10th International Workshop on Modeling the Ocean

Numerical modeling of storm surges in the coast of Mozambique: the cases of tropical cyclones Bonita (1996) and Lisette (1997)

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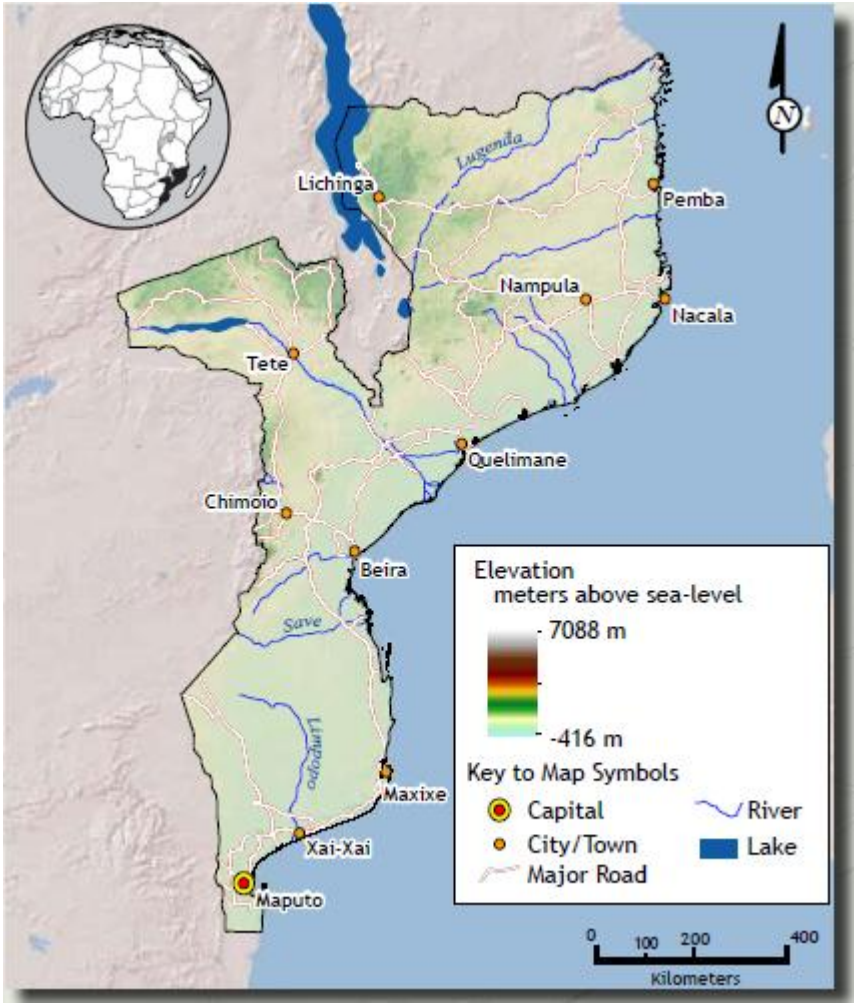
Outline

- Introducrion
- Model and Data
- Results
- Concluding Remarks

Mozambique: country overview

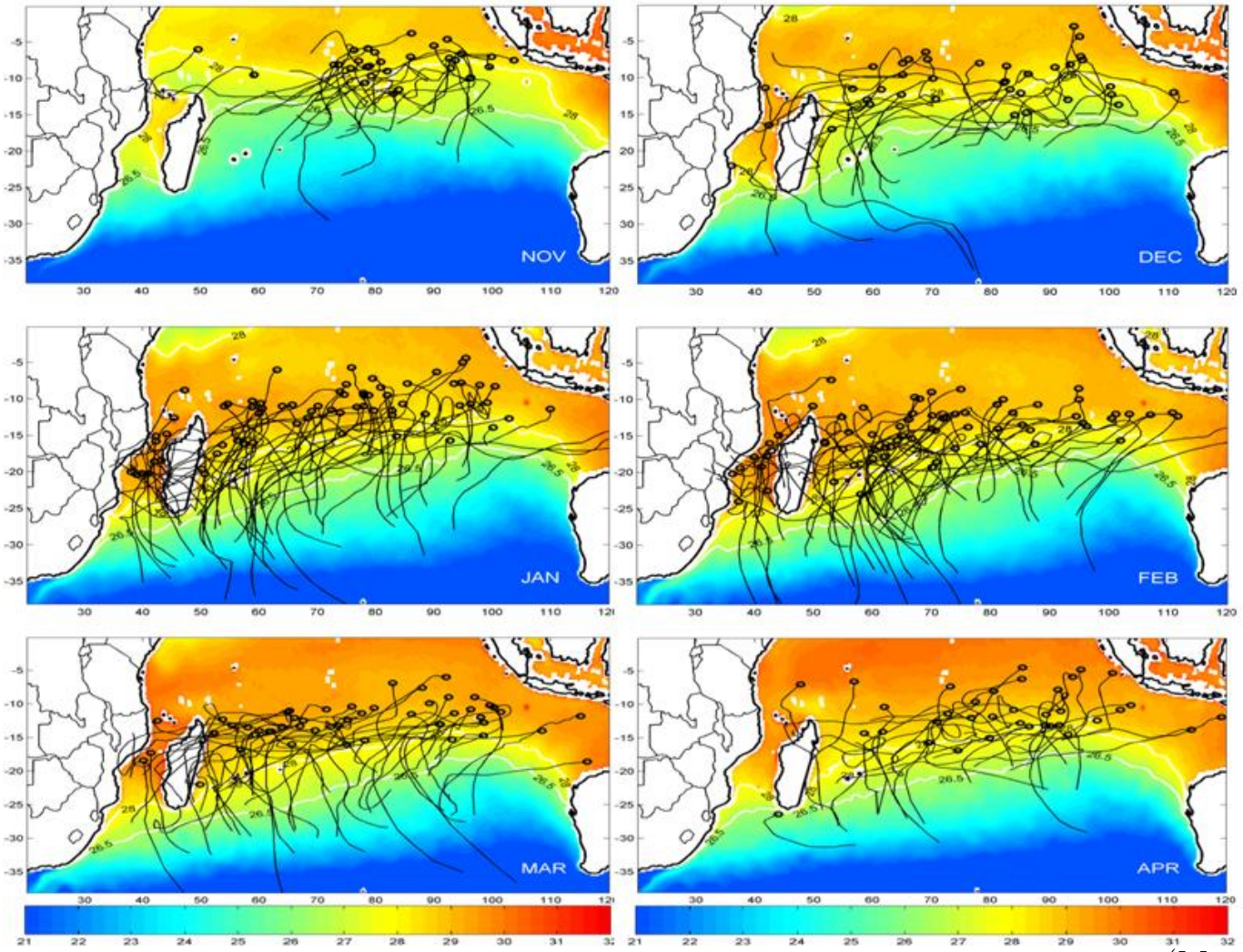


(GFDRR, 2011)

- Located southeastern Africa;
- Coastline: 2700 km;
- About 50% of the population live near the coast;
- Economically disadvantaged country;
- Facing many development challenges;
- Often affected by intense meteorological activity;

Why to model storm surges in the coast of Mozambique?

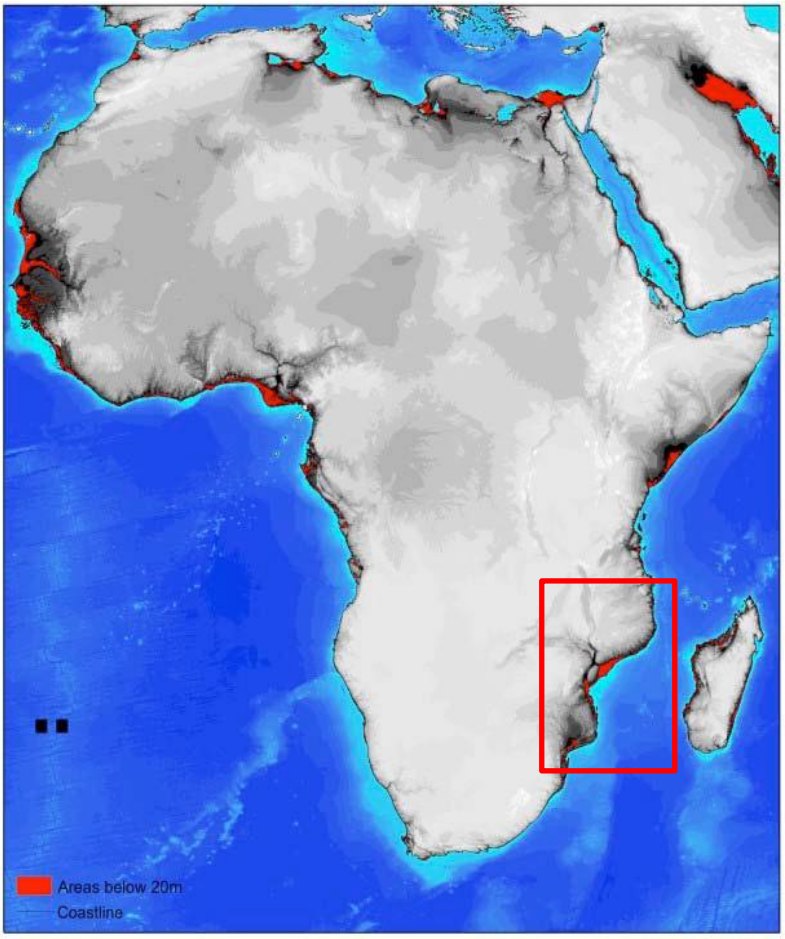
Genesis and tracks of tropical cyclones in Southwest Indian Ocean between 1980-2007 (November - April) and monthly climatological SST



