Multiple linear regression of sea level in the southwest Pacific as a first step towards local sea level projections

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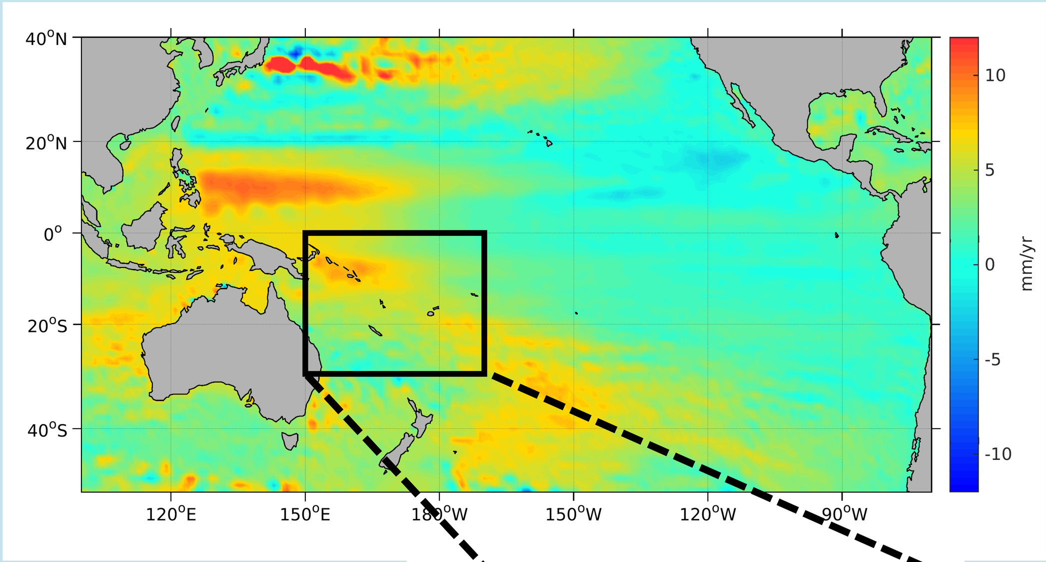
Motivation

Sea level rise ? → **Adaptation in the Pacific islands**

- Rising global mean sea levels as a result of ocean warming and melt of glaciers and ice caps amounts to 3.3 ± 0.5 mm/yr over the altimetry period (1993-2016)
- Sea level rise is not uniform, and regional variations (essentially due to ocean thermal expansion) superimpose on the global mean
- In the western Pacific region, sea levels over the altimetry period were 3-4 times higher than the global mean, reaching up to 10-12 mm/yr (*Figure 1*)
- Saltwater intrusion, flash flooding, perigean spring tide events are forcing relocation in the present-day, and atoll nations facing threats of complete inundation towards the end of the century.
- Sea level projections on the local scale are needed to develop efficient adaptation planning and risk minimization measures



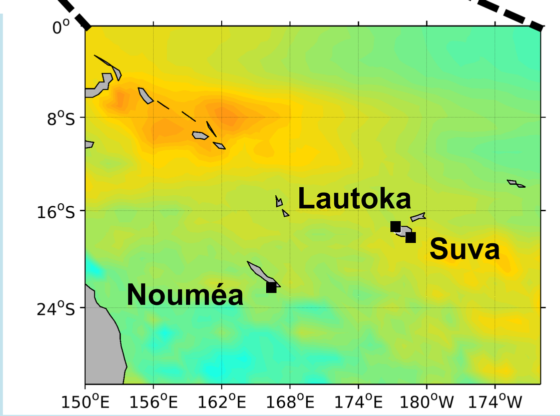


Figure 1: Sea level trends in the Pacific region over the 1993-2014 period (GMSL trend included). Inset shows the study sites – Suva, Lautoka (Fiji), Nouméa (New Caledonia)

Aim

To develop a statistical model for local sea level variability in the south western Pacific islands on interannual-to-decadal timescales, and for long-term trends

Datasets, Methodology

- Sea level observations:
  - Tide gauge records (PSMSL), ORAS4 reanalysis
- Regressor variables:
  - Thermosteric, halosteric components (≤ 700 m) (ORAS4)
  - Mass change (GRACE)
  - $\mathrm{curl}_z\,\tau$, τ_x, τ_y, SST (ERA-Interim)

$$sla\,(site,t) = \sum_i \alpha_i\, P_i\,(x_i\, y_i,\, t - t_i) + \varepsilon(site,t) \qquad (1)$$

where:

- *site* is the geographical site studied (Suva, Lautoka or Nouméa)
- α_i are the site-specific regression coefficients
- P_i are the potential predictors (representing sea level drivers) averaged over a spatial area (x_i,y_i)
- t_i is a temporal lag
- ε is a site-specific residual

