Abrupt trend change in the early 2010s observed in sea level variations at the world coastlines, as well as in the global mean sea level and its components.

L. Leclercq (LEGOS), J. Oelsmann (Tulane Univarsity), H. B. Dieng (Université de Ziguinchor), A. Cazenave (LEGOS), M. Passaro (TUM), F. Birol (LEGOS), S. Jevrejeva (NOC), E. Bergsma (CNES), R. Abarca-del-Río (University of Concepcion), S. Connors (ESA), J. Legeais (CLS)

Objectives:

- Study of the impact of internal climate modes on interannual coastal sea level
- Study on the cross-shore behavior from the coast towards the open ocean.

Data and Method:

- Method: use of Empirical Orthogonal Function (EOF) decomposition
- Data sets considered (over January 2002-June 2021)

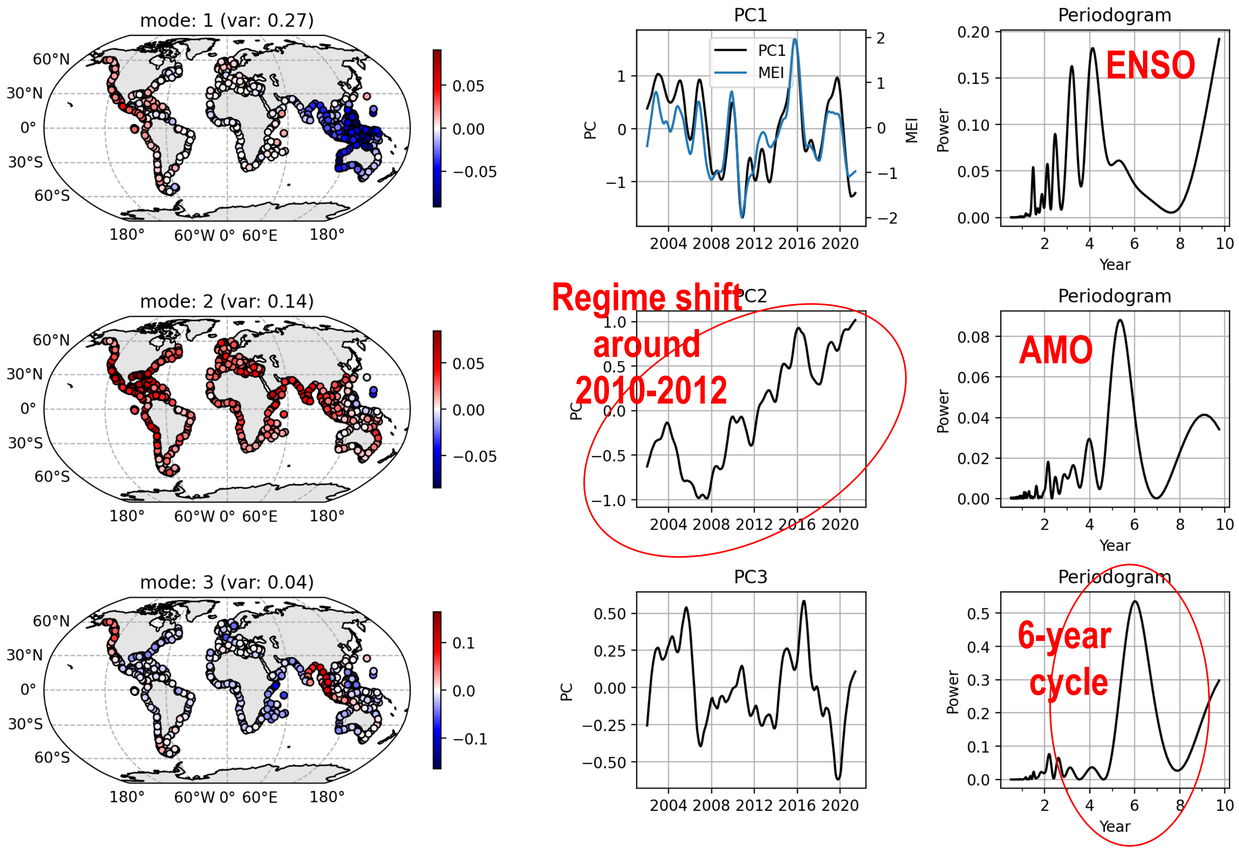
(1) Coastal sea level data at the 1135 altimetry-based virtual coastal stations (ESA CCI coastal sea level product, version v2.4)

