Cause of substantial global mean sea level rise over 2014-2016

William Llovel, Kévin Balem, Soumaïa Tajouri and Antoine Hochet

LOPS, Brest, France.

IMHOTEP OST/ST project
(IMpacts of freshwater discHarge interannual variability on Ocean heaT-salt contents and rEgional sea level change over the altimetry Period)

Motivation

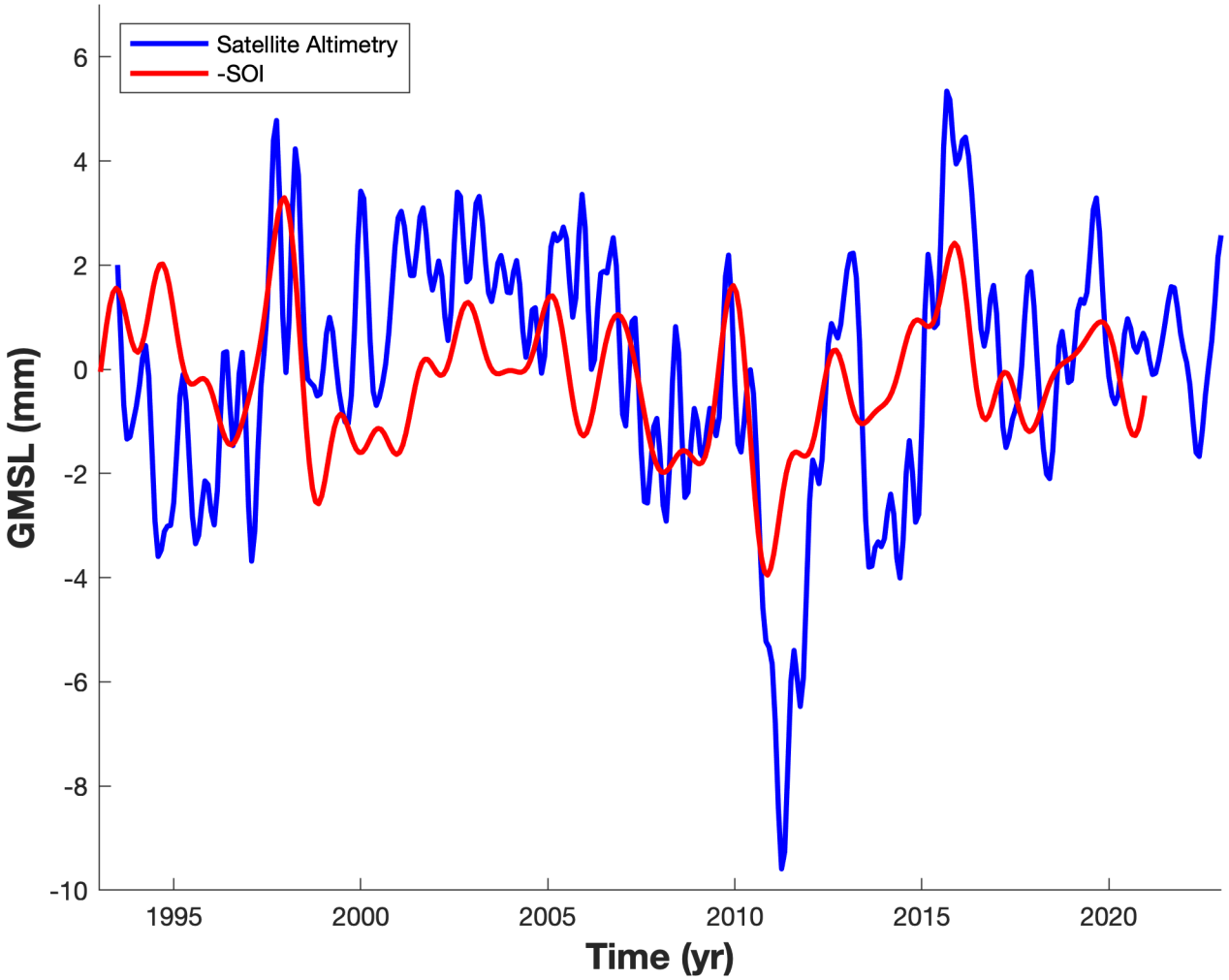
Relevant climate index !

Global mean sea level rise over 1993-2023

1/ Long term trend/acceleration
2/ Interannual variability

Long-term trend : 3.58 +/- 0.4 mm/yr

Detrended GMSL over 1993-2023



Large interannual variability

- ENSO events
  - Only mass origin (Nerem et al., 2010; Llovel et al., 2011; Cazenave et al., 2012)
  - Both mass and steric origins (Piecuch et al., 2016; Hamlington et al., 2020)
- La Nina events
  - 2011 event (Boening et al., 2012; Fasullo et al., 2013)

Global mean sea level budget : theoretical framework

$$\Delta H_{SeaLevel} = \Delta H_{steric} + \Delta H_{mass}$$

Global ocean warming

Global ocean mass increase (barystatic sea level)

