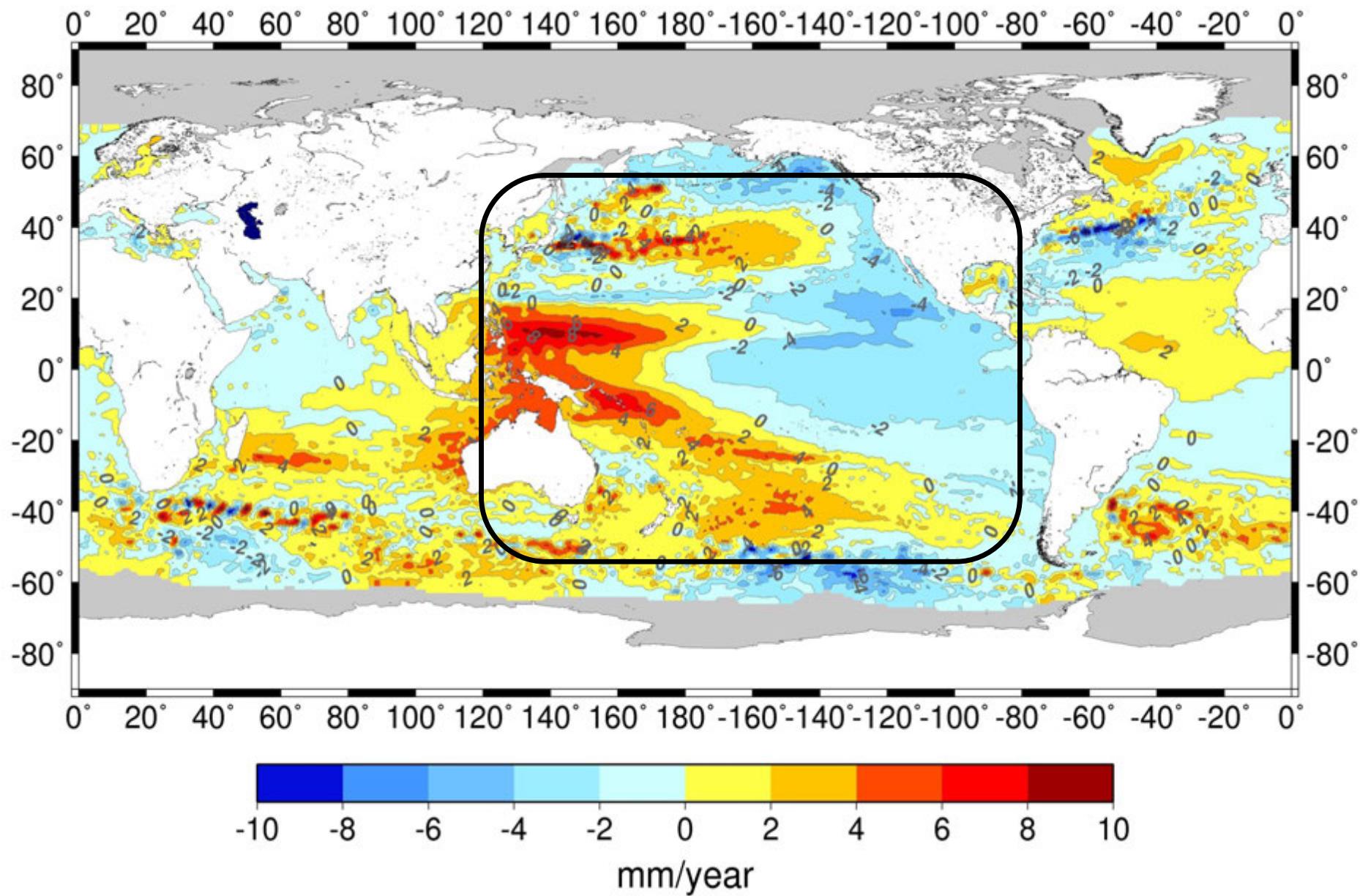
A photograph of a sunset over a coastal landscape. The sun is low on the horizon, casting a bright orange glow across the sky and reflecting off the water. In the foreground, dark silhouettes of hills and trees are visible against the bright light. The ocean waves are visible in the lower left, and the overall scene is peaceful and scenic.

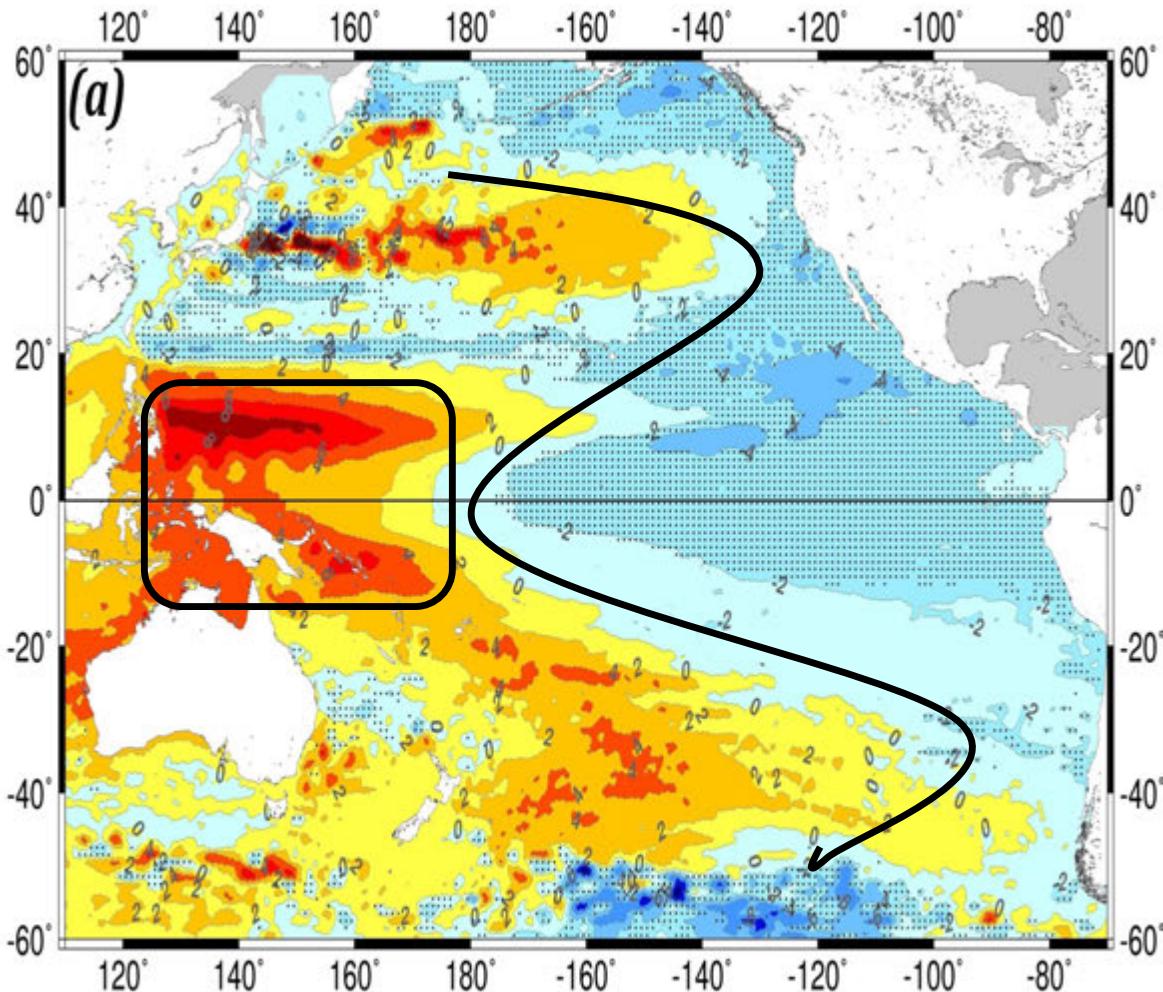
Is anthropogenic sea level fingerprint already detectable in the Pacific Ocean over the altimetry era?