(Mavume *et al.* 2009)

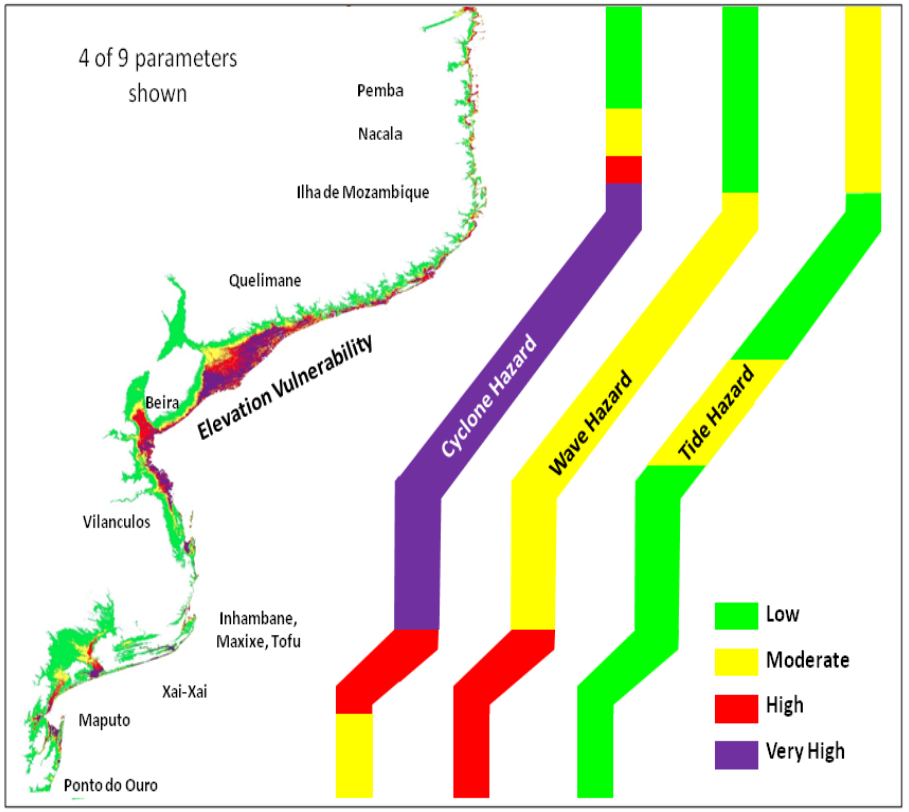
Why to model storm surges in the coast of Mozambique?

Areas below the 20 m elevation contour



(Adapted: Brooks *et al.*, 2006)

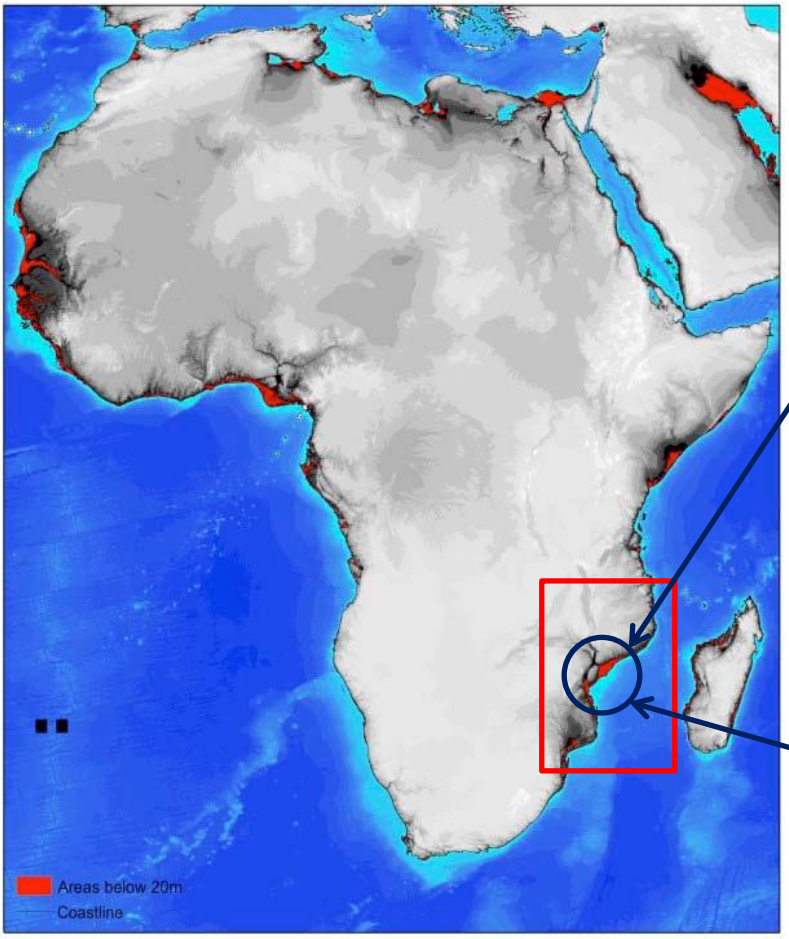
Vulnerability along the coastline



(Theron and Barwell, 2012)

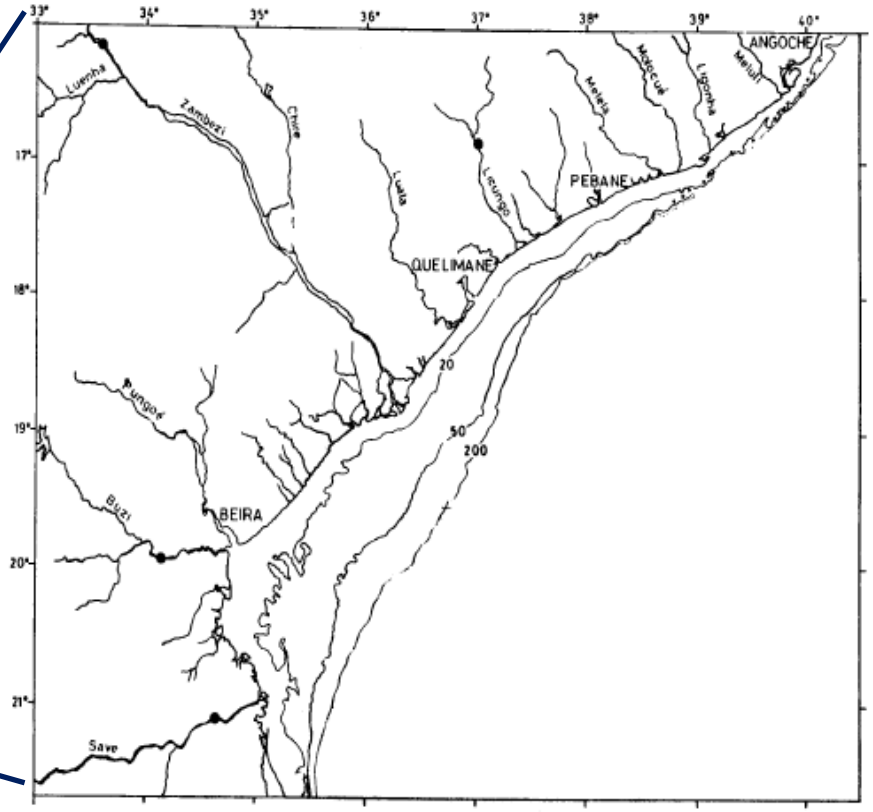
Why to model storm surges in the coast of Mozambique?