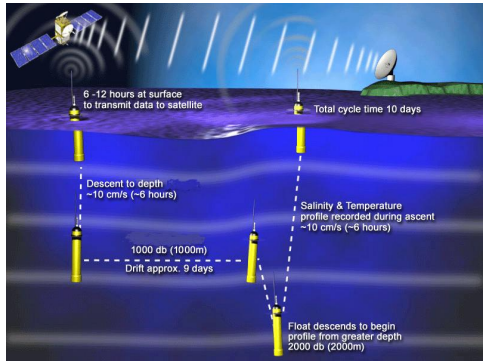
$$\Delta H_{steric} = -\frac{1}{\rho_0}\int_{-H}^{0} \Delta\rho(T,S,p)dz$$

$$\Delta H_{mass} = \frac{\Delta Pb}{\rho_0 g}$$

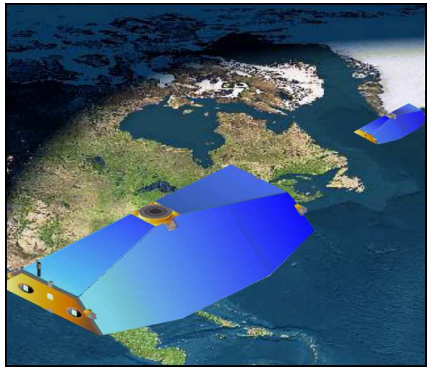
Global mean sea level budget : 2006-2016

$$\Delta H_{SeaLevel} = \Delta H_{steric} + \Delta H_{mass}$$

Jason-1/2/3- Sentinel6-MF
Saral/Altika, Sentinel-3A/B,
etc…



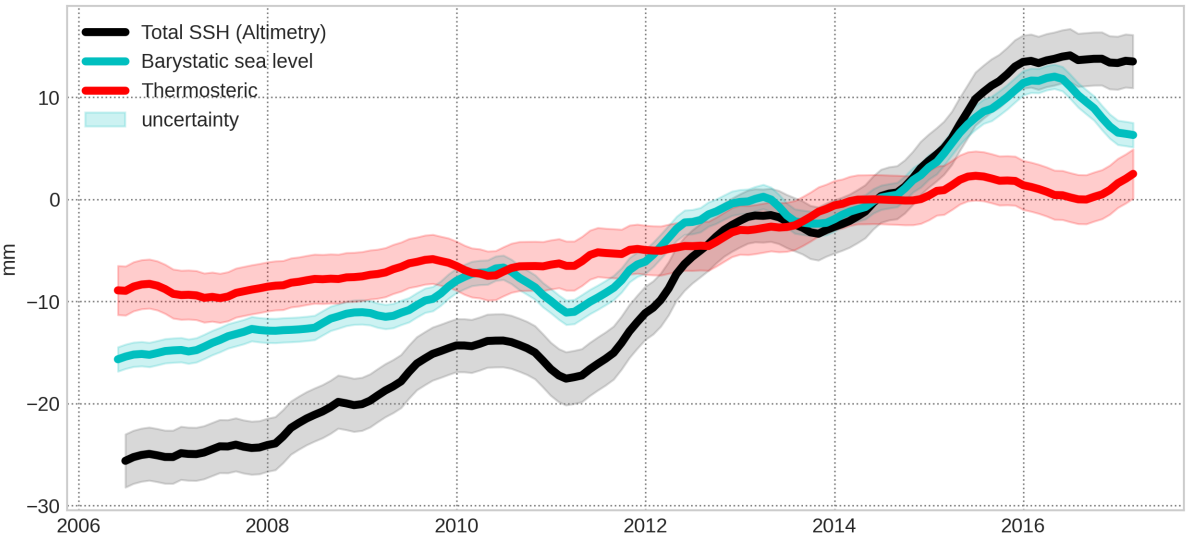
Argo (~2005/2006)