H. PALANISAMY, B. MEYSSIGNAC, A. CAZENAVE
T. DELCROIX
LEGOS, Toulouse, France

Altimetry based sea level trend pattern (global mean removed) 1993-2013



Pacific Ocean sea level trend 1993-2013 (global mean removed)



Two main natural climate modes:

→ **Pacific Decadal Oscillation (PDO) / Interdecadal Pacific Oscillation (IPO)**

- *Zhang and Church, 2012*
- *Han et al., 2013,*
- *Hamlington et al., 2013,2014*
- *England et al., 2014*

→ **El Niño Southern Oscillation (ENSO)**

- *Stammer et al., 2013*
- *Timmermann et al., 2010*
- *Merrifield , 2011,2012*
- *McGregor et al., 2012*
- *Nidheesh et al., 2013*

Detection and attribution @ regional scale

Difficulties

- Unforced internal climate variability introduces strong changes in regional sea level on time scales varying from years to decades..
 - example: periodicity of unforced climate modes :
 - ENSO 3-8 years
 - IPO 20-30 years
- Unfavorable signal to noise ratio to detect the forced response..

Method

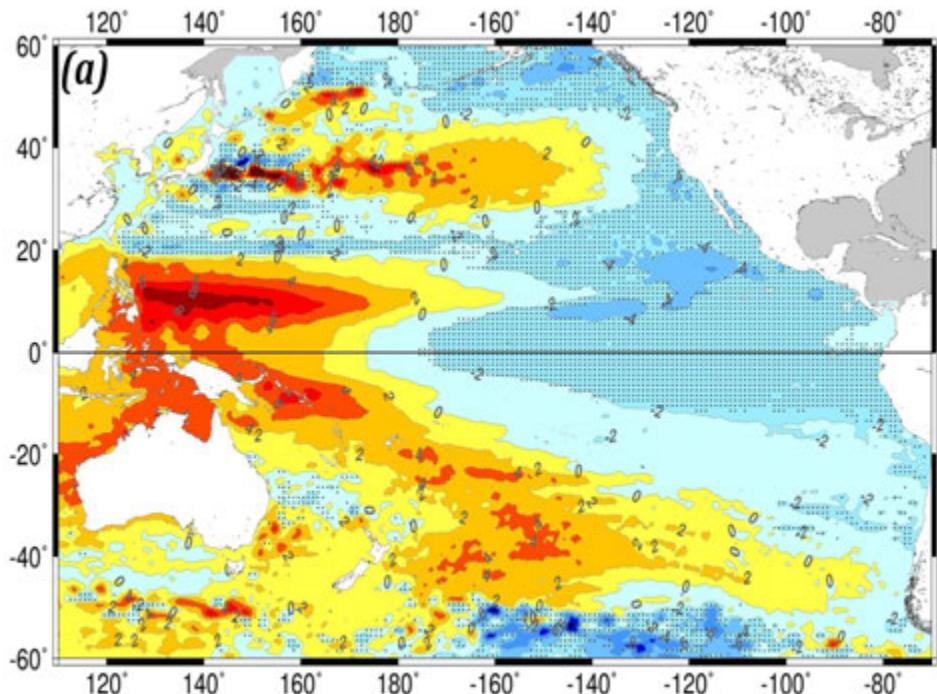
- Extract and remove the unforced internal climate mode from observed sea level signal.
- CAN WE SUCCESSFULLY ATTRIBUTE THE RESIDUAL SIGNAL TO EXTERNAL FORCING ?**
- Relate the residual sea level signal to externally forced signal..
 - Subject of two recent studies in the Pacific Ocean
 - Hamlington et al., 2014
 - Palanisamy et al., 2015

Pacific Ocean and Interdecadal Pacific Oscillation

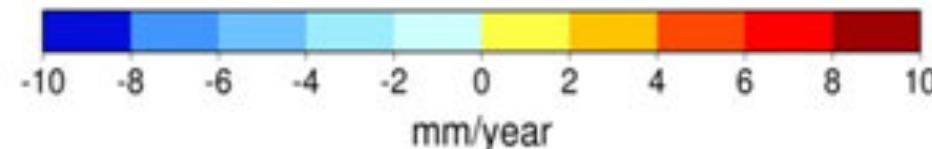
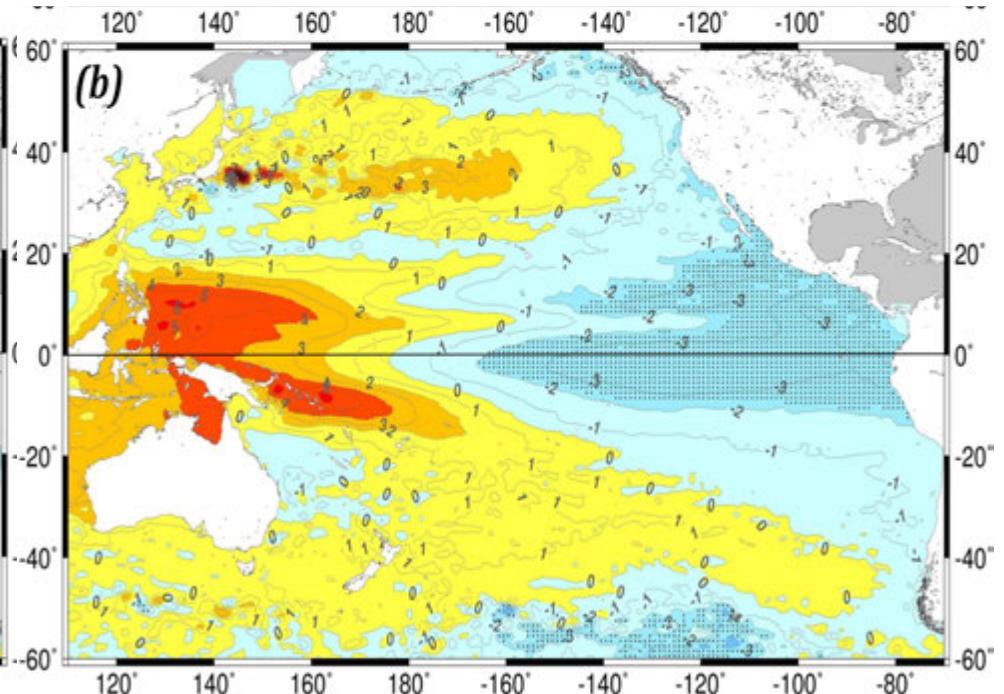
Linear regression of IPO on altimetry sea level over 1993-2013

