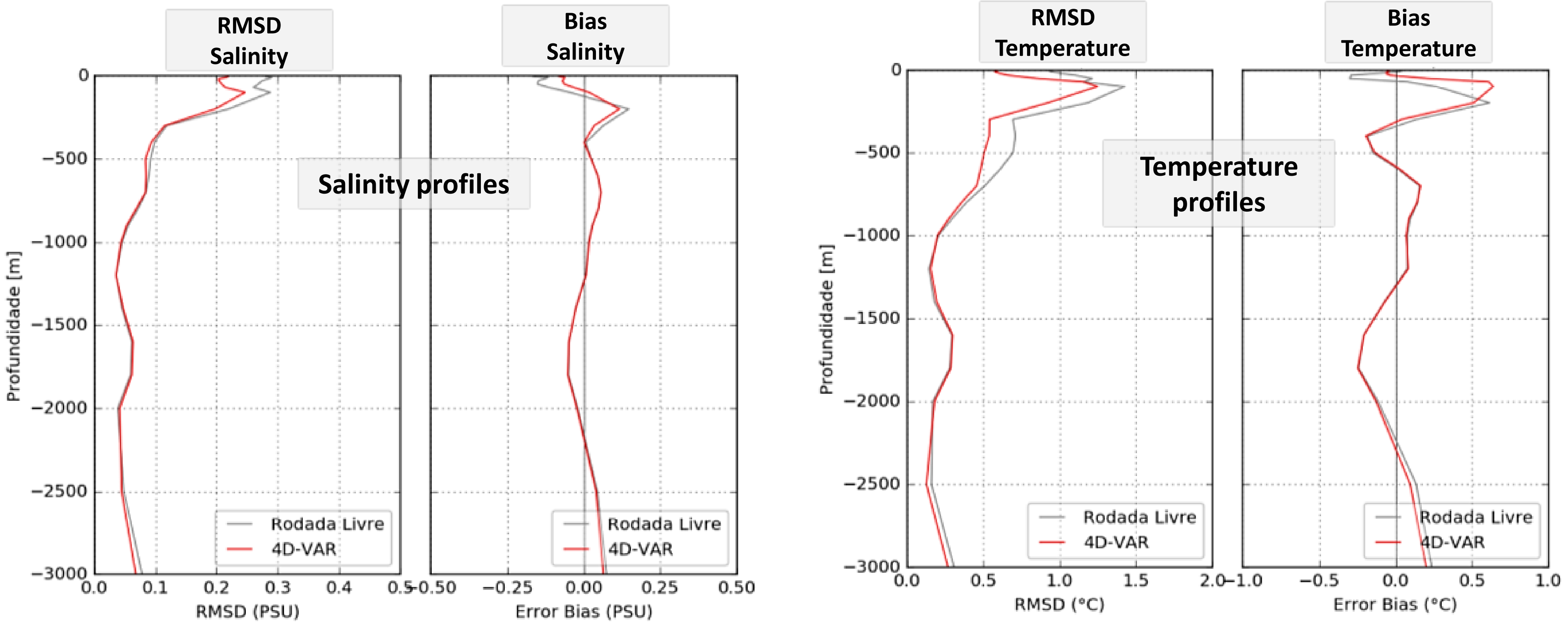
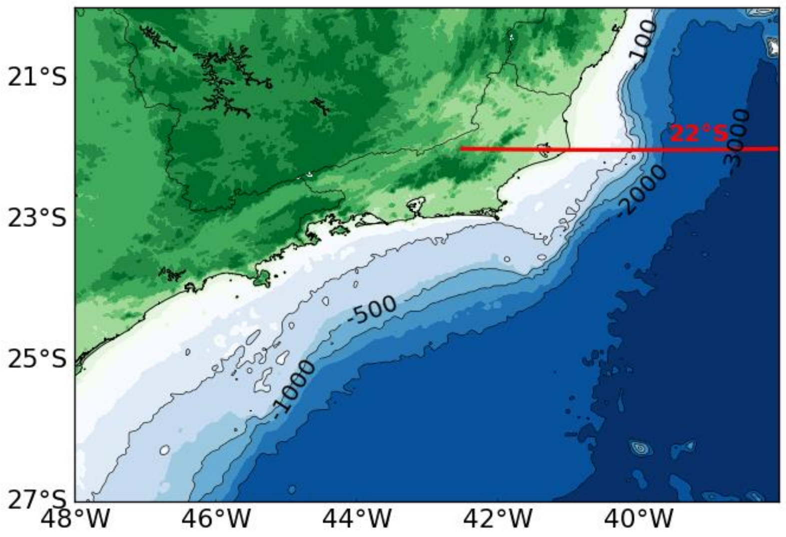


Fig. 10: Root Mean Square Deviation (RMSD) and Error Bias between assimilated T&S profiles and free (gray line) and assimilative run (red line).