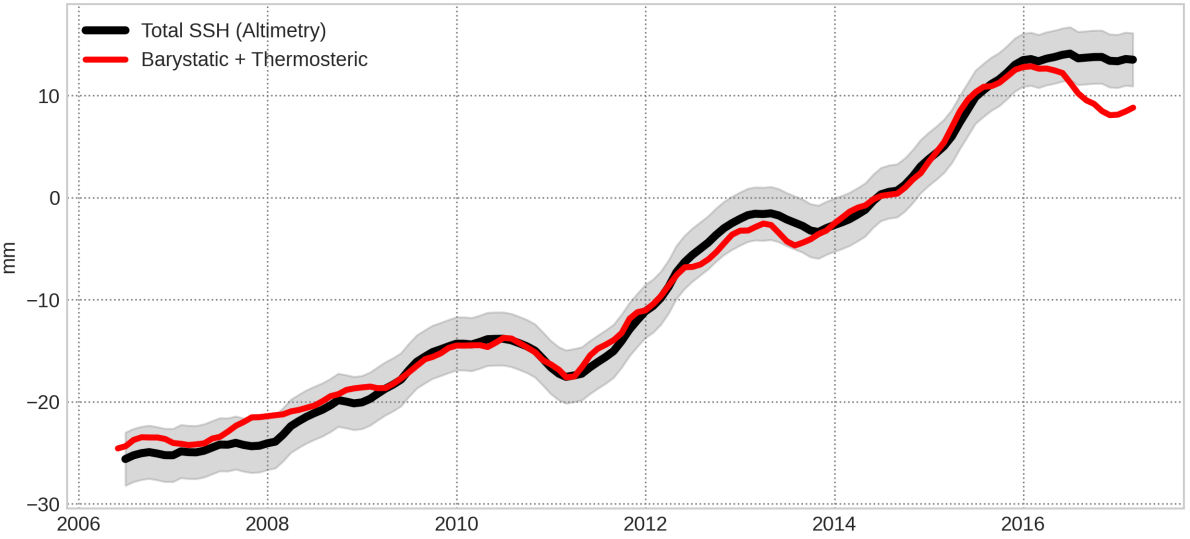


GRACE (2002-2017)
GRACE-FO (2018-…)

Results

Global mean sea level budget over 2006-2016

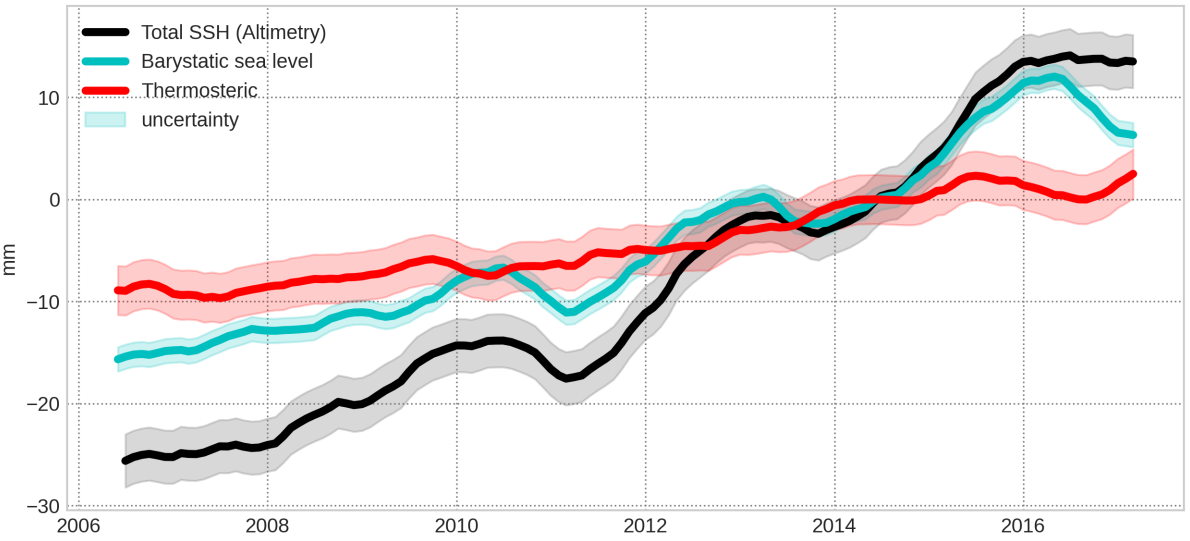


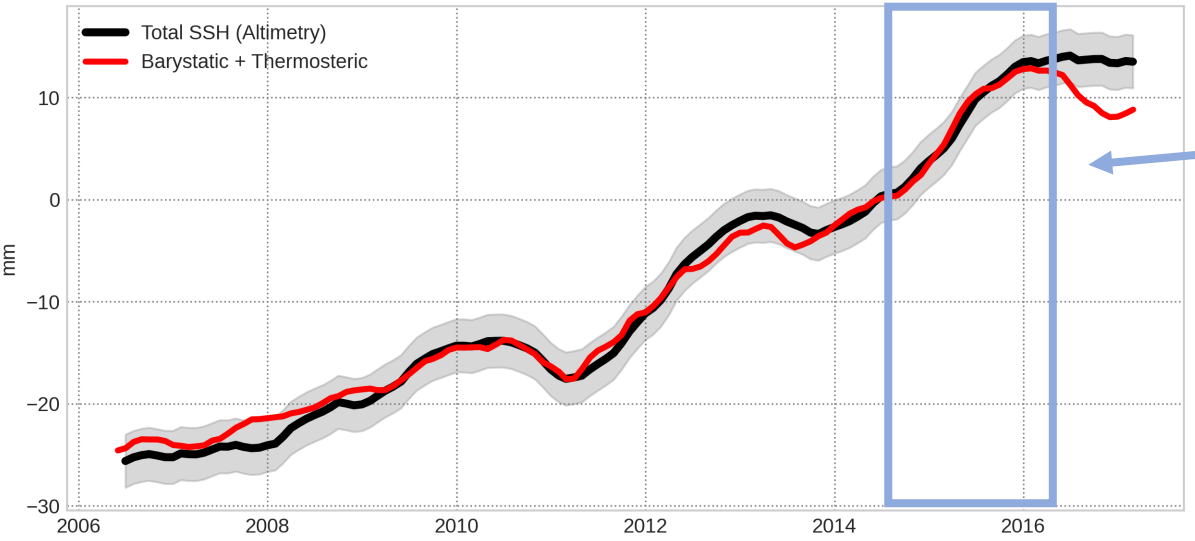


Non-closure after mid-2016 (Chen et al., 2020; 2022; Barnoud et al., 2021)