$$\text{ALTI}(x,y,t) = \alpha \text{ IPO}(x,y,t) + \beta$$

Altimetry-based sea level trend

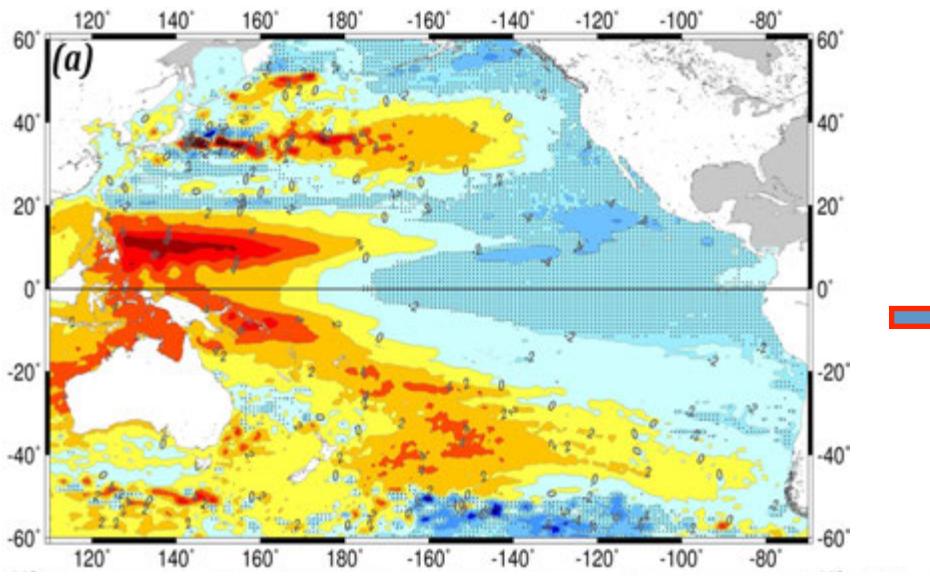


IPO contribution to Pacific Ocean sea level change over 2 recent decades

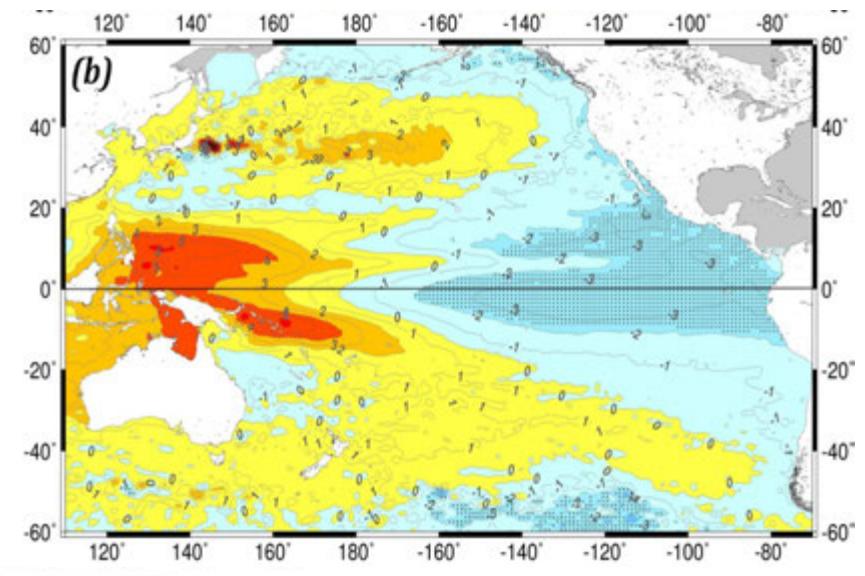


Pacific Ocean and Interdecadal Pacific Oscillation

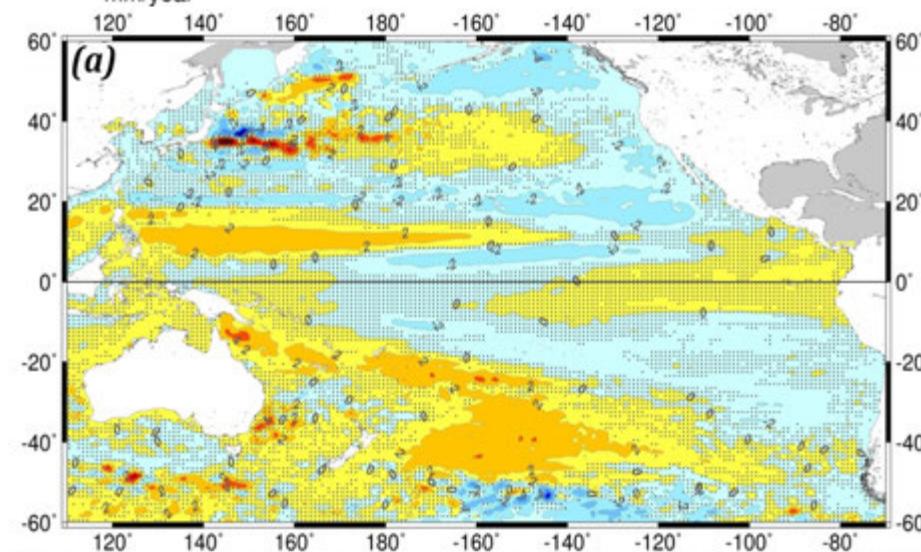
Altimetry-based sea level trend