Areas below the 20 m elevation contour



(Brooks *et al.*, 2006)

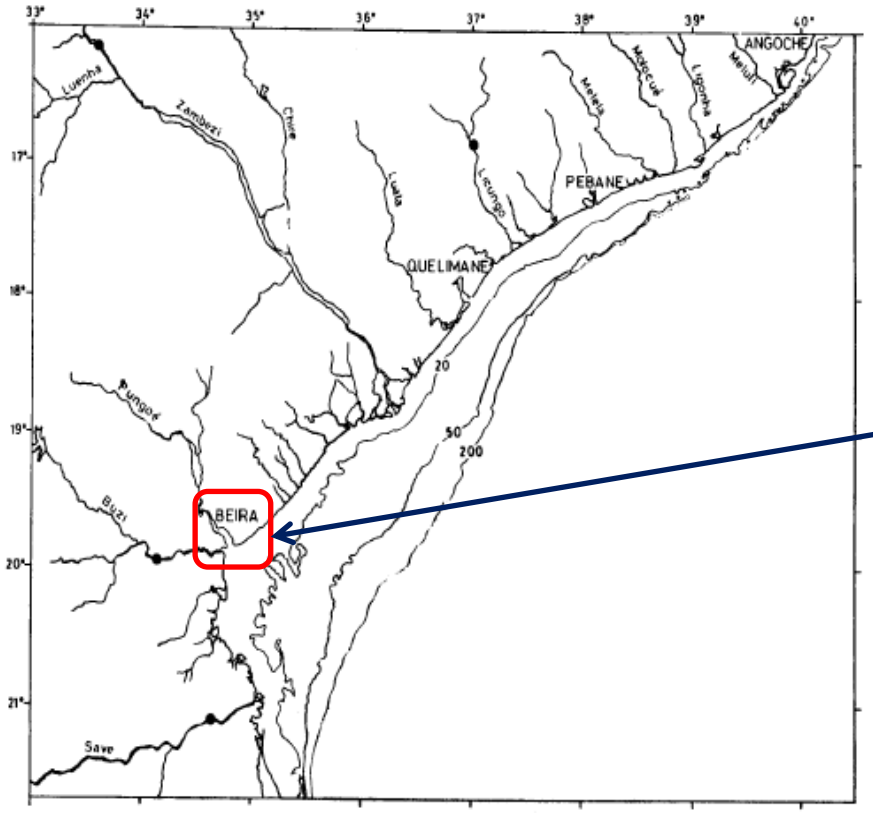
The Sofala Bank:
Bathymetry (m) and main rivers



(Sete *et al.*, 2002)

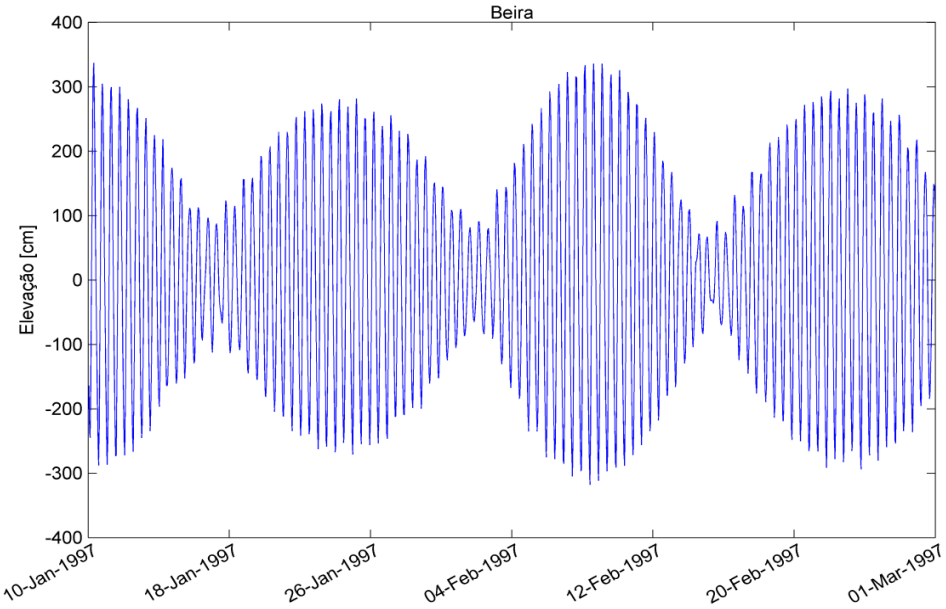
Why to model storm surges in the coast of Mozambique?

The Sofala Bank:
bathymetry (m) and main rivers



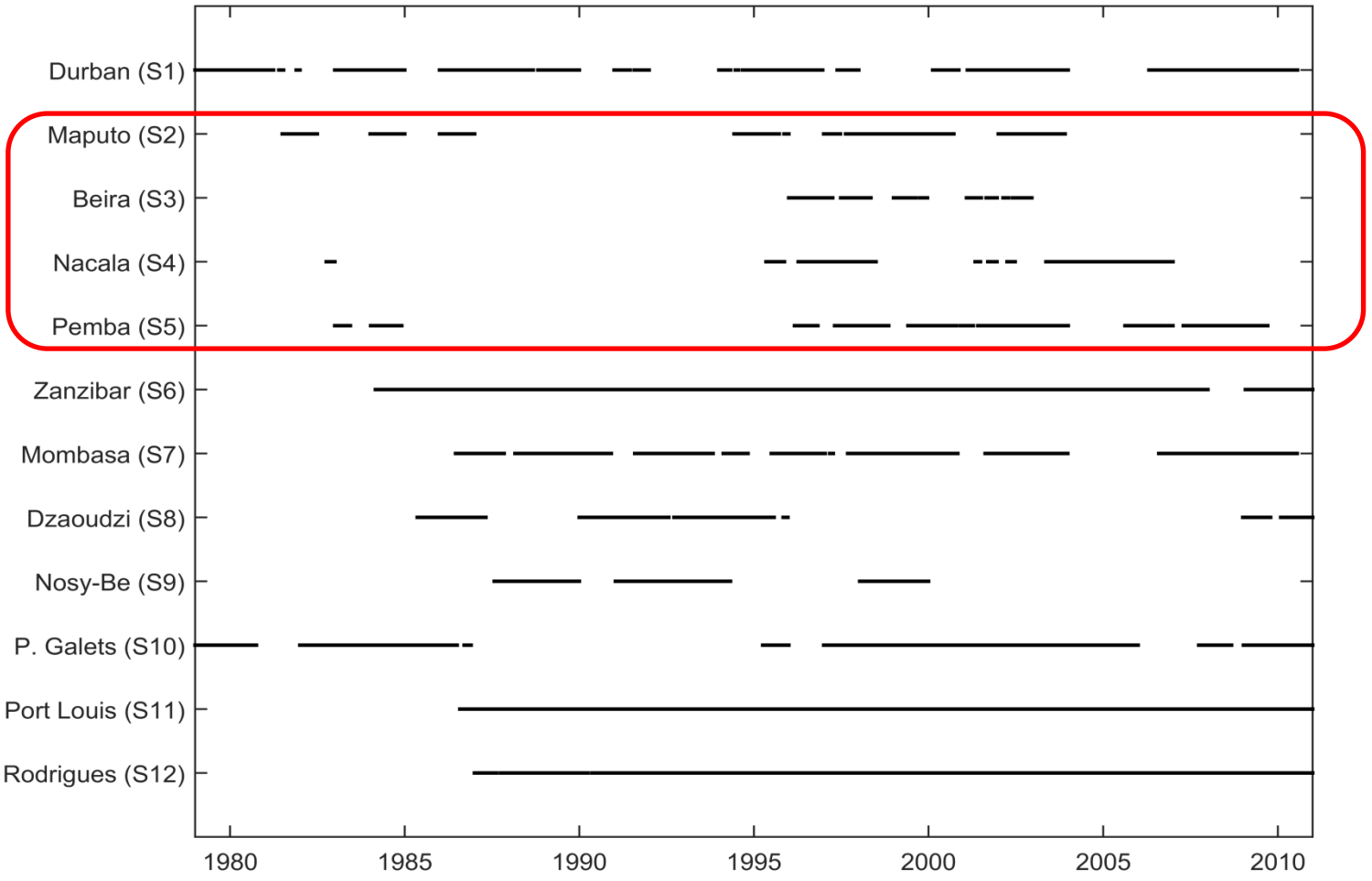
(Sete *et al.*, 2002)