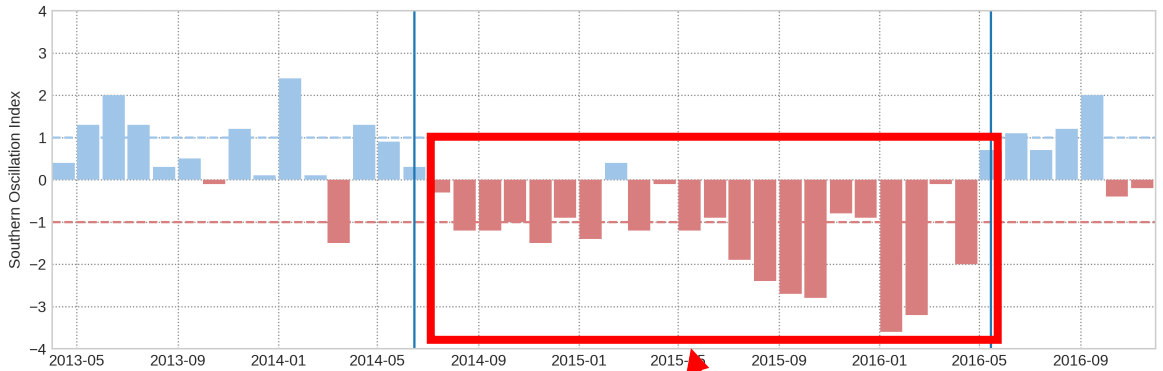
Results

Global mean sea level budget over 2006-2016





ENSO index



El Nino events

2 El nino events :

- one aborted in 2014-2015
- an extreme event in 2015-2016

Results: over June 2014-May 2016

-> **GMSL increase of 15 mm**

-> 8 mm from the long term trend

-> 7 mm during El Nino events