IPO contribution to Pacific Ocean sea level change over 2 recent decades

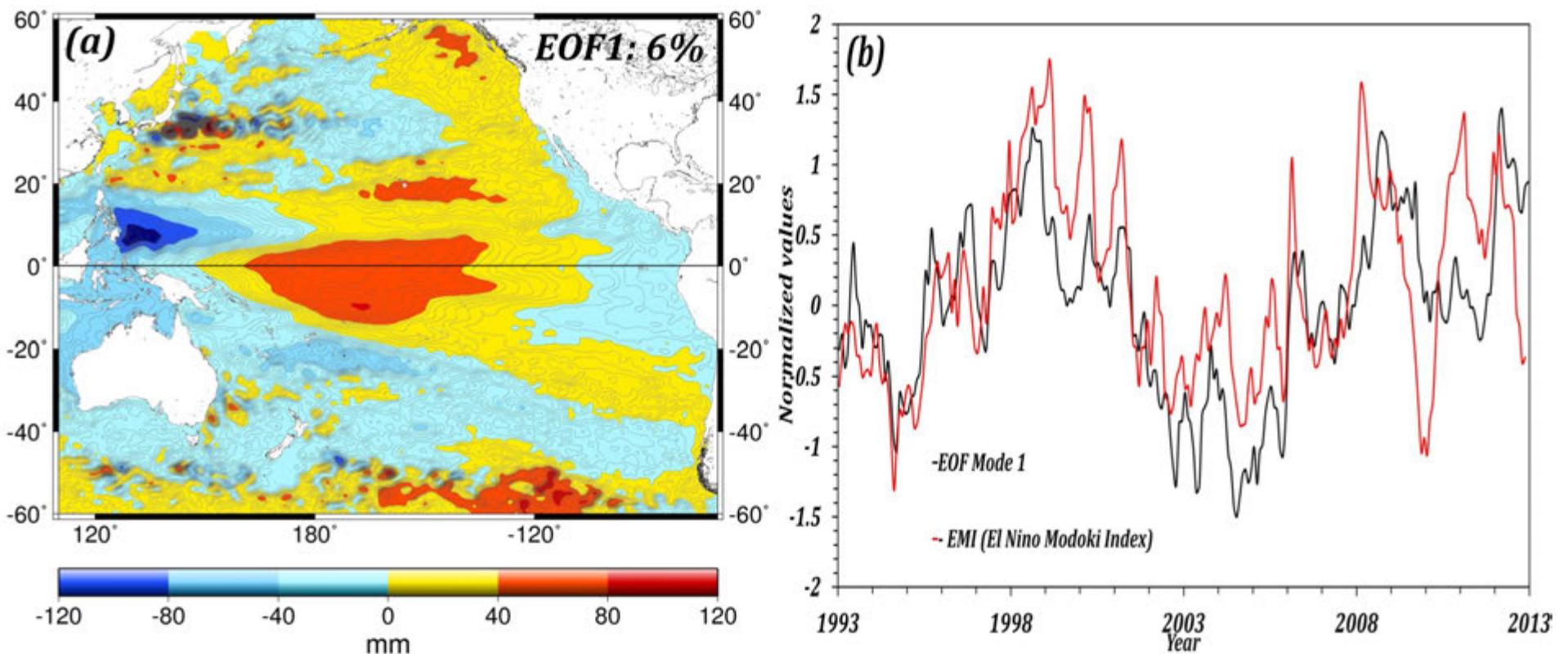


Altimetry-based sea level trend without IPO



Analysis of the residual (Altimetry-IPO) signal

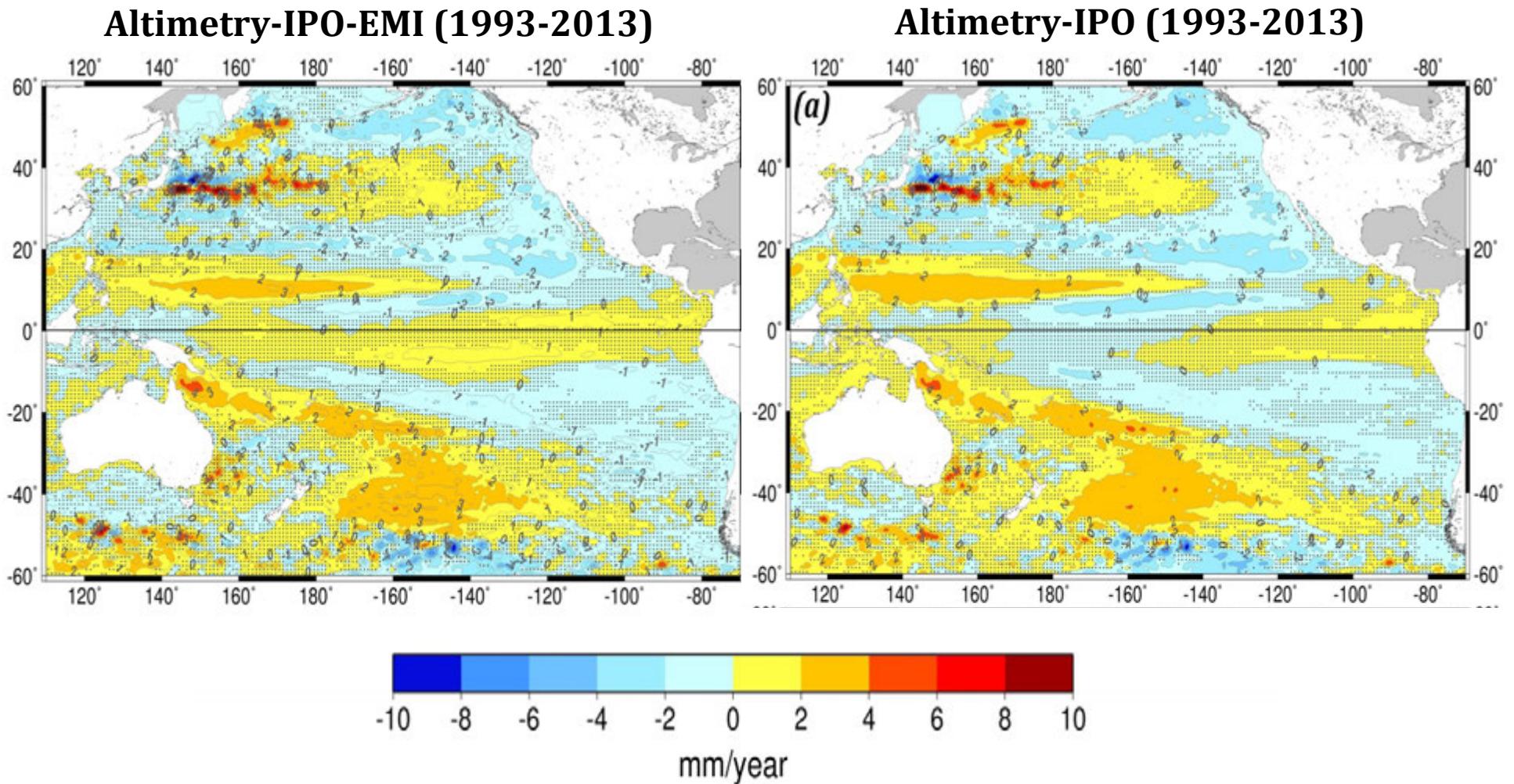
First Empirical Orthogonal Function (EOF) mode of Altimetry-IPO sea level



EVIDENT EL NIÑO MODOKI SIGNAL!