Tidal ranges can reach up to 7 meters

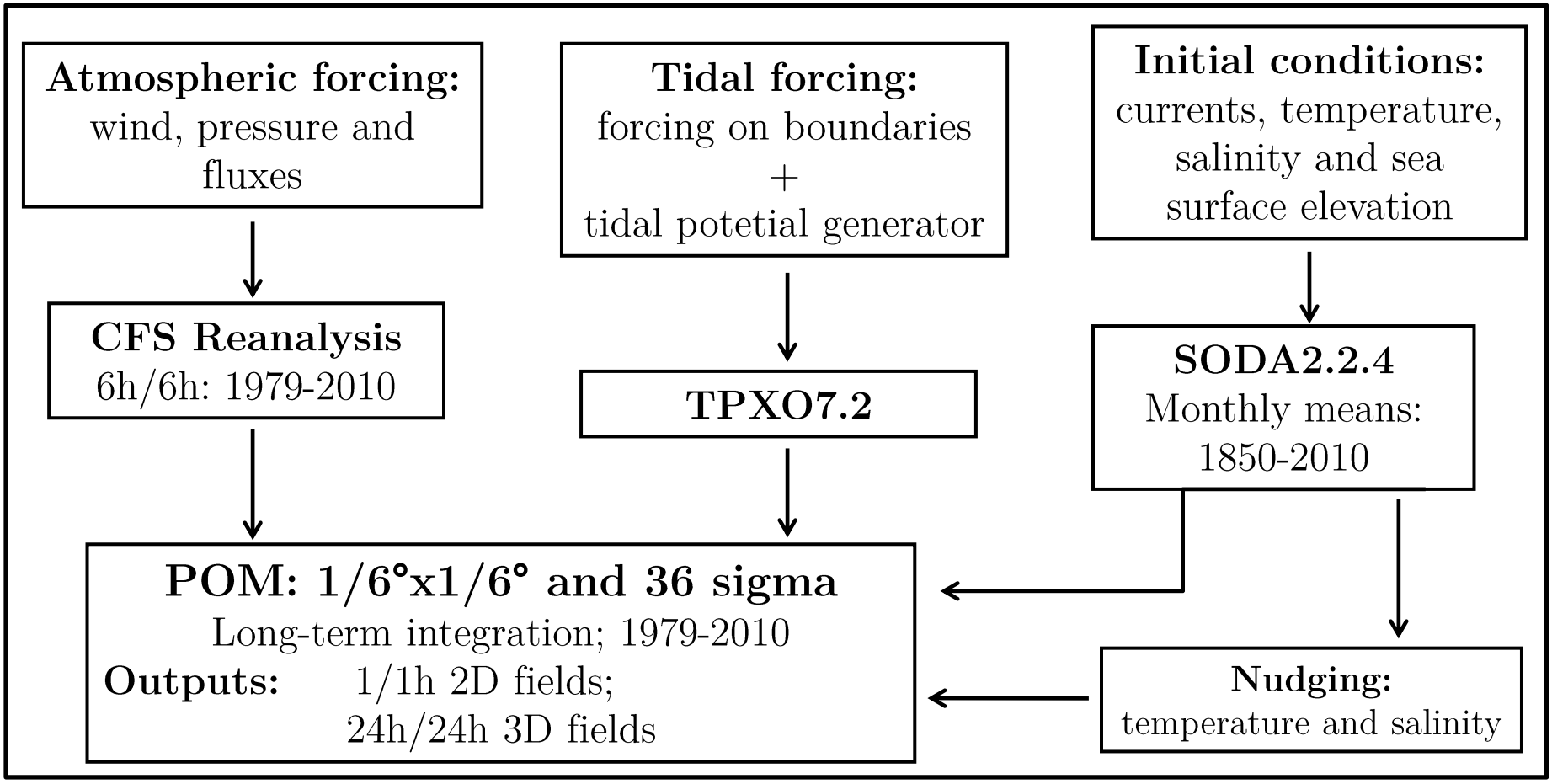


Why to model storm surges in the coast of Mozambique?

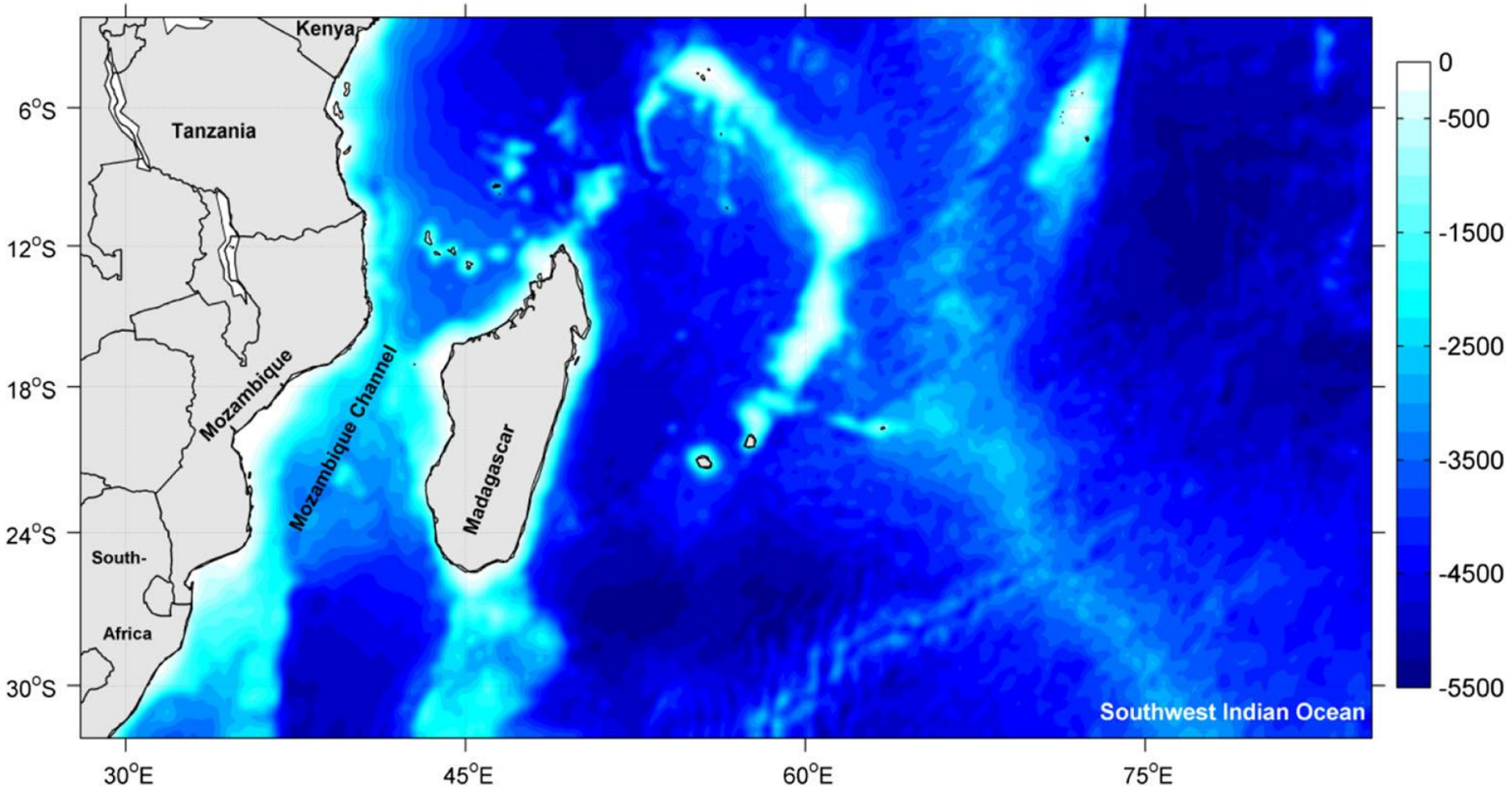
Tide gauge data availability in the Southwest Indian Ocean (SWIO)



The Princeton Ocean Model (Blumberg and Mellor, 1987) on the SouthWestern Indian Ocean



SWIO bathymetry grid (in meters)