(2) Gridded altimetry data from the Copernicus Climate Change Service (C3S)

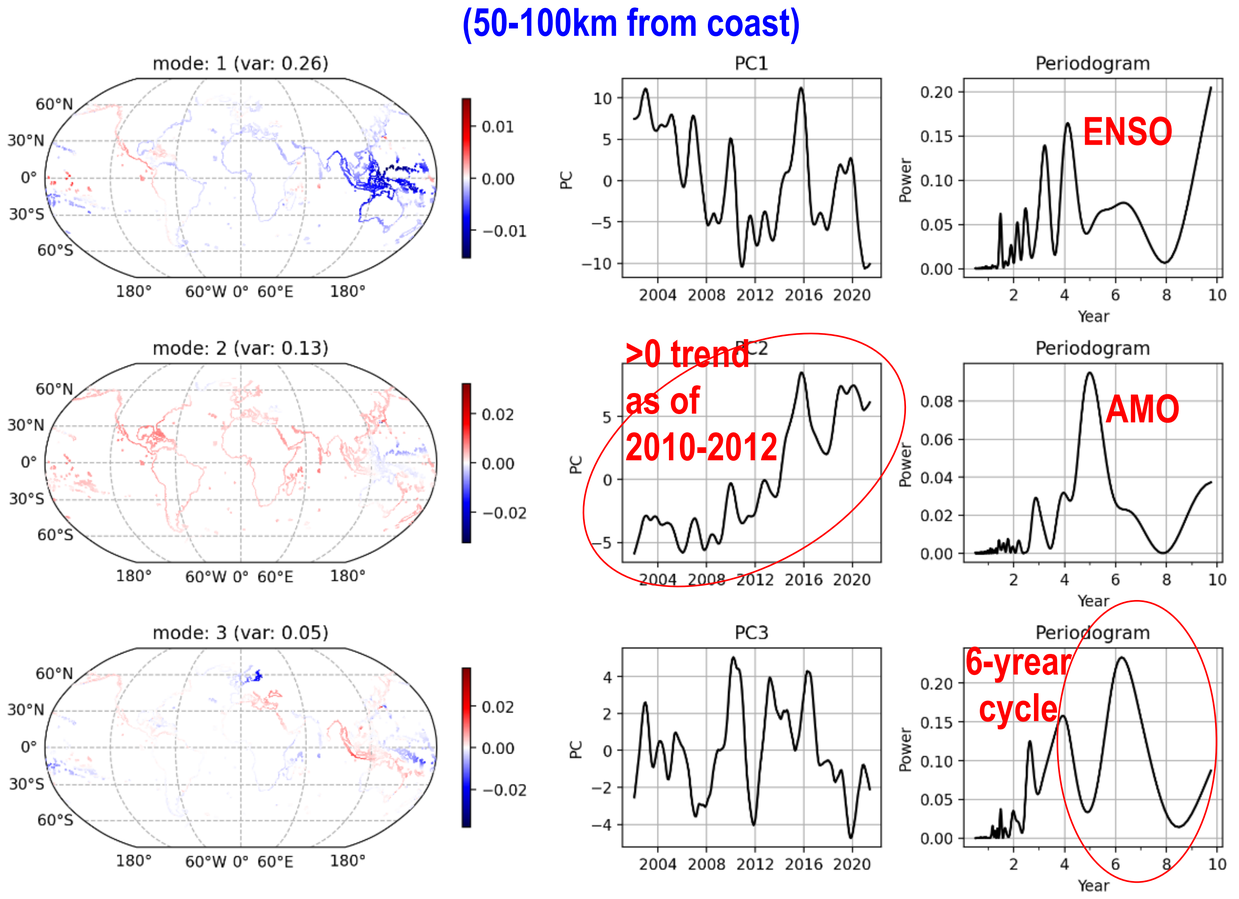
(3) An ensemble mean of four ocean reanalyses

Results:

EOF décomposition of coastal sea level data over 2002-2021 (CCI product v2.4)



EOF décomposition of the C3S gridded data over 2002-2021 (50-100km from coast)