-> **20% due to global ocean warming**

-> **80% ocean mass increase**

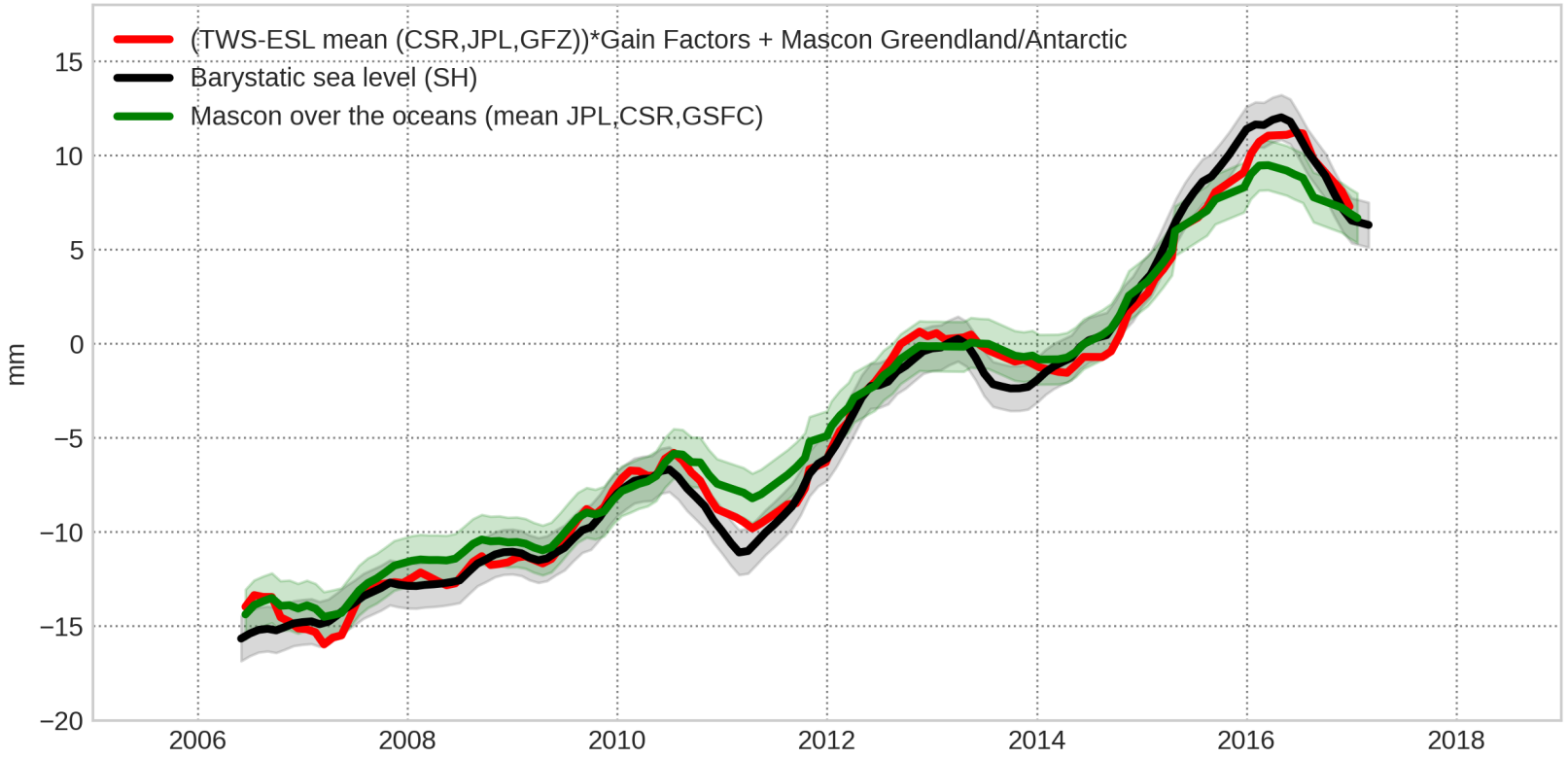
Barystatic sea level rise

Global mass budget

$$\Delta M_{Atmosphere} + \Delta M_{Ocean} + \Delta M_{Land} = 0$$

On a monthly mean basis

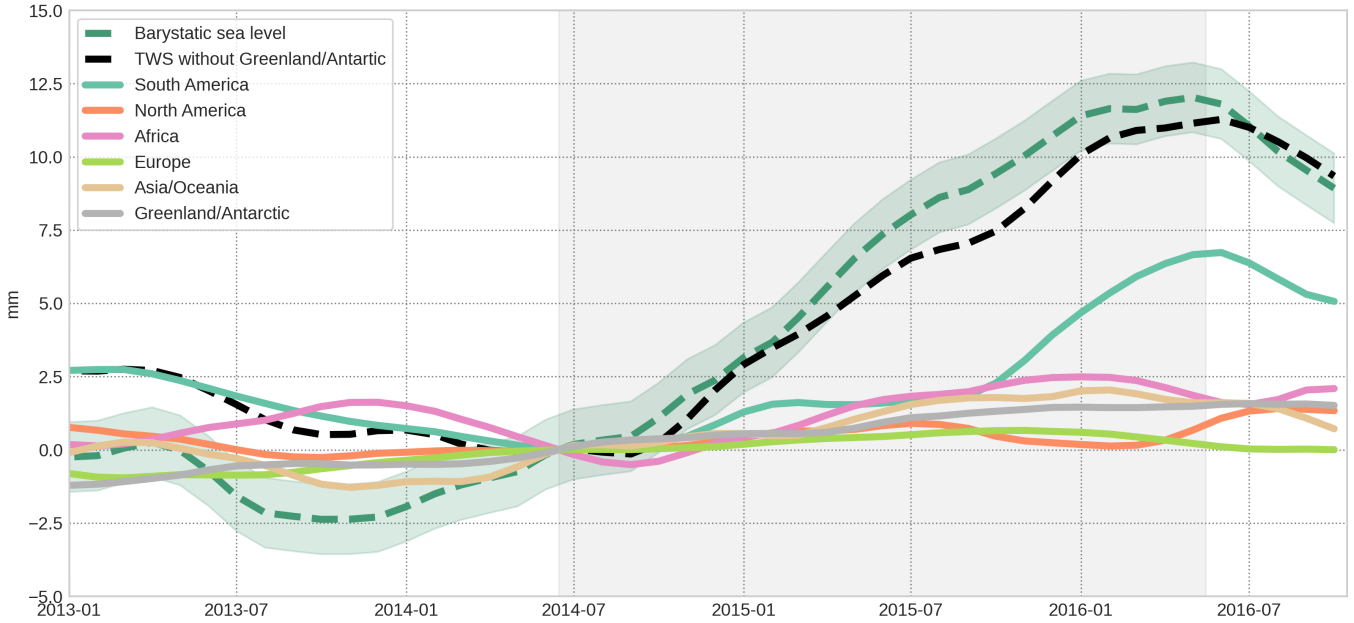
$$\Delta M_{Ocean} \approx -\Delta M_{Land}$$