- Large scale comparisons

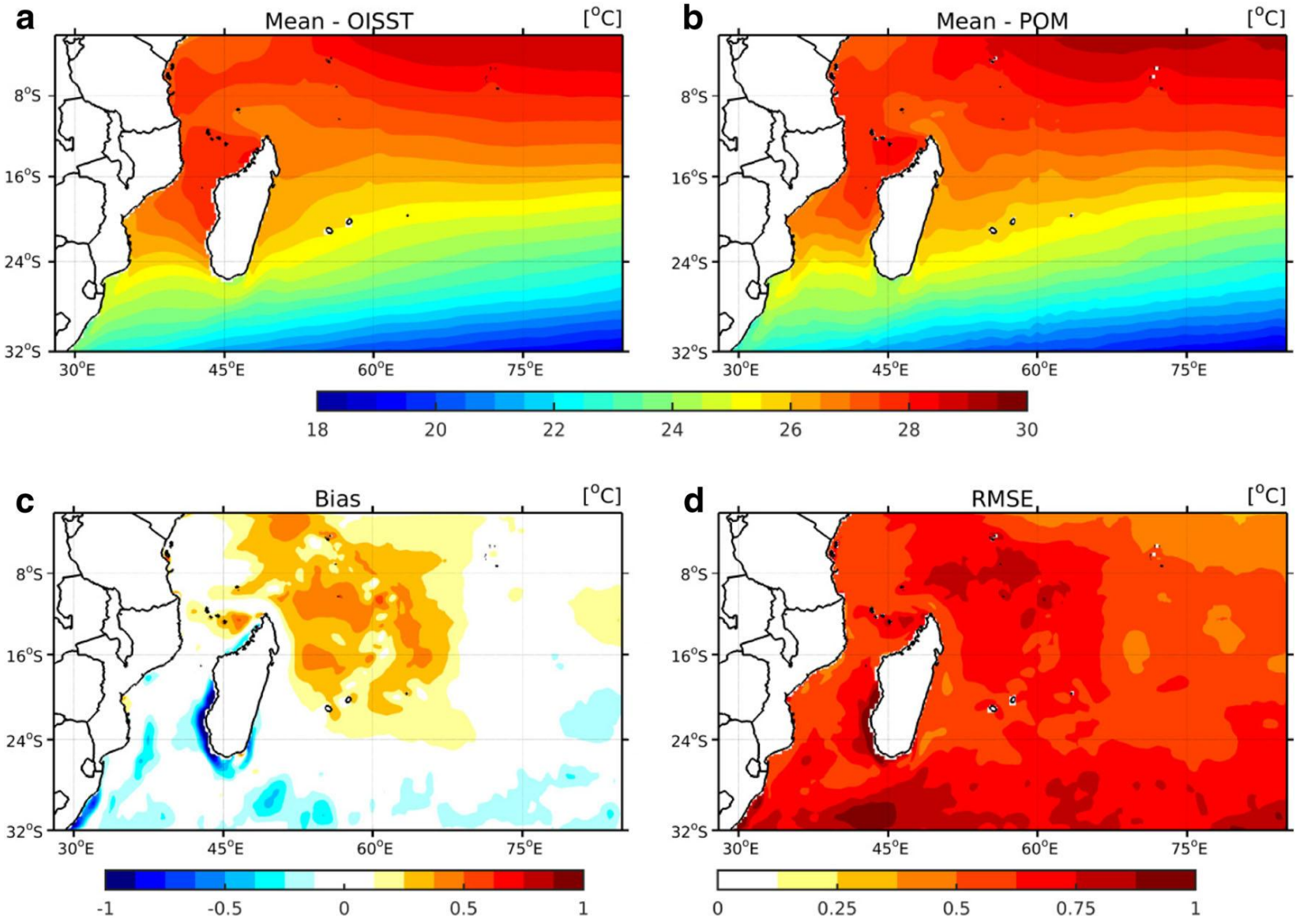
Dataset		Resolution		Reference
		Temporal	Spatial	
Sea Surface Temperature (SST)	**OISST**	Daily (1981 – Present)	0,25°x0,25° (Global)	Reynolds *et al.* (2007)
Sea Surface Height	**AVISO**	Daily (1992 – Present)	0,25°x0,25° (Global)	Ducet *et al.* (2000) Rio *et al.* (2011)
Tidal constituents	**TPXO**	---	0,25°x0,25° (Global)	Egbert *et al.* (1994)

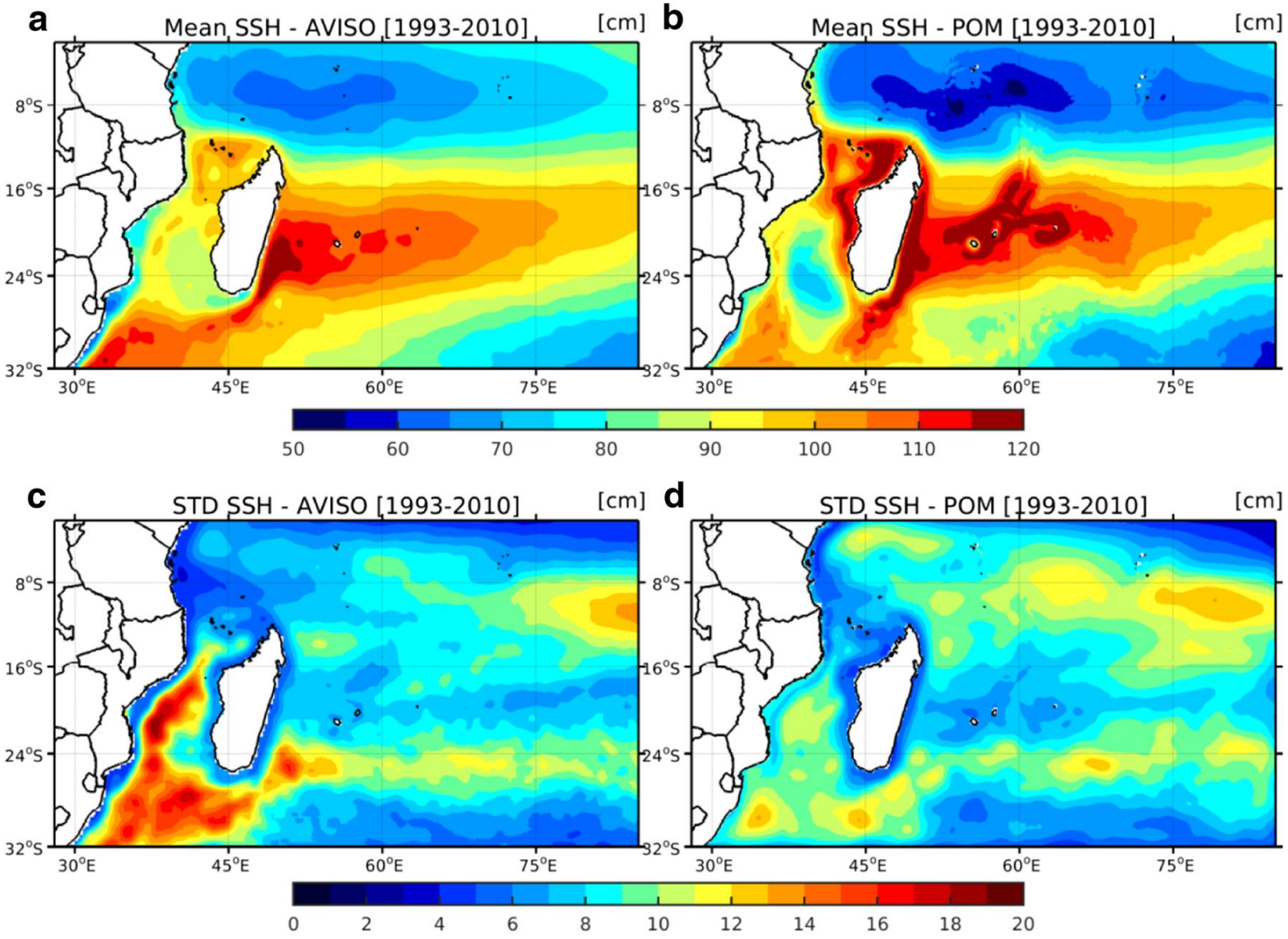
- *In-Situ* comparisons
  - **Sea level:**

    Global Sea Level Observing System (GLOSS)

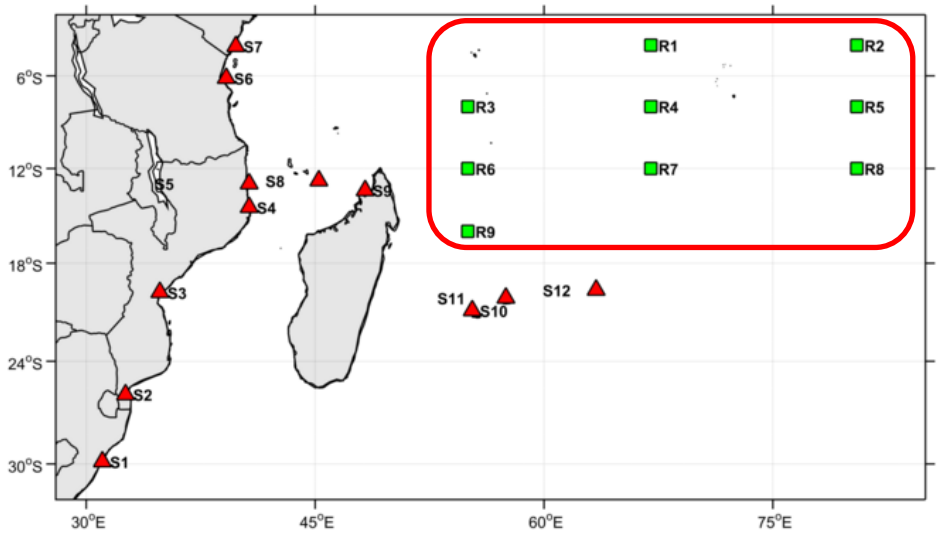
    National Institute for Hydrography and Navigation - Mozambique (INAHINA)
  - **SST and Sea Surface Salinity (SSS):**

    Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (**RAMA**; McPhaden *et al.*, 2009)