Results

- Brazil Current Transport



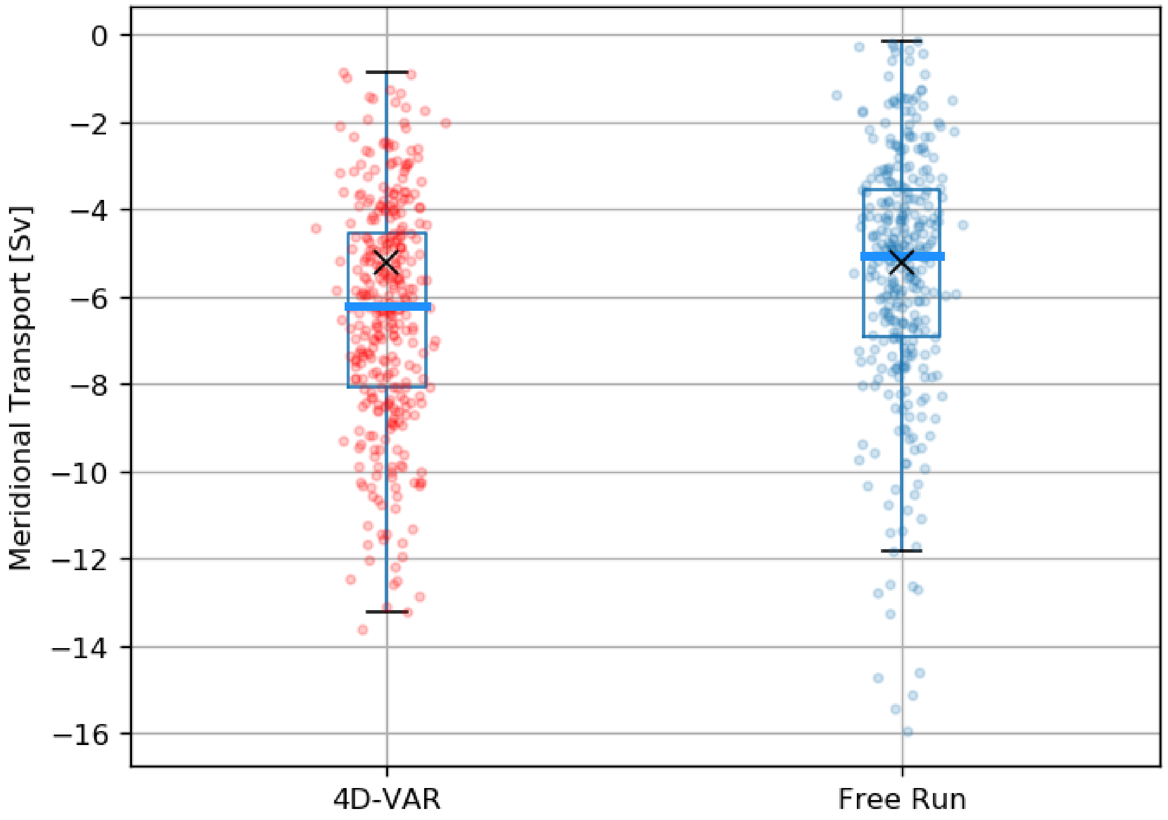


Fig. 12: Box-plot of Brazil Current transport at 22°S: simulated values (circles) and literature estimated transport (black cross) (Signorini, 1978).

Results

- Surface currents (ROMS vs OSCAR)