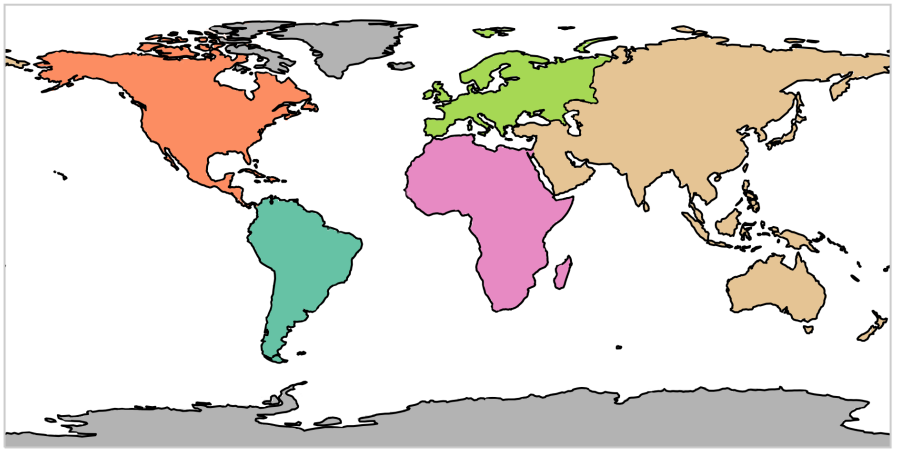
Global ocean mass budget

- **Directly over the oceans** (need a GIA correction)
  - **SH solutions** (JPL/CSR/GFZ)
  - **MasCon solutions** (JPL/CSR/GSFC)
- **TWS in equivalent GMSL** (JPL/CSR/GFZ)

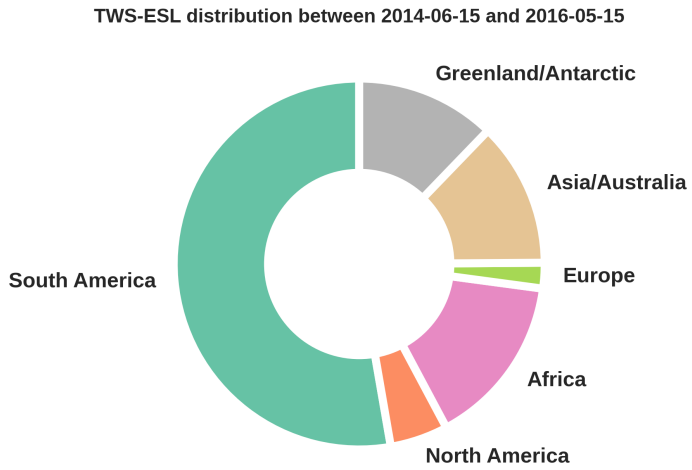
Global ocean mass budget over June 2014 – May 2016



Masks



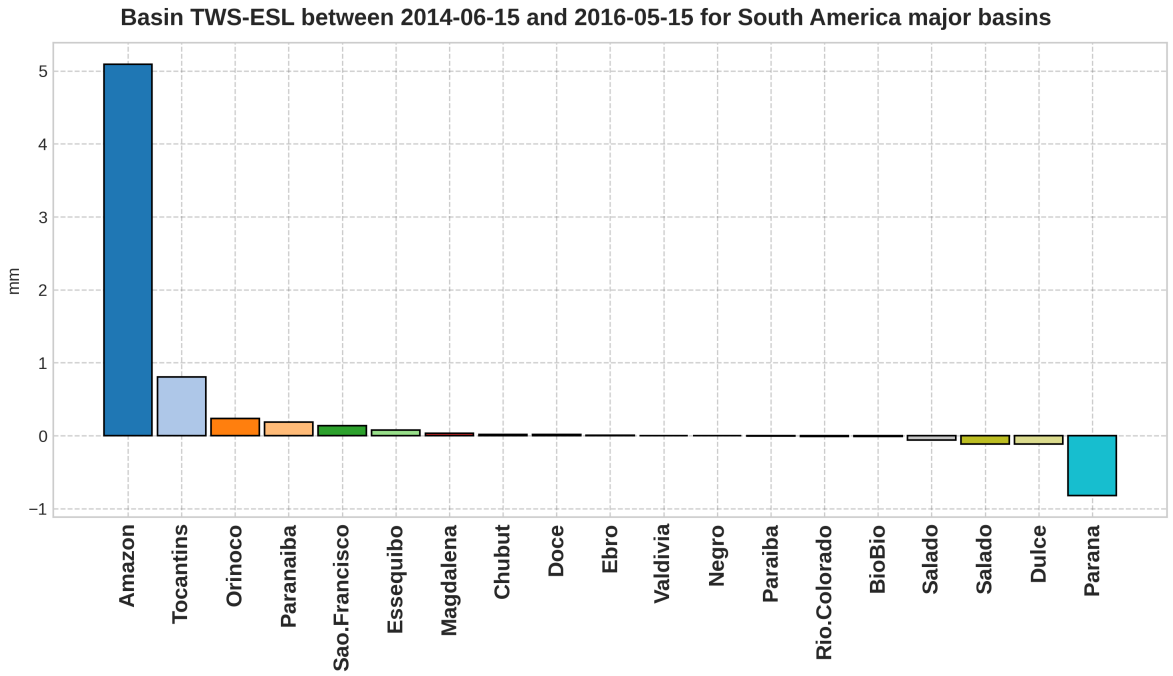
Pie chart



Result

-> large contribution (~50%) from the South America continent

Terrestrial water storage change in equivalent GMSL (June 2014-May 2016)