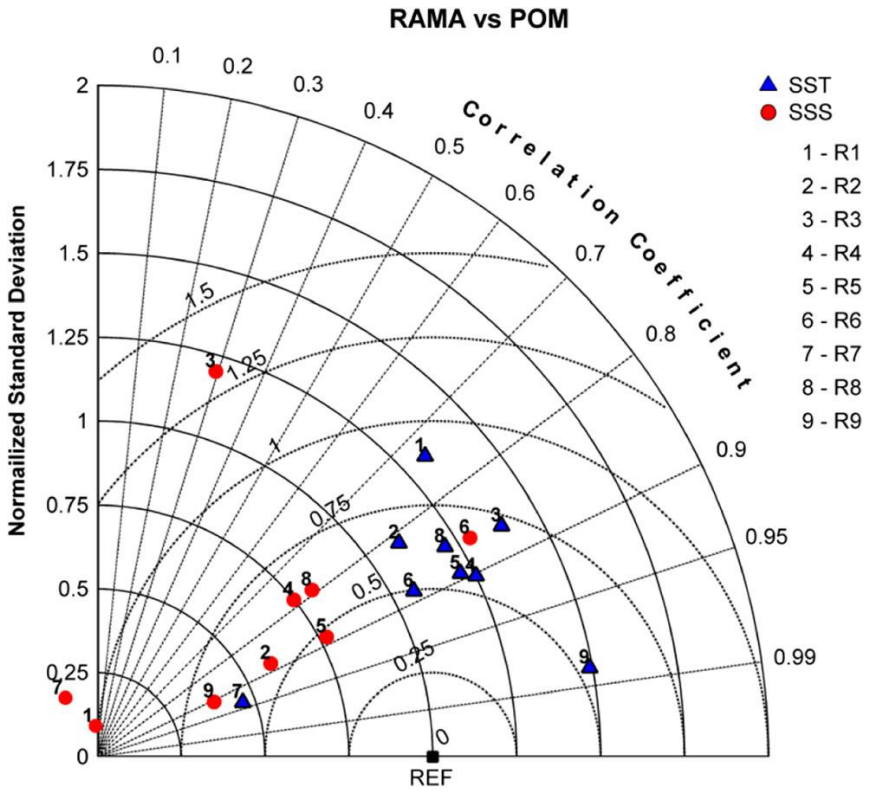

a
Mean - OISST
[°C]
b
Mean - POM
[°C]
8°S
16°S
24°S
32°S
30°E
45°E
60°E
75°E
18
20
22
24
26
28
30
c
Bias
[°C]
d
RMSE
[°C]
-1
-0.5
0
0.5
1
0
0.25
0.5
0.75
1

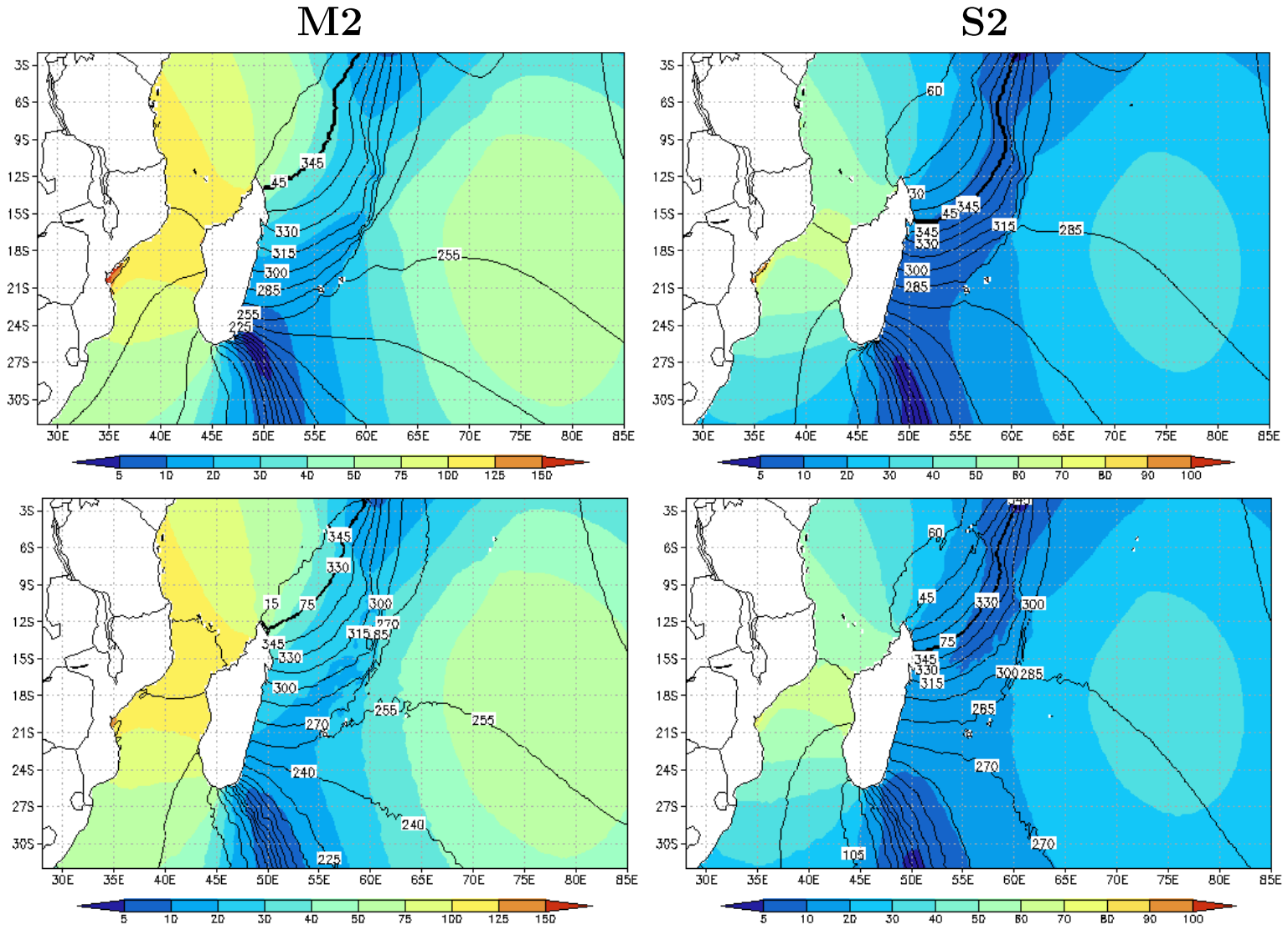

a
Mean SSH - AVISO [1993-2010]
[cm]
b
Mean SSH - POM [1993-2010]
[cm]
8°S
16°S
24°S
32°S
30°E
45°E
60°E
75°E
50
60
70
80
90
100
110
120
c
STD SSH - AVISO [1993-2010]
[cm]
d
STD SSH - POM [1993-2010]
[cm]
0
2
4
6
8
10
12
14
16
18
20

Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (**RAMA**; McPhaden *et al.*, 2009)