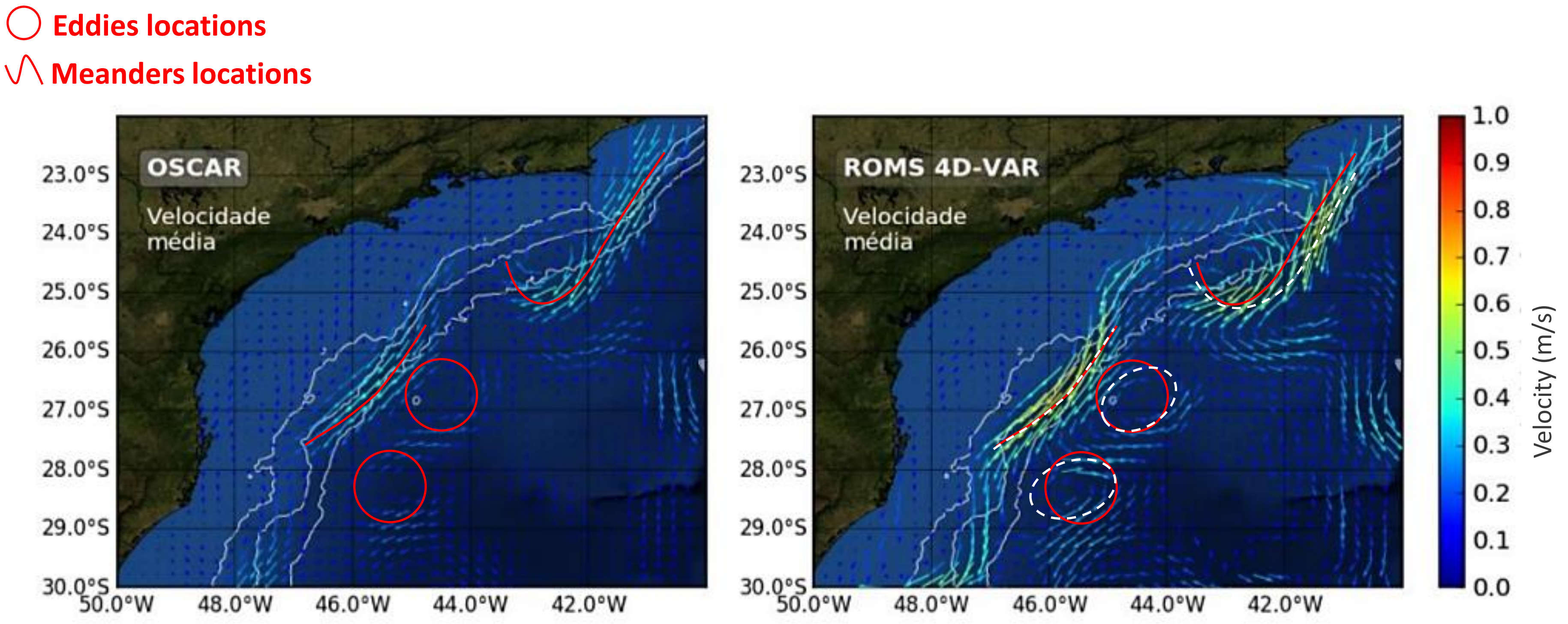
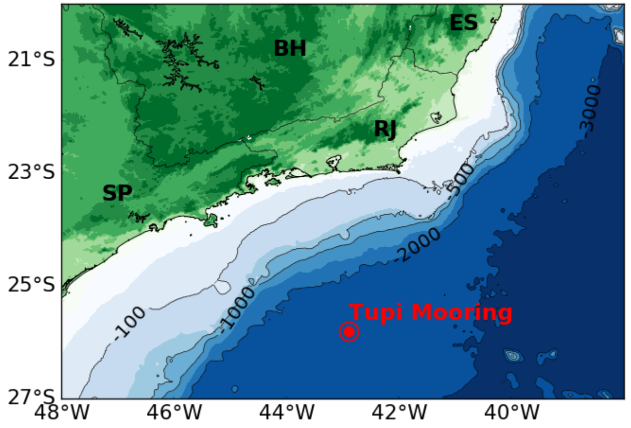


Fig. 11: Surface mean currents (m/s) for January, 2010: at left, OSCAR model; at right: assimilative run. Features of surface circulation are present and correctly positioned in the assimilative run.

Results



- Currents time series (ROMS vs Tupi Mooring)