Periodicity ≈ 3 years

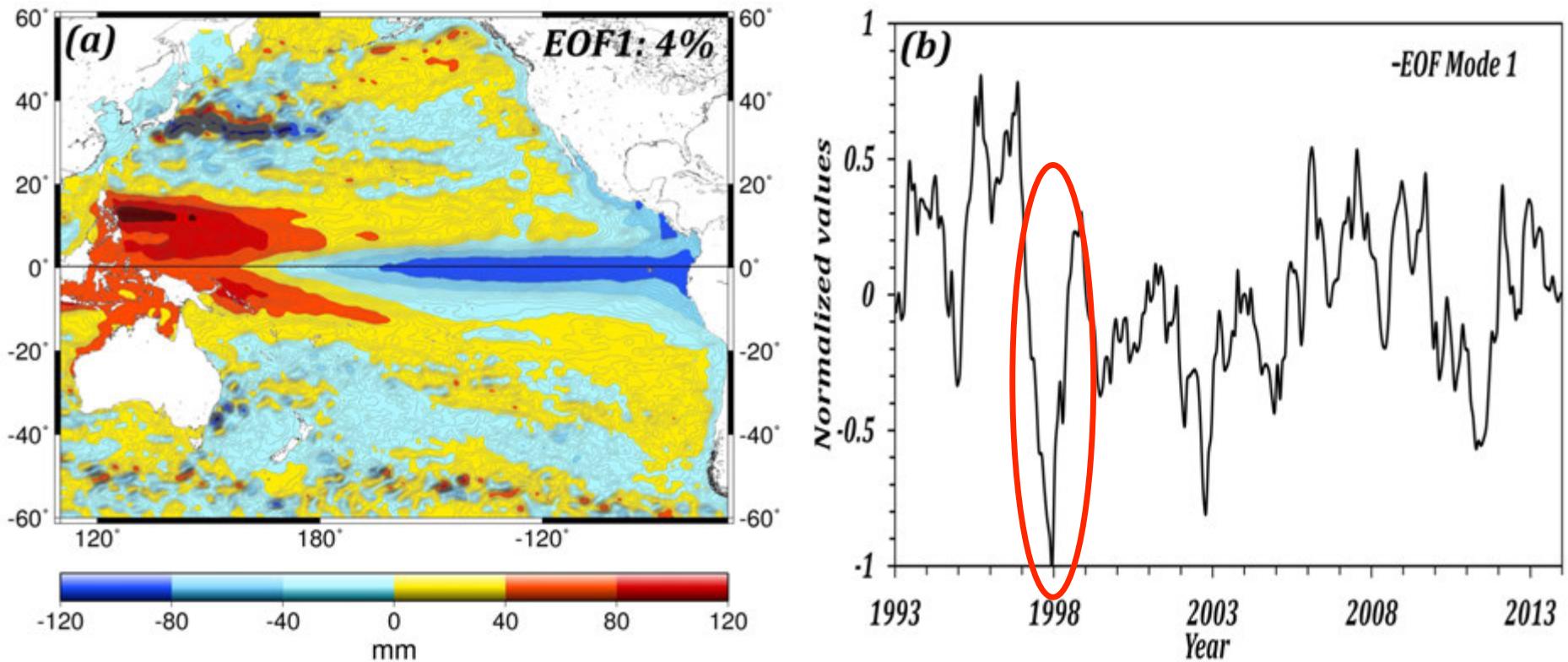
Analysis of the residual (Altimetry-IPO-EMI) signal



Removal of El Niño Modoki signal from the altimetry signal without IPO results only in a small decrease of the residual trend magnitude with no other significant changes.

Analysis of the residual (Altimetry-IPO-EMI) signal

First Empirical Orthogonal Function (EOF) mode of Altimetry-IPO-EMI sea level



Evident 1998 El Niño signal

Analysis of the residual signal

Analysis of the residual signal shows that

- *Linearly regressing IPO on observed sea level and removing its contribution does not totally remove the entire internal sea level variability..*
- *Non linear ENSO modes that do not co-vary with IPO remain as the residual sea level signal..*

***HOW ELSE CAN WE BE SURE THAT THE RESIDUAL PATTERN
IS NOT ANTHROPOGENIC?***

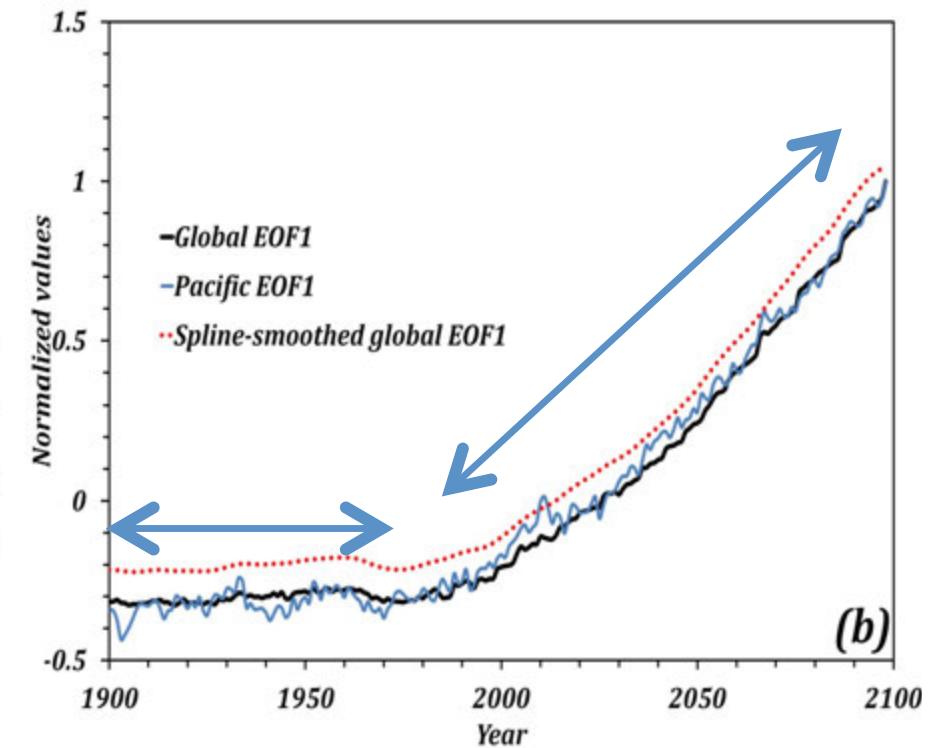
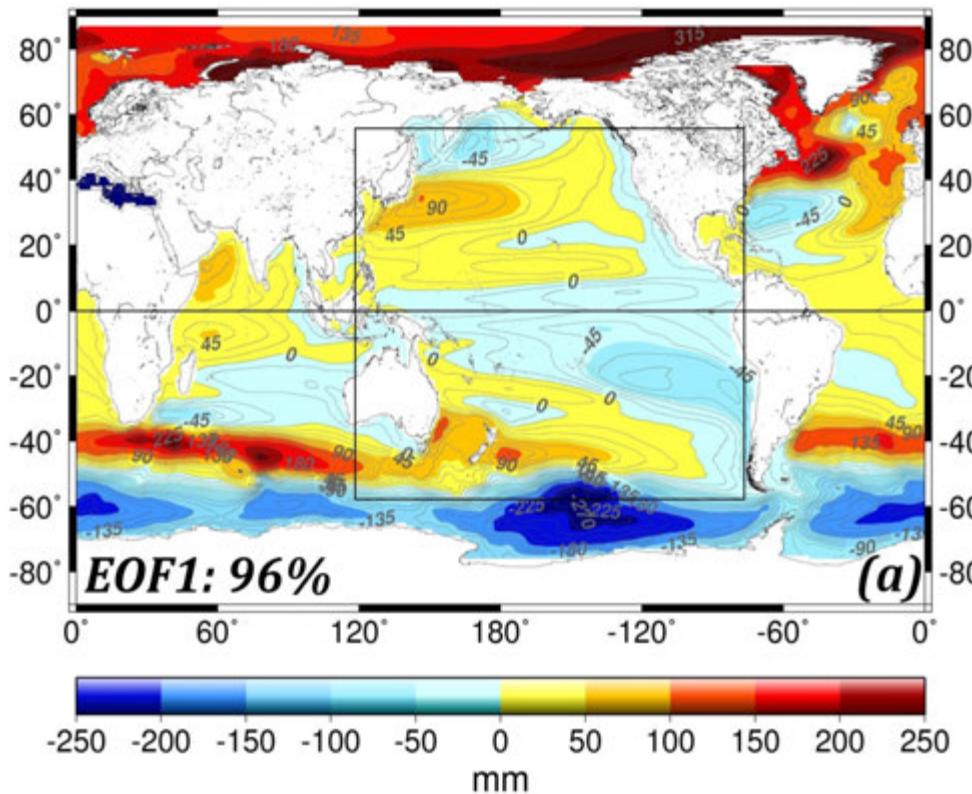
CMIP5 models