Tide gauge and RAMA stations locations

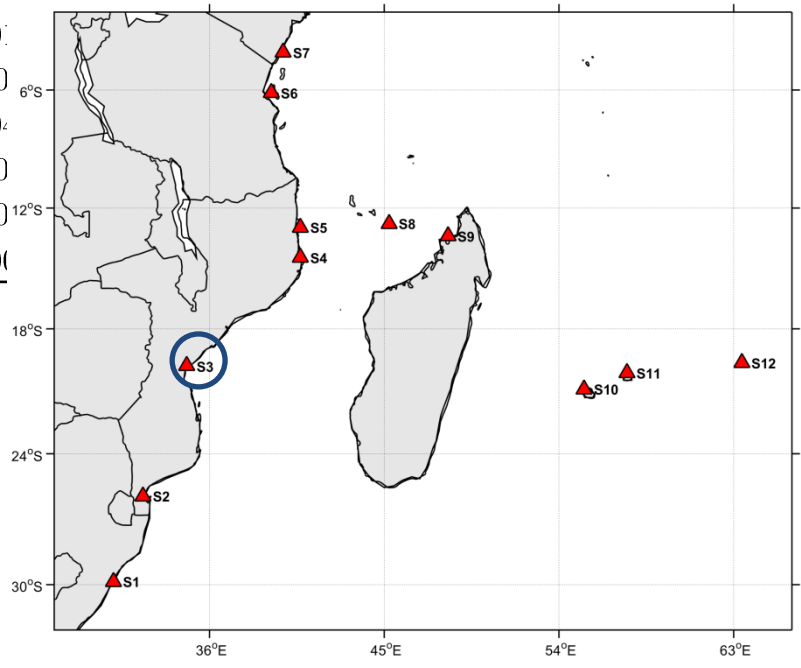




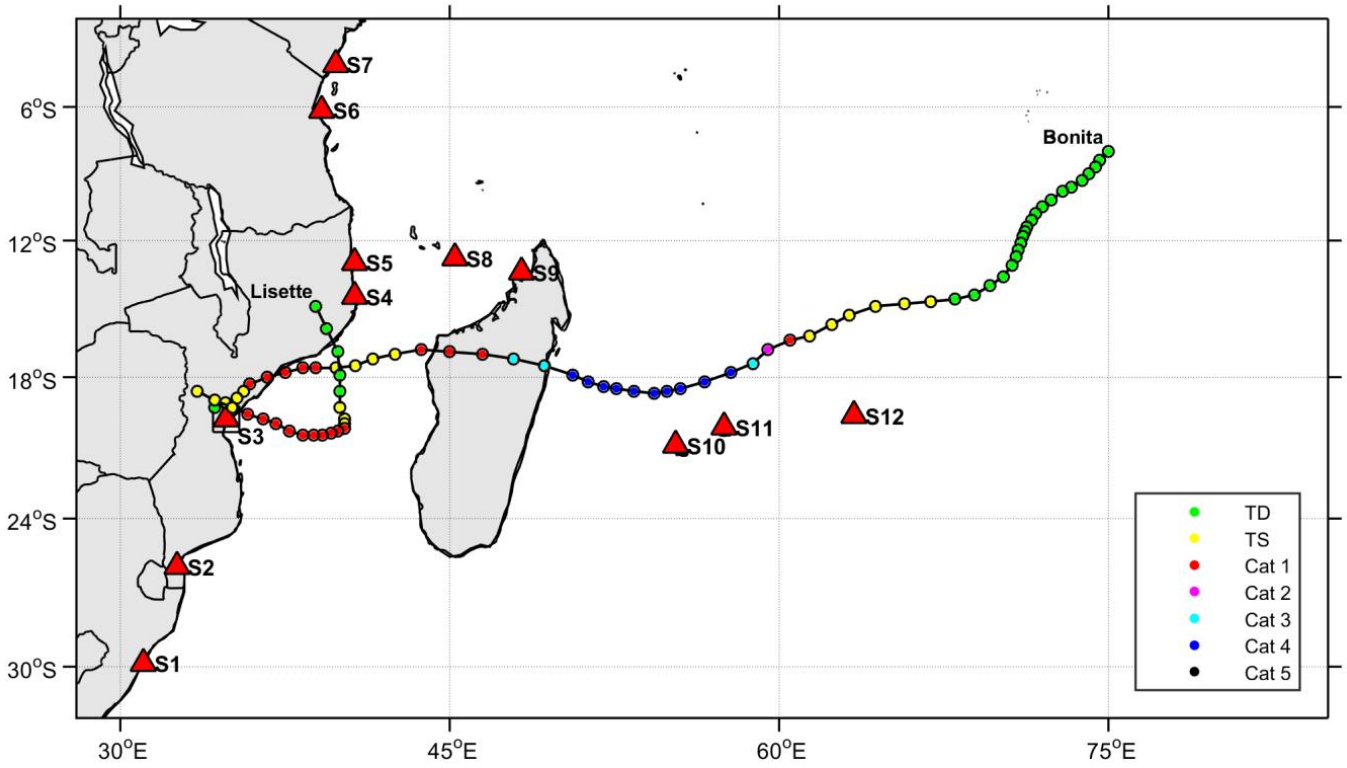
Cotidal charts of amplitude (shaded; in cm) and phases (contours; degree)

Model vs. tide guages

Station	M2			S2		
	Observed amplitude	Error		Observed amplitude	Error	
		Amplitude (m)	Phase (°)		Amplitude (m)	Phase (°)
S1 (Durban)	0,558	+0,001	+3,610	0,313	+0,009	+4,970
S2 (Maputo)	0,925	-0,180	-75,230	0,536	-0,085	-80,320
S3 (Beira)	1,706	-0,308	-67,400	0,887	-0,032	-72,20
S4 (Nacala)	1,218	-0,100	-50,130	0,577	+0,027	-52,470
S5 (Pemba)	0,944	+0,169	-50,090	0,499	+0,089	-52,620
S6 (Zanzibar)	1,198	-0,098	+4,130	0,610	-0,058	+4,820
S7 (Mombasa)	1,032	-0,015	+1,410	0,517	-0,0	
S8 (Dzaoudzi)	1,018	-0,029	-1,780	0,520	+0,0	
S9 (Nosy-Be)	1,113	-0,068	+1,100	0,563	-0,0	
S10 (Pte Galets)	0,178	-0,005	-2,950	0,094	+0,0	
S11(Port Louis)	0,143	+0,074	-16,680	0,093	+0,0	
S12(Rodrigues)	0,403	-0,023	-12,970	0,250	-0,0	

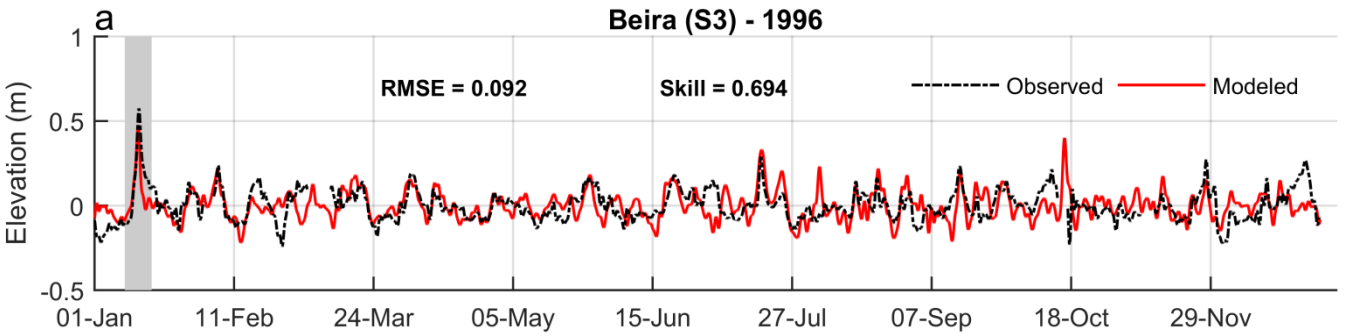


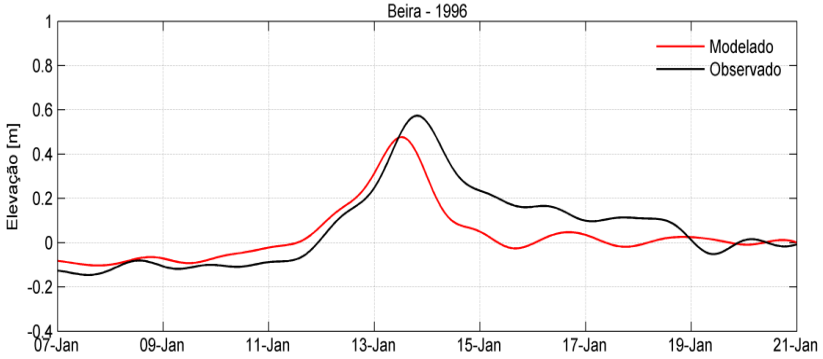
Tracks of TC Bonita (1996) and Lisette (1997)



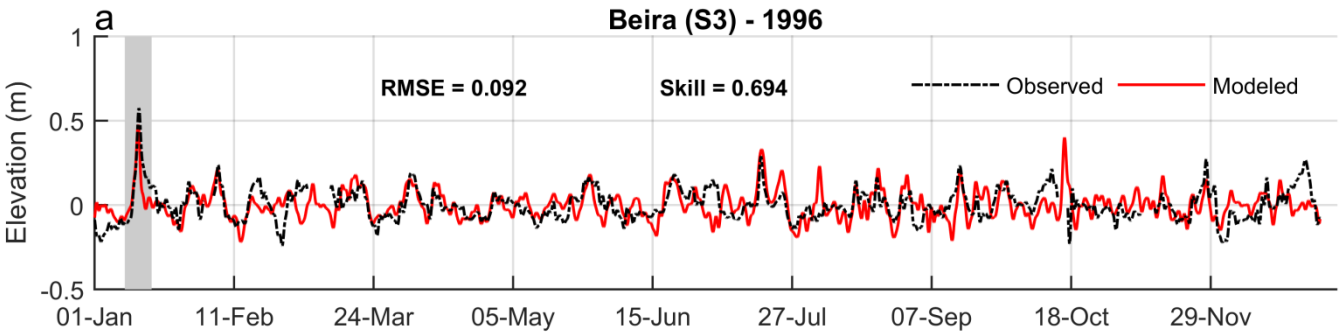
Saffir-Simpson scale
Maximum sustained wind (1-min/knot):
TD: <34;
TS: 34-63;
Cat 1: 64-83;
Cat 2: 84-95;
Cat 3: 96-113;
Cat 4: 114-135;
Cat 5: >135.