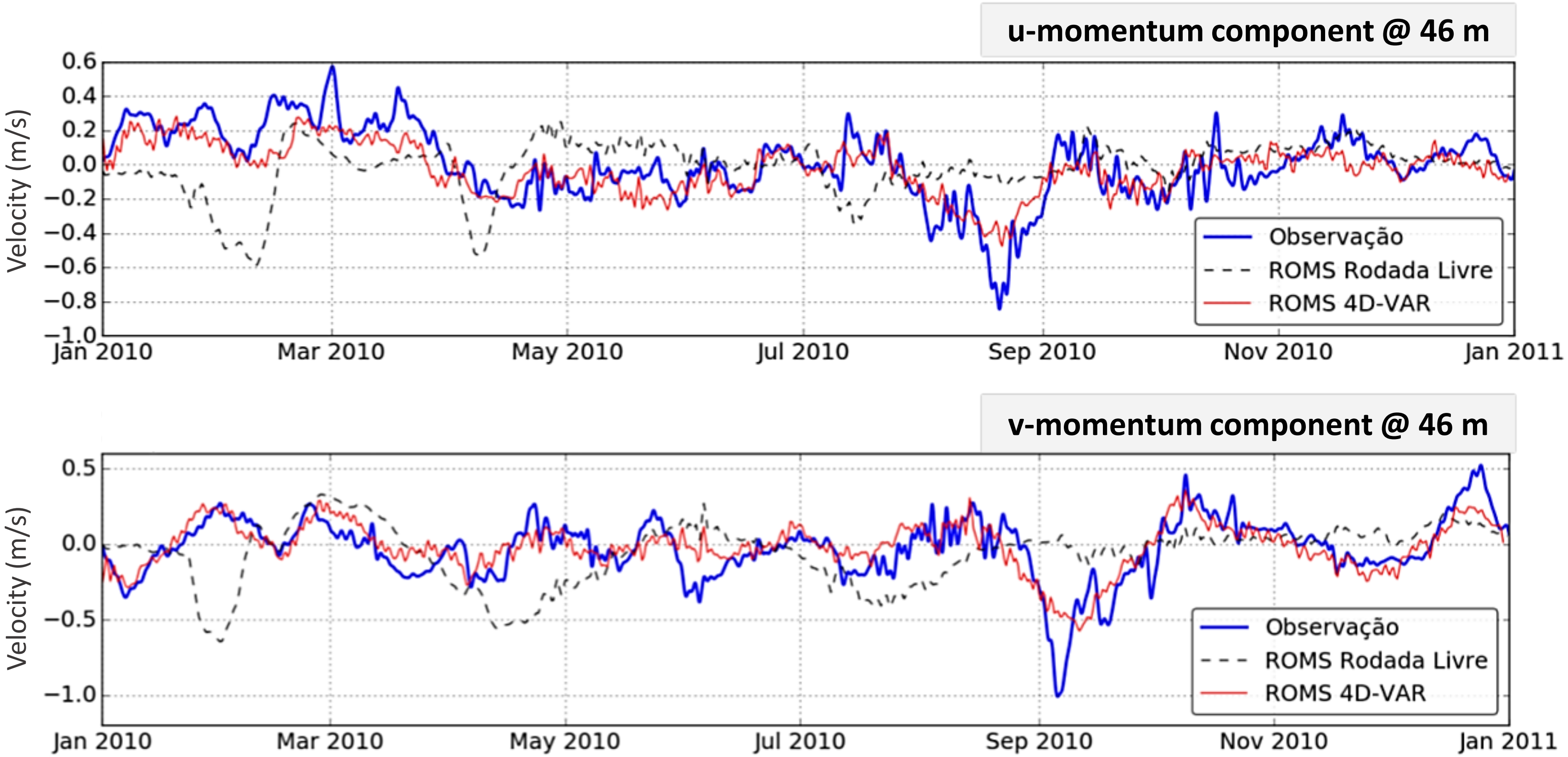


Fig. 12: Velocity componentes time series at Tupi mooring location for observations (blue line), ROMS free run (dotted gray line) and ROMS 4D-VAR (red line).

Results

- Currents profiles (RMSD)