<i>Dynamic sea level data</i>	
<i>CMIP5</i>	<i>No. of realizations</i>
<i>ACCESS1.0</i>	1
<i>ACCESS1.3</i>	1
<i>CanESM2</i>	5
<i>CCSM4</i>	6
<i>CNRM-CM5</i>	5
<i>CSIRO-Mk3.6.0</i>	10
<i>GFDL-CM3</i>	1
<i>GFDL-ESM2M</i>	1
<i>HadGEM2-CC</i>	1
<i>HadGEM2-ES</i>	4
<i>INM-CM4</i>	1
<i>IPSL-CM5A-LR</i>	4
<i>IPSL-CM5A-MR</i>	1
<i>MIROC5</i>	3
<i>MIROC-ESM</i>	1
<i>MIROC-ESM-CHEM</i>	1
<i>MPI-ESM-LR</i>	3
<i>MPI-ESM-MR</i>	1
<i>MRI-CGCM3</i>	1
<i>NorESM1-M</i>	1
<i>NorESM1-ME</i>	1
Total no. of realizations	53
Total no. of models	21

- **21 CMIP5 models used**
- ***Historical (1850-2005) simulations continued by RCP8.5(2006-2099)***
- ***An ensemble mean of all the models:***
- ***internal variability at different temporal phase is (more or less) compensated***
- ***sea level variability with external (natural/anthropogenic) forcing only***
- ***Mean of the realizations of each model followed by the mean of 21 models***

Ensemble CMIP5 sea level and internal variability

First EOF mode of CMIP5 multi-model ensemble : 1900-2098

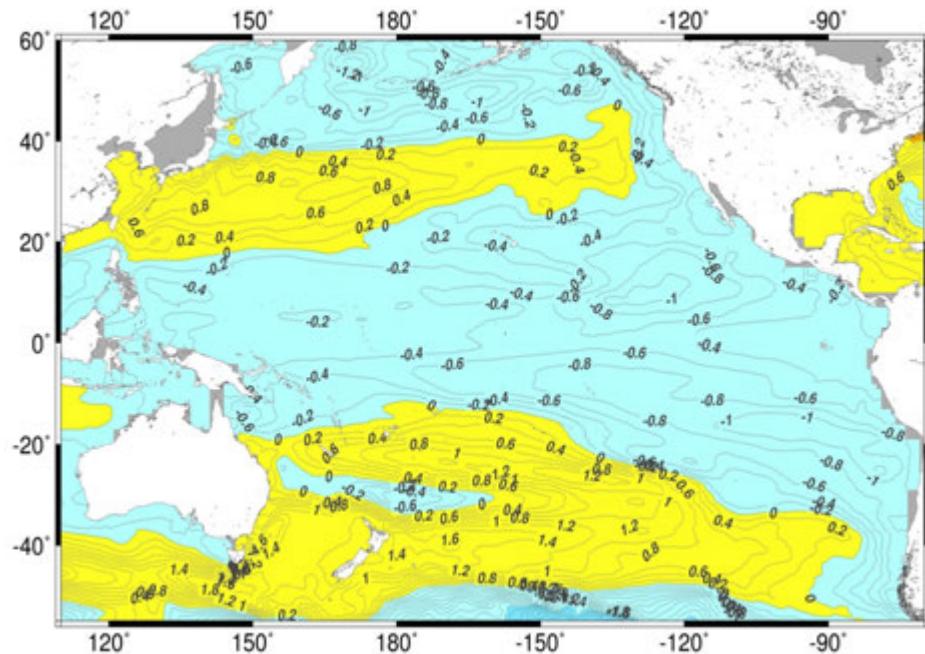


Spline smoothing performed to remove the small amplitude oscillations and the corresponding temporal curve is regressed..

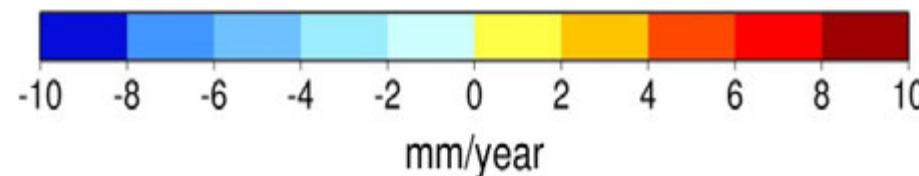
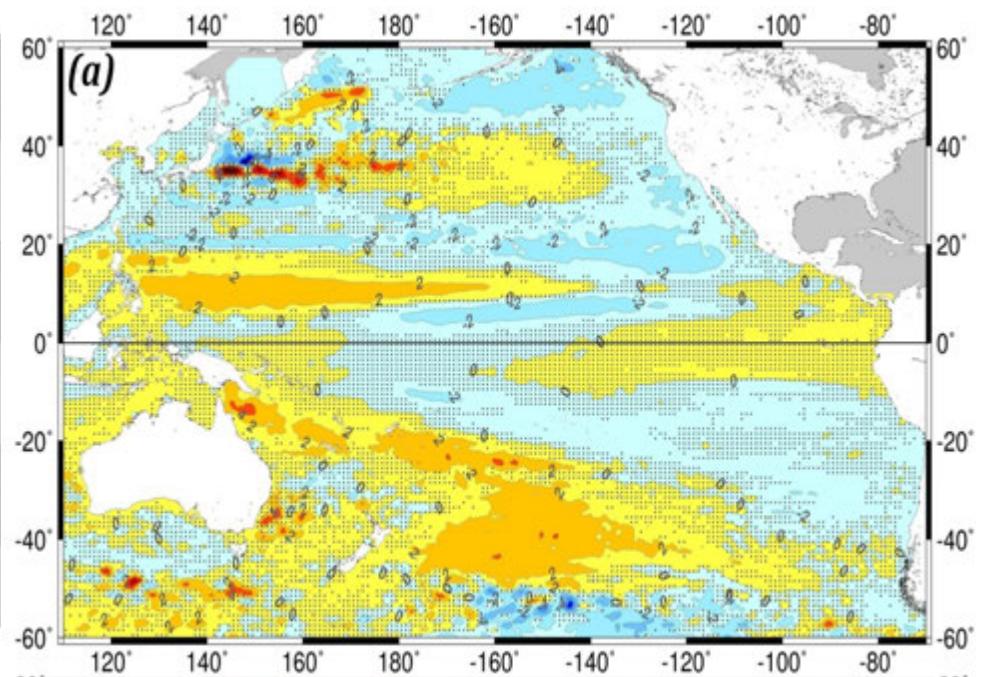
The role of anthropogenic forcing??