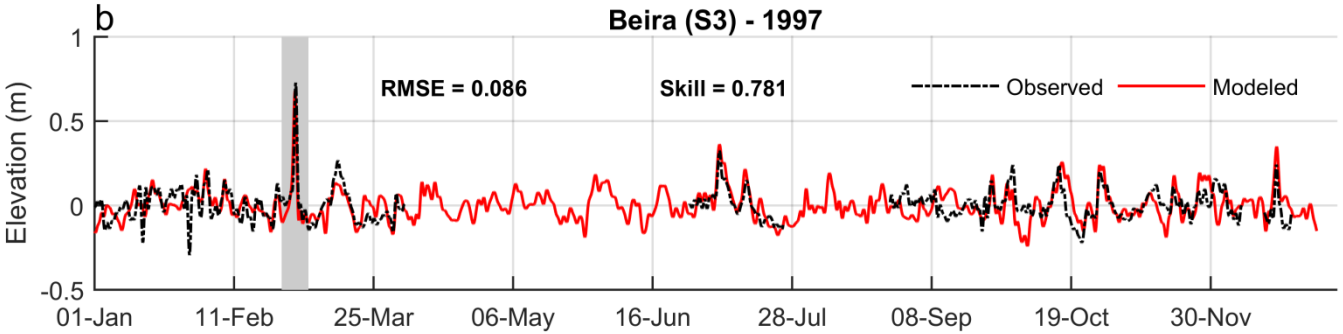
Times series of residual sea level in Beira (for 1996 and 1997)

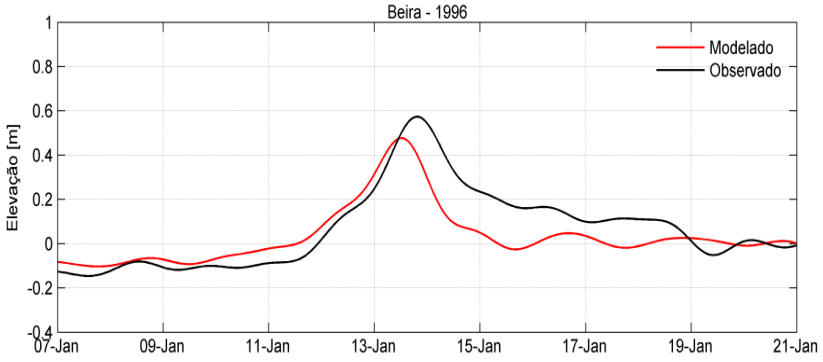


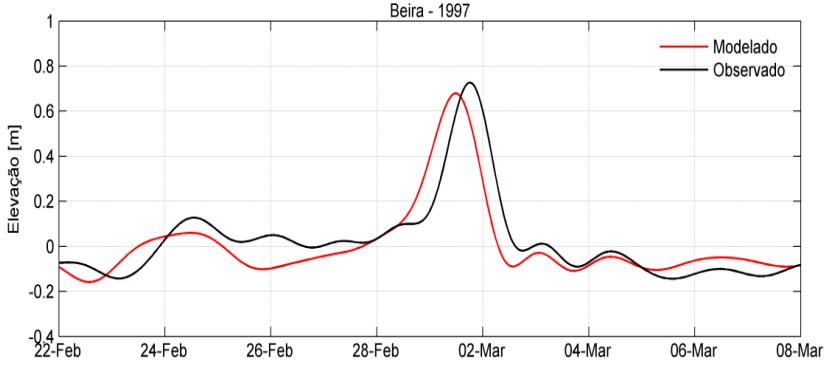


Times series of residual sea level in Beira (for 1996 and 1997)









Sensitivity experiments: TC Bonita and Lisette

- Factor separation by Stein and Alpert (1993): **2^n simulations**

  n – number of factors (tides and sea level pressure)

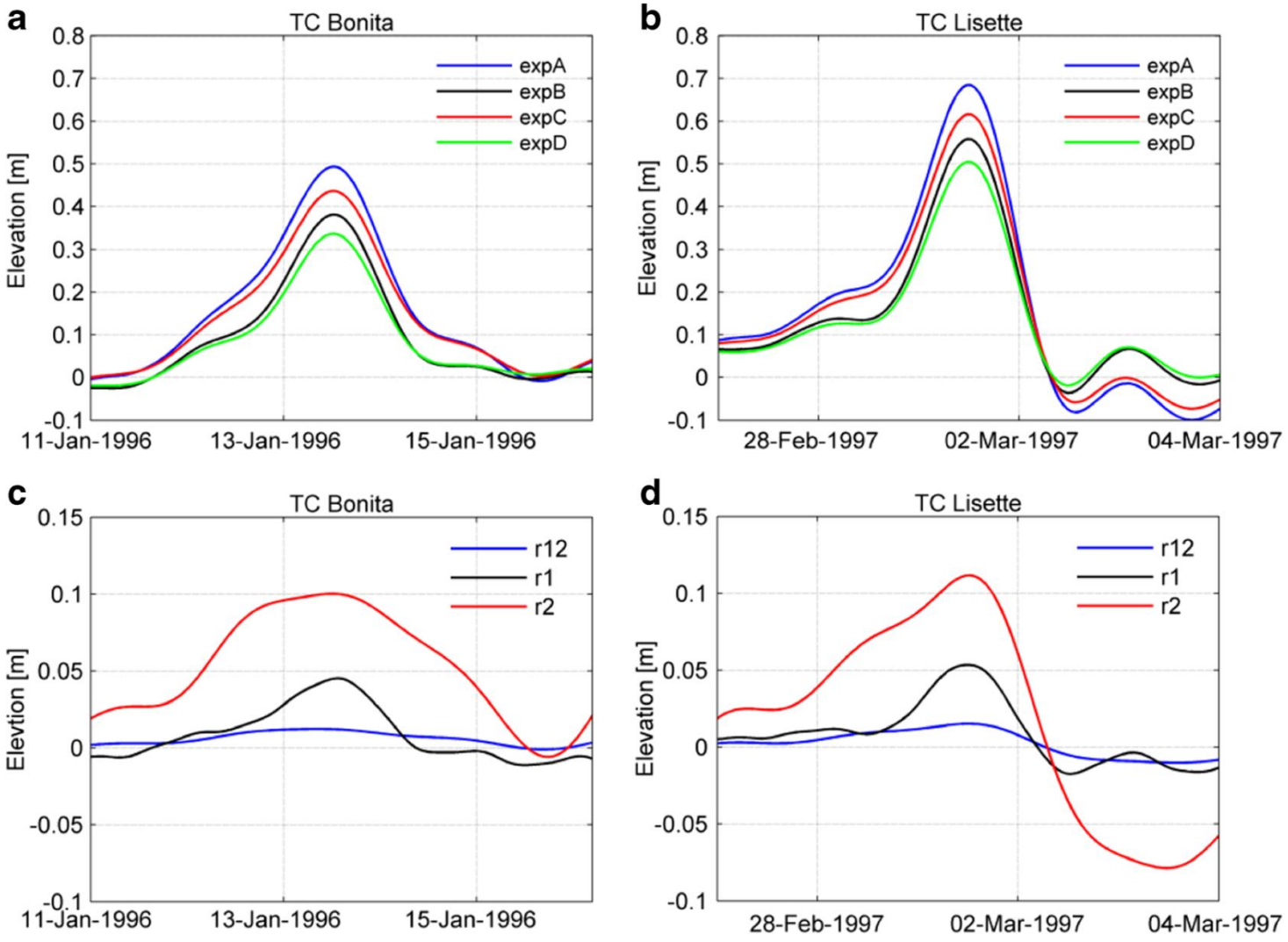
Experiment	Forcing
expA (control)	(wind+fluxes) + tides + SLP
expB (tide)	(wind+fluxes)+ tides
expC (pressure)	(wind+fluxes) + SLP
expD	(wind+fluxes)

r1 = expB - expD residual tidal due to tide-surge

r2 = expC - expD residual due to pressure

r12 = expA - (expB+expC) + expD residual due to tide-pressure

Sensitivity experiments: TC Bonita and Lisette



Concluding remarks

- The capabilities of POM in simulating the observed features on SWIO has been shown
  - The model was able to adequately reproduce the spatial pattern of SST in the study domain, although with a slight positive bias;
  - POM presented a tendency to overestimate (underestimate) the SST (SSS) variability in comparison to the RAMA project data;
  - Large-scale circulation features were in good agreement with observation but mesoscale features (mesoscale eddies) were misrepresented by the model;
  - Tides are well represented in the whole domain with few exceptions for the central region of Mozambique where the model was unable to reproduce tidal deformation on the shelf;
  - Even with a modest horizontal resolution (~17 km) POM responded well to extreme meteorological forcing imposed by TCs Bonita and Lisette;
  - Sensitivity experiments of the impact of landfalls of TCs Bonita and Lisette in Mozambique using different forcing combinations showed an improved storm surge prediction when tides and SLP are included;

Thank you!

Bié *et al.* (2017), *Ocean Dynamics*, 67(11)