SSH = thermosteric sea level + halosteric sea level + mass

Rossby wave propagation ← $\mathrm{Curl}_z\,\tau$

- Study period – **1979-2014**
- Interannual-to-decadal variability, and trend
- Analysis is primarily based on correlation between local sea level and predictor variables, with representative proxy boxes for each variable selected based on areas having highest correlation
- Multi-linear regression (MLR) of statistically significant variables

R^2	% variance exp.	Trends (mm/yr) ORAS4	Trends (mm/yr) Model
Steric + mass MLR (2003-2014)			
0.95	0.91	6.7	6.3
$\mathrm{Curl}_z\,\tau$ dominated MLR (1979-2014)			
0.84	0.71	3.1	1.9 !
GMSL adjusted MLR (1979-2014)			
0.82	0.69	1.2	1.1 ✓

Table 1: Comparison metrics between ORAS4 and MLR modeled sea levels for the **Suva site** (correlation coefficient, % variance explained, trends)

* ***Results shown only for ORAS4 – Suva site***

Results

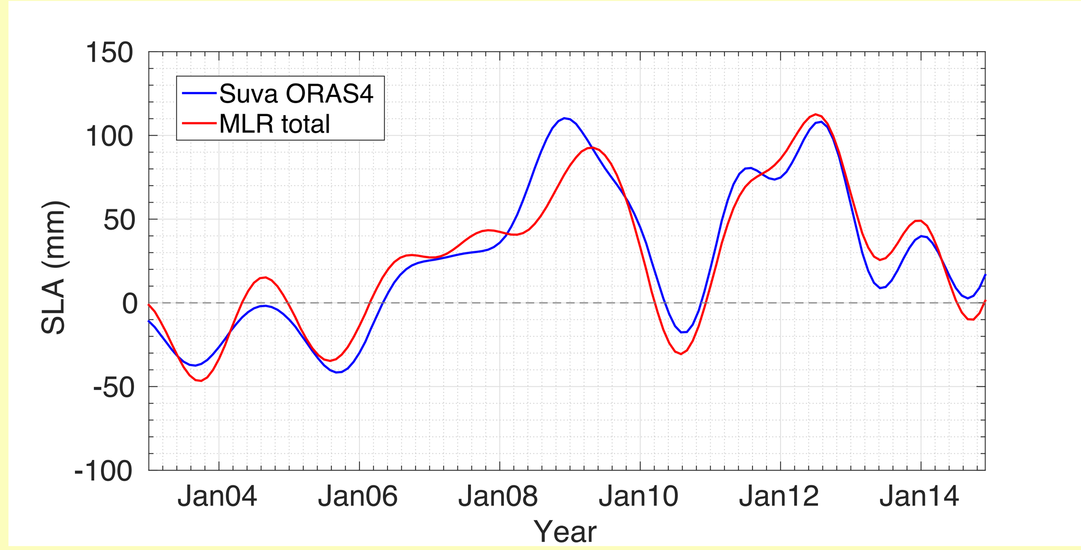


Figure 2: ORAS4 and MLR modeled sea levels based on steric and mass predictors over the 2003-2014 period for the Suva site

- Figure 2 shows that the local sea level can almost be perfectly modeled using thermosteric, halosteric, mass changes
- i.e. local sea level change is a sum of density and volume changes
- Although mass changes is selected as a significant predictor, it represents a very small proportion of local sea level variance (< 5%)

