Anthropogenic forcing fingerprint on the tropical Pacific sea level trend pattern from the CMIP5 simulations of the XXIst century

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CLIVAR WGOMD - SOP Workshop on Sea Level Rise, Ocean/Ice Shelf Interactions and Ice Sheets
Observed Sea Level Trend Patterns from Jan. 1993 to Dec. 2010 (global trend removed)

Are the observed trend patterns stationnary?
Are they linked to internal variability only?
Is there some imprint of external forcings (anthropogenic, solar, volcanic)?
Observed Sea Level Trend Patterns from Jan. 1993 to Dec. 2010 *(global trend removed)*

![Satellite Altimetry measurement](image1)

Observed Thermal Expansion Trend Patterns from Jan. 1993 to Dec. 2010 *(global trend removed)*

![In situ hydrographic measurement](image2)

*Cazenave & Llovel, 2010
Lombard et al. 2009
Kohl & Stammer 2008
Wunsch et al. 2007*

*(Levitus et al., 2012)*
• **Observed sea level grids**
  - satellite altimetry (since 1993)
  - sea level reconstruction (since 1950)

• 8 coupled climate models (CMIP5):
  - CNRM-cm5, GFDL ESM2G, NCAR CCSM4, HadGEM2 ES,
  - IPSL-cm5, MIROC 5, BCC CSM1 1, ACCESS1 0
  - 500 year long control runs (constant external forcing)
  - 20th century runs (solar+volcanic+anthropogenic var)
  - run rcp 8.5
  - run rcp 2.6
Reconstructed sea level trend patterns (1950-2009) from reduced optimal interpolation (Kaplan et al 2000)

- 99 long tide gauges records + spatial EOFs from 47-years of the DRAKKAR/NEMO ocean model SSH,
- 47 years of SODA reanalysis and 17 years of satellite Altimetry

1950-2009 spatial patterns (global trend removed)
Spatial trend patterns of the sea level reconstruction computed over successive 17-year windows

Altimetry spatial trend patterns (1993-2010)

Reconstructed spatial trend patterns (1950-2009)

Reconstructed trends in successive 17-year windows

1992-2009

1972-1989

1958-1975
Spatial trend patterns of the sea level reconstruction computed over successive 17-year windows

Altimetry spatial trend patterns (1993-2010)

Reconstructed spatial trend patterns (1950-2009)

EOF1 of Reconstructed trends in successive 17-year windows
36.6% of the total variance

Normalised amplitude

Altimetry era

1965 2010

EOF1 of the 17-year trend
Nino3 index (8-yr smoothing)
• Observed sea level grids
  - satellite altimetry (since 1993)
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• 8 coupled climate models (CMIP5):
  CNRM-cm5, GFDL ESM2G, NCAR CCSM4, HadGEM2 ES,
  IPSL-cm5, MIROC 5, BCC CSM1 1, ACCESS1 0
  - 500 year long control runs (constant external forcing)
  - 20th century runs (solar+volcanic+anthropogenic var)
  - run rcp 8.5
  - run rcp 2.6
Spatial trend patterns of the CNRM control run computed over successive 17-year windows

CNRM CM5 control run

EOF1 of trends in successive 17-year windows
20% of the total variance

Similar patterns in observations (reconstruction) and CNRM control run, which fluctuate with periods (20-30 years) of sea level acceleration/deceleration

~20-30 yr\(^{-1}\)

2-D reconstruction
EOF1 of trends in successive 17-year windows. 36.6% of the total variance

- EOF1 of 17-year trend
- Nino3 index (8-yr smoothing)
Spatial trend patterns of the CNRM control run computed over successive 17-year windows

EOF1 of 17-yr windows trends from GFDL control run and Fourier analysis

Power spectra of 17-year trends in box b (red) and of 17-year trend of best fit AR2 process with 95% confidence interval

~18-22 yr\(^{-1}\)
~28-30 yr\(^{-1}\)

Periods of increased/decreased intensity of the trend patterns (sea level acceleration/deceleration) linked to internal low-frequency variability of ENSO
Spatial trend patterns of the AOCGCM control run for 8 CMIP5 models

Periods of increased/decreased intensity of the trend patterns (sea level acceleration/deceleration) linked to internal low-frequency variability of ENSO
Confirm results obtained with 8 CMIP3 models: Meyssignac et al. 2012b (clim. of the past)

Periods of increased/decreased intensity of the trend patterns (sea level acceleration/deceleration) linked to internal low-frequency variability of ENSO
• **Observed sea level grids**
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• **8 coupled climate models (CMIP5):**
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  - 500 year long control runs (constant external forcing)
  - 20th century runs (solar+volcanic+anthropogenic var)
  - run rcp 8.5
  - run rcp 2.6
CMIP5 XXth century runs extended over the XXIst century with the rcp 8.5 scenario runs (it includes Volcanic+Sun variability and GHG+ Aerosols emissions)

CNRM CM5
control run
EOF1 of trends in successive 17-year windows

Amplitude

period

0  50  30  20  10  8  6  4  2

Amplitude

-12  mm/yr  12
The fluctuations of the trend patterns in XXth century runs extended with the rcp 8.5 scenario have significantly (SL> 95%) higher amplitudes and lower frequencies than fluctuations of the trend patterns in the control runs.
• Observed sea level grids
  - satellite altimetry (since 1993)
  - sea level reconstruction (since 1950)

• 8 coupled climate models (CMIP5):
  CNRM-cm5, GFDL ESM2G, NCAR CCSM4, HadGEM2 ES,
  IPSL-cm5, MIROC 5, BCC CSM1 1, ACCESS1 0
  - 500 year long control runs (constant external forcing)
  - 20th century runs (solar+volcanic+anthropogenic var)
  - run rcp 8.5
  - run rcp 2.6
CMIP5 XXth century runs extended over the XXIst century with the rcp 2.6 scenario runs (it includes Volcanic+Sun variability and GHG+ Aerosols emissions)

The fluctuations of the trend patterns in 20c3m runs extended with rcp 2.6 scenario are for most of them undistinguishable from fluctuations of the trend patterns in the control runs.
Conclusions

- The past sea level reconstruction suggests that the observed spatial trend patterns over the altimetry era (~17 years) in the tropical Pacific have oscillated in the past following a low frequency ENSO modulation.

- AOGCM runs with constant, preindustrial external forcing show similar low-frequency modulation, during which sea level accelerates/decelerates (or equivalently trend patterns of increasing/decreasing intensity) (but with different characteristic periods: 18-20yr, 26-30yr or 38-44yr).

- 20th Century AOGCM runs extended with rcp8.5 scenarios show spatial trend patterns in sea level similar to those observed in control runs and observations. Their temporal variability show significantly higher amplitudes and lower frequencies. (this is not the case for the rcp2.6 scenarios)

- CMIP5 simulations suggests that high level anthropogenic emissions (rcp8.5) may increase the amplitude of the regional variability in tropical Pacific sea level and lower the frequencies of its temporal fluctuations.

- In contrast, in low level anthropogenic emissions scenarios (rcp2.6), the amplitude of the internal variability of the climate system in the tropics seem to hide most of the changes.