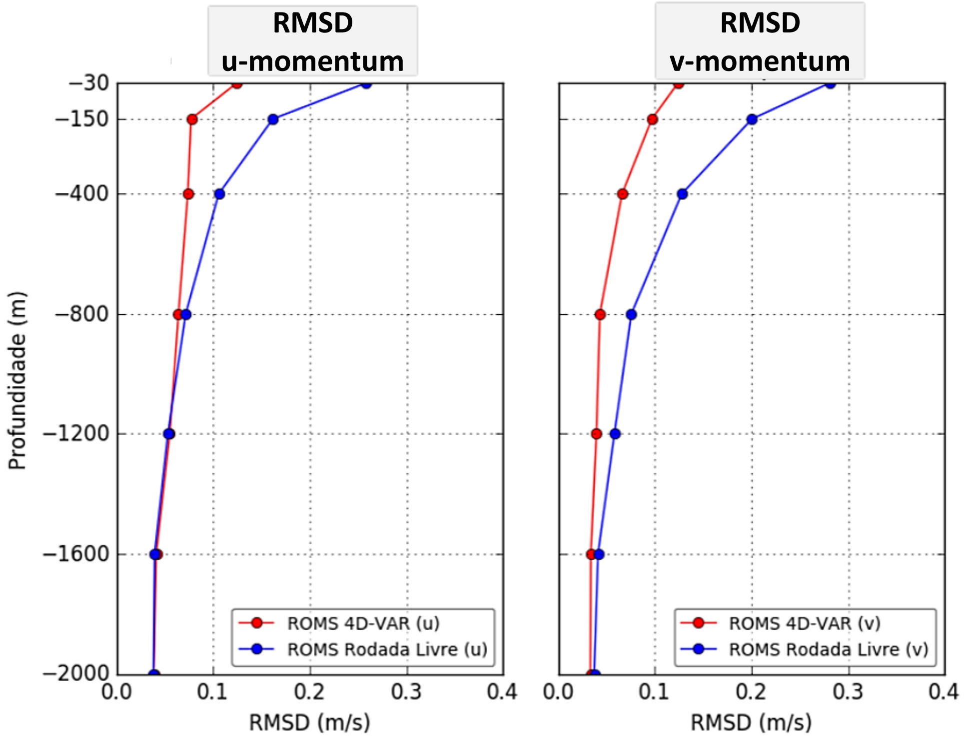


Fig. 19: Root Mean Square Deviation (RMSD) between observed velocity components at Tupi mooring at various depths and ROMS free run (blue line) and ROMS 4D-VAR (red line).

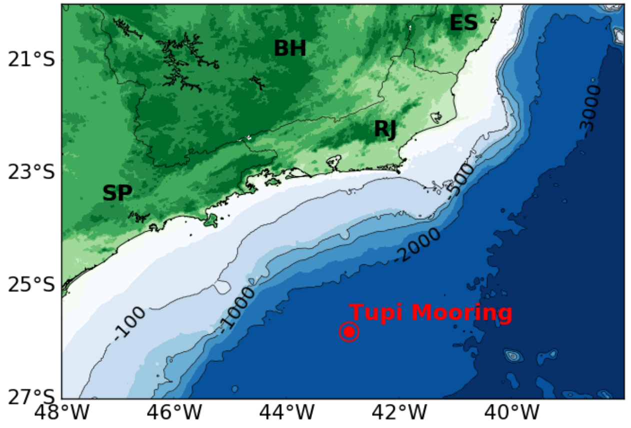


Table 3. Error reduction estimates for ROMS 4D-VAR.

DEPTH	ROMS Free run		ROMS 4D-VAR		4D-VAR improvement	
	RMSD (u)	RMSD (v)	RMSD (u)	RMSD (v)	Variation (u)	Variation (v)
30 m	0.2582	0.2810	0.1243	0.1239	52%	56%
150 m	0.1616	0.2005	0.0769	0.0968	52%	52%
400 m	0.1055	0.1277	0.0735	0.0659	30%	48%
800 m	0.0714	0.0755	0.0639	0.0429	10%	43%
1200 m	0.0529	0.0580	0.0549	0.0394	-4%	32%
1600 m	0.0391	0.0410	0.0409	0.0336	-4%	18%
2000 m	0.0380	0.0370	0.0383	0.0330	-1%	11%

Remarks

- ROMS 4D-VAR module successfully implemented:
  - ✓Improved circulation down to 400 m in most of domain
  - ✓Convergence of method at all assimilation cycles
- However ...
  - Possible overfitting to observations due to high number of iterations
  - Low improvement at subsurface fields
  - Short timestep to keep stability
  - High computational time: 20 hours per assimilation cycle with 160 processors (Intel Xeon CPU E5-2670 @ 2.60GHz)
- Need for improvements in free run and 4D-VAR setup

Ongoing work

- Free run with improved setup
  - ✓Bathymetry corrections
  - ✓RadNud boundary conditions
  - ✓Nesting to Mercator 1/12 Global Ocean Sea Physics Analysis
  - ✓Increased time step (60 → 180 seconds)
- New 4D-VAR experiments:
  - ⌛ RadNud boundary conditions in NLM
  - ⌛ Reduction of inner loops (avoid overfitting; reduce computational time)
  - ⌛ Different assimilation window size
  - ⌛ Different observation error
  - ⌛ Different viscosity and diffusivity for TLM
  - ⌛ Multivariate balance operator

Thank you!

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