1993-2013

CMIP5 regressed ensemble



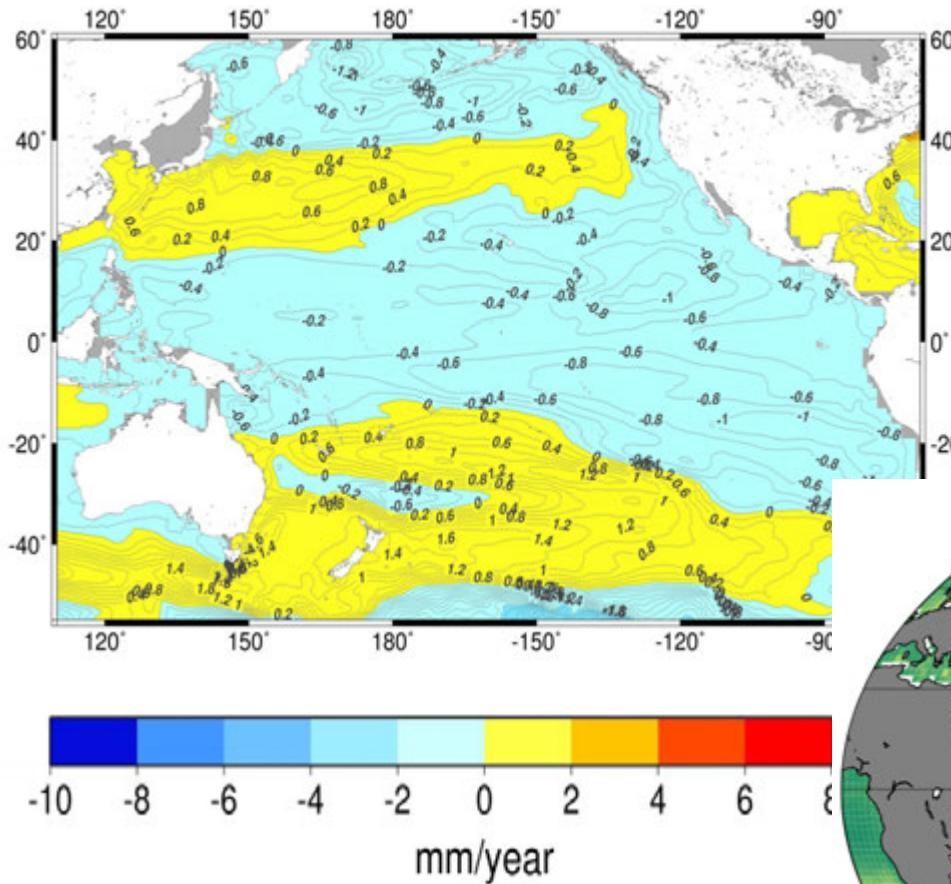
Altimetry-IPO



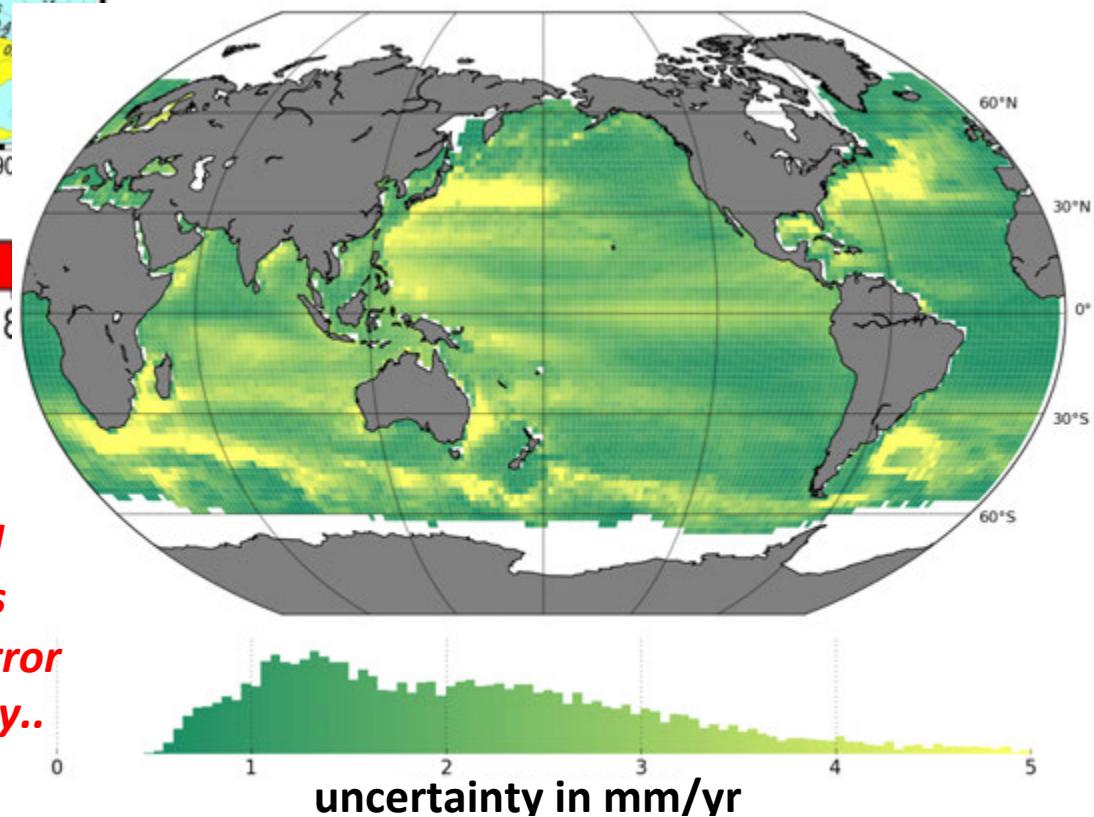
No significant trend due to external forcing observed in the CMIP5 ensemble over the altimetry era!