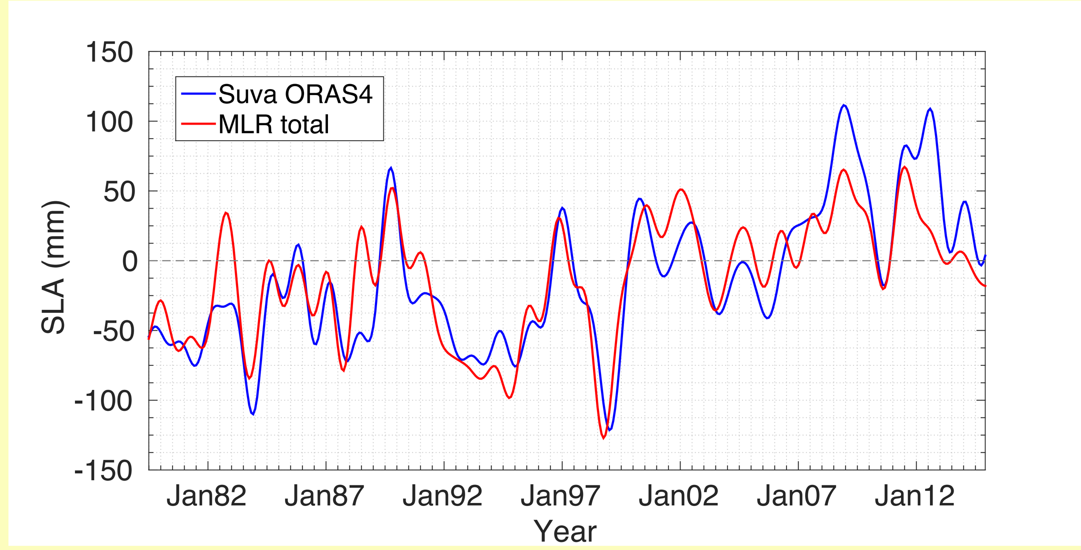


Figure 3: ORAS4 and $\mathrm{curl}_z\,\tau$ dominated MLR modeled sea levels over the 1979-2014 period for the Suva site

- The $\mathrm{curl}_z\,\tau$ dominated MLR model shows skill, although loss in efficiency is apparent compared to the steric and mass-based MLR model
- Limitations such as using only a single lag (6-month), and one proxy box to represent $\mathrm{curl}_z\,\tau$
- Although the model shows skill in terms of correlation coefficient with the ORAS4 sea level, and % variance explained, it is unable to capture the trend in sea level (*Table 1*)
- $\mathrm{curl}_z\,\tau$ represents regional variability; the halosteric component, τ_x, τ_y and SST represent local drivers, but the global signal is not accounted for by this set of predictors

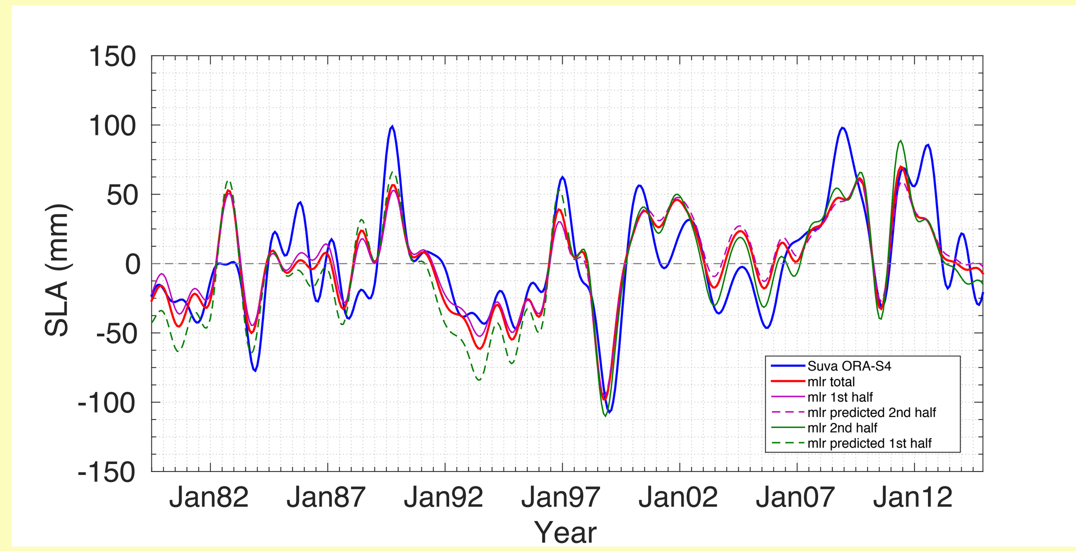


Figure 4 :ORAS4 and **GMSL-timeseries-adjusted** MLR modeled sea levels over the 1979-2014 period for the Suva site, combining a stationarity test for the Suva site

- The MLR model is now able to capture the sea level trend
- The global signal is indeed an important constituent of local sea level trends

Stationarity test

- Can we apply an MLR model calibrated over one period to another? (application to future projections of sea level)
- Model performance is reduced when applied to periods other than which it was calibrated over, however the modeled sea levels still show skill – the amplitude and phasing of local sea level variability are still captured to a certain degree

Conclusion and Perspectives

- Climate models typically have resolutions too coarse (~100 km) to provide information on the local scale for small islands
- Our results have shown that global sea level and large scale regional drivers (in this case represented by $\mathrm{curl}_z\,\tau$) still account for the larger part of variance in local sea level variability at the islands, and that local effects related to coastal dynamics are relatively small
- This large-scale regional variability can be simulated in climate models, serving as a link between local scale information and low resolution model simulations.
- Combined with adjustments for known biases in climate models in the tropical Pacific, such as the double ITCZ/zonal SPCZ, and the westward extension of the equatorial cold tongue, the MLR model has potential for downscaling studies at islands.

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