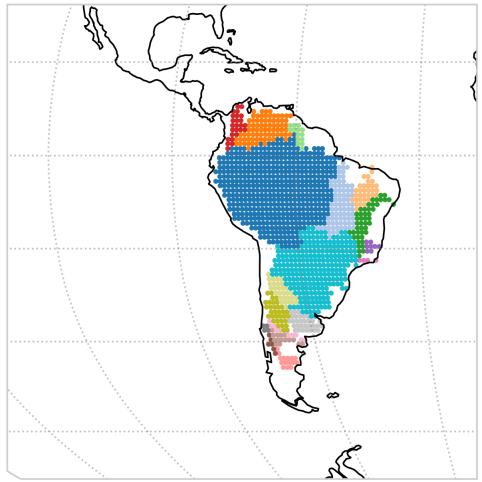


Results

- Compensation between Parana and Tocantins' rivers (~1mm)
- Large contribution from the Amazon (5mm)
- No significant contribution from the other basins

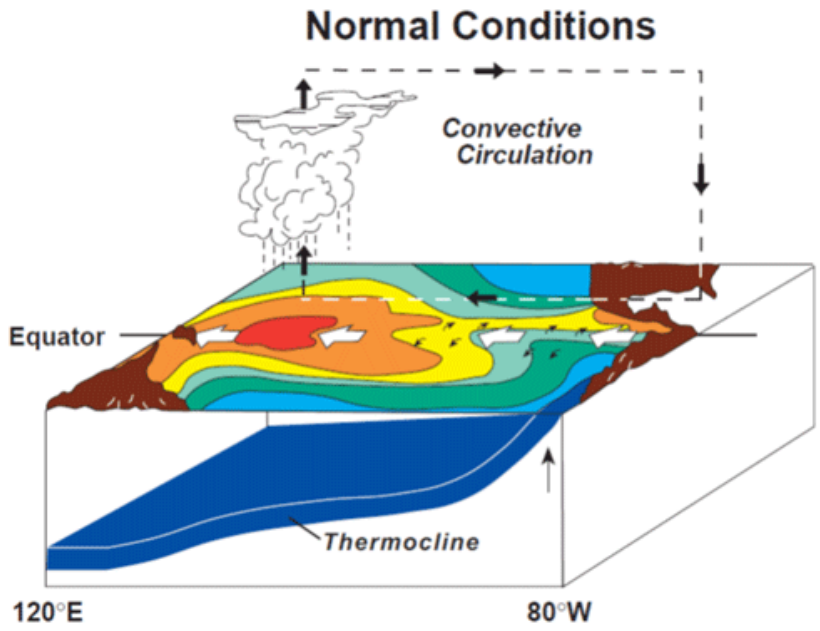
Hydrological basins

(Oki and Sud, 1998)