The role of anthropogenic forcing??

CMIP5 regressed ensemble



Expected uncertainty in altimetry trend
see talk of Prandi et al.



CMIP5 based externally forced sea level trend amplitude in the tropical Pacific is significantly lower than the expected error in trend patterns from satellite altimetry..

Conclusion

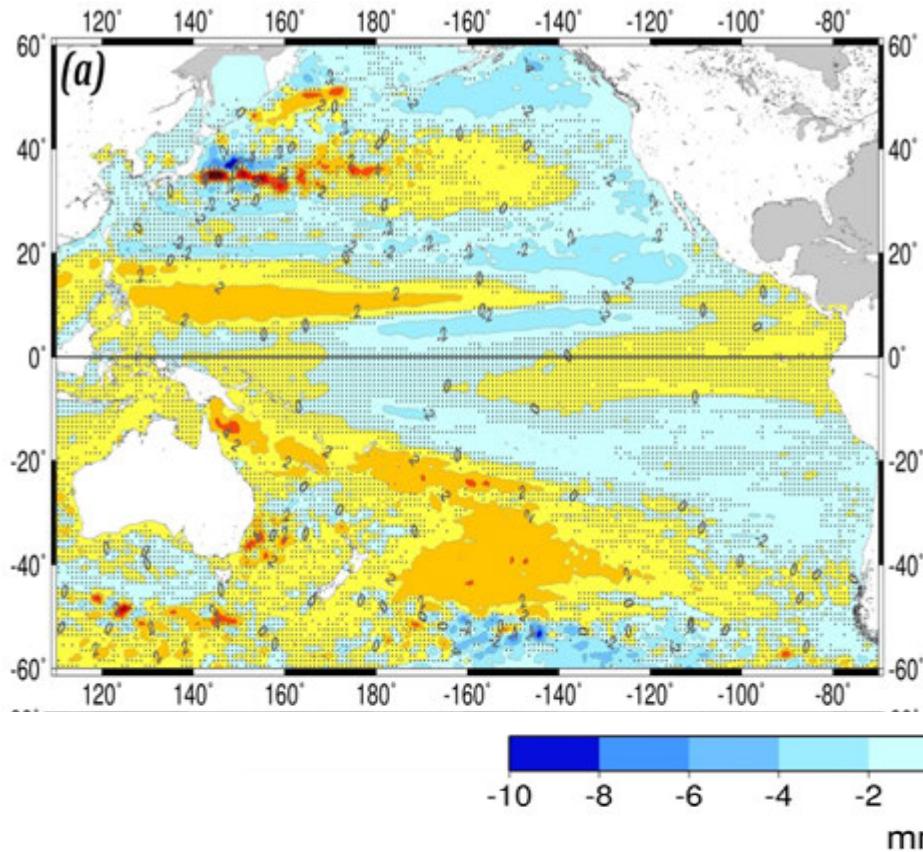
- *Over the altimetry period (since 1993), sea level in the tropical Pacific can be principally explained by natural internal climate modes.*
- *It is difficult over this region and over 1993-2014 to detect the small anthropogenic signal because*
 - 1) it is buried in the large signal from natural climate variability which can not be removed with a simple linear regression method*
 - 2) and GCMs suggest that the potential anthropogenic signal is of the same order of magnitude as the Altimetry uncertainty*
- *Focus on other regions (e.g., North Atlantic, Northern and Southern Ocean, etc.) for detection/attribution studies..*
- *Impact of external anthropogenic forcing on internal climate modes??*

More details in:

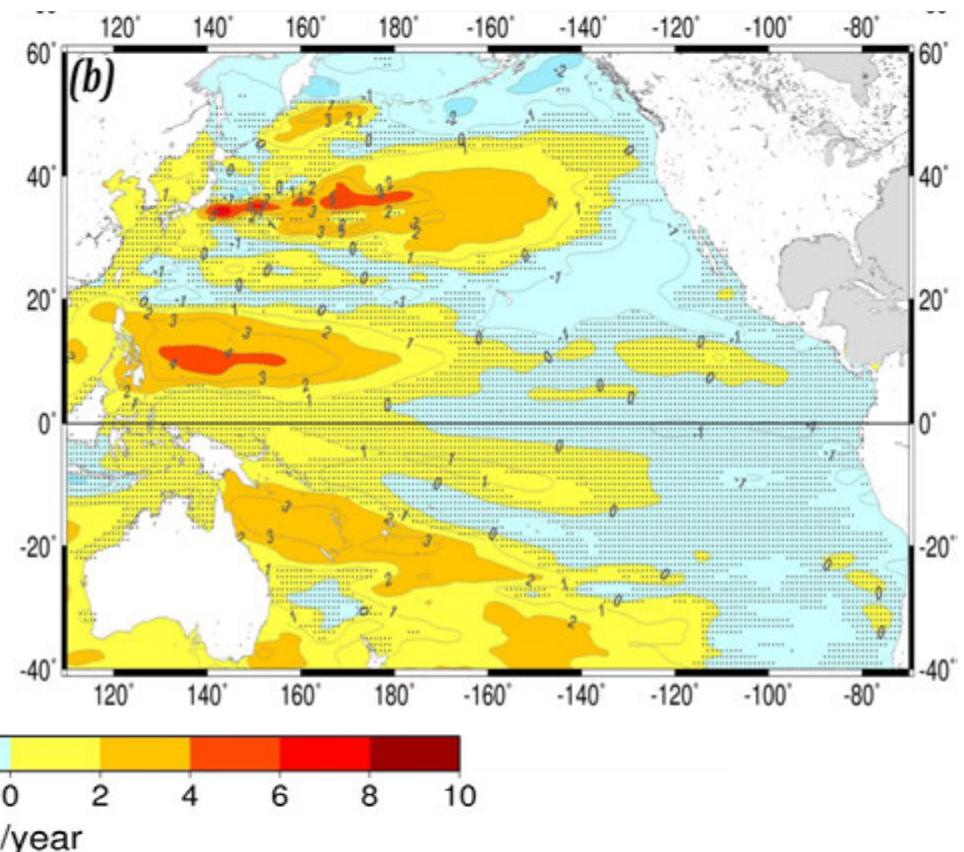
Palanisamy, H., B. Meyssignac, A. Cazenave, and T. Delcroix (2015), Is anthropogenic sea level fingerprint already detectable in the Pacific Ocean?, *Environ. Res. Lett.*, 10(8), 084024, doi:10.1088/1748-9326/10/8/084024.

Linear regression and aliasing effect

Altimetry sea level trend – IPO
1993-2013



Reconstructed sea level – IPO
1993-2012



Linear regression of IPO index on the observed altimetry based sea level over 20 years (1993-2013) and removing its contribution..

Linear regression of IPO performed over 53 years (1960-2012) using 2D reconstructed sea level ([Meyssignac et al., 2015](#)) and the residual over 1993-2012..