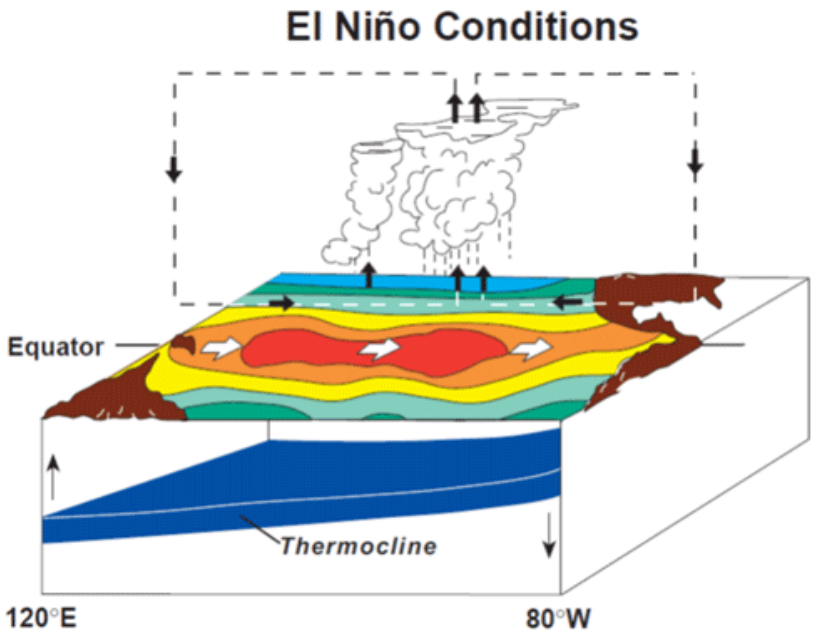


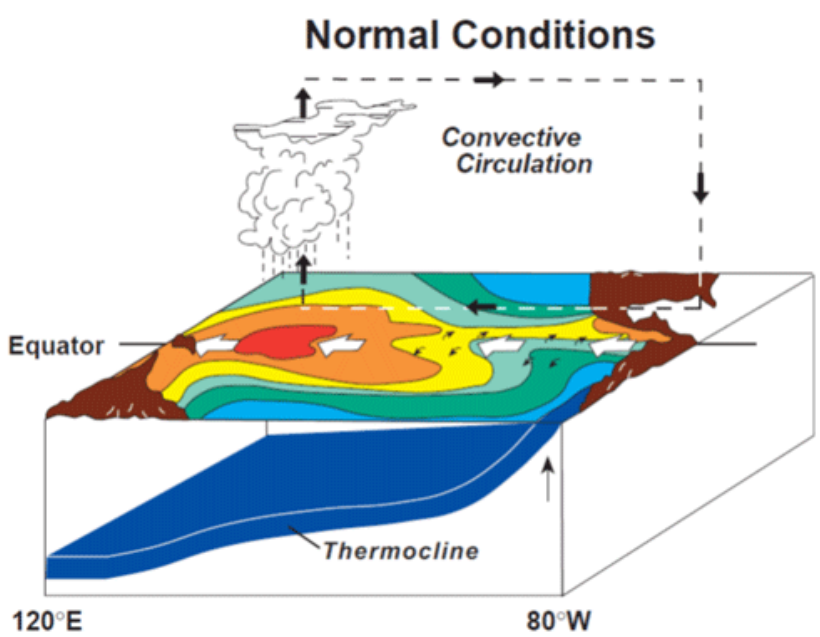
$$\frac{dTWS}{dt} = P - E - R$$

El Nino Southern Oscillation: ENSO



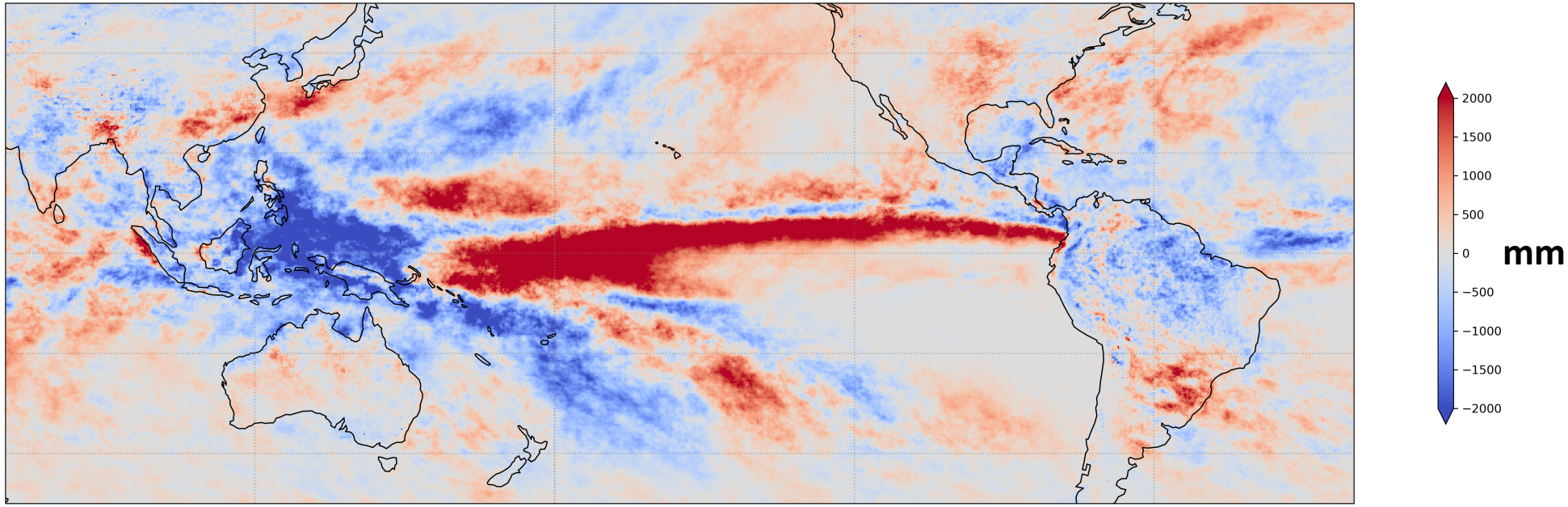
El Nino Southern Oscillation: ENSO





El Nino events

Map of time mean difference (June 2014- May 2016 minus June 2012-May2014) based on TRMM data.



TRMM precipitation data. Difference between precipitation from [June 2014 to May 2016] and [June 2012 to May 2014].

Red = excess of Precip.
Blue = lack of Precip.

Conclusions

1. Closure of sea level budget over 2006- mid 2016 (Llovel et al., 2019; Barnoud et al., 2021)

2. 2 El Nino events : one aborted in 2014-2015 and an extreme event in 2015-2016 : unusual feature in GMSL record !

3. Over June 2014-May 2016: GMSL increase of 15 mm !

    1. 20% due to global ocean warming

    2. 80% has a mass origin

    3. TWS change in the Amazon basin contributes to 5 mm of GMSL (33%)

4. Climate models suggest more and more CP El Nino events leaving larger imprint on TWS changes. Needs to better understand past El Nino events.

Llovel, W., Balem, K., Tajouri, S., & Hochet, A. (2023). Cause of substantial global mean sea level rise over 2014–2016. Geophysical Research Letters, 50, e2023GL104709. https://doi.org/10.1029/2023GL104709.