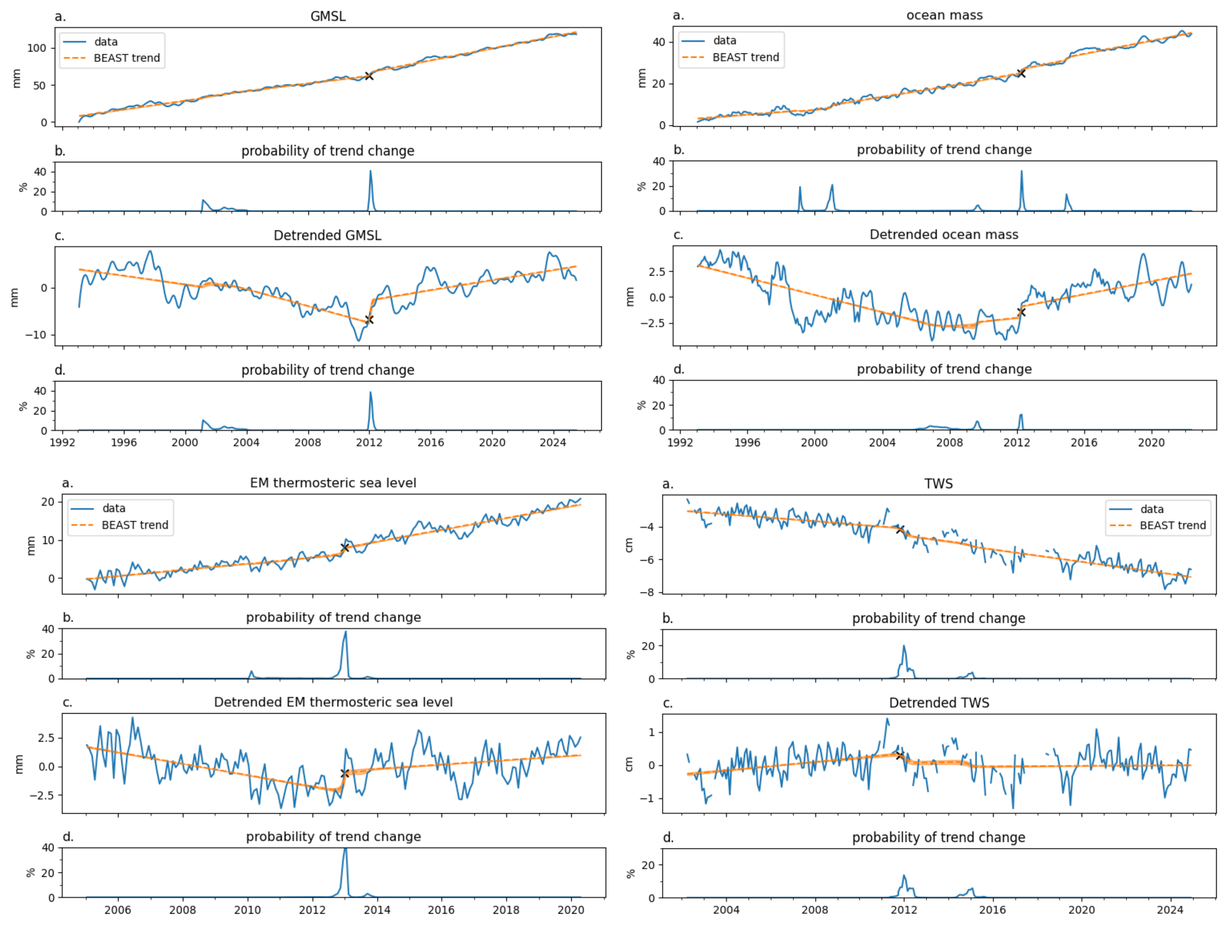


1. As expected, dominant influence of ENSO worldwide on coastal sea level at interannual time scale
2. Evidence of a 6-year cycle in coastal sea level in some regions
3. Evidence of a regime shift in coastal sea level as of 2010-2012

Study made in the context of ESA CCI Sea Level project:

Abrut trend change in the Global Mean Sea Level (GMSL) and components around 2012 ?

- Use of the "Bayesian Estimator of Abrupt change, Seasonal change and Trend (BEAST)" method (Zhao et al. 2019)
- Search for changes in trend in sea level and components over the altimetry era (1993-present)
- Different time series considered:
  - GMSL (Copernicus altimetry-based DT2024 product)
  - Thermosteric sea level (Argo-based ensemble mean with SIO, IPRC, JAMSTEC, EN4 products)
  - Ocean mass (barystatic update from Horwath et al., 2022):
    - Individual mass components:
      - Ice sheets (Greenland + Antarctica; IMBIE product)
      - Glaciers (Copernicus product; Dussaillant et al., 2025)
      - Terrestrial Water Storage (TWS; GRACE data)



Conclusions:

- Over the altimetry era, the global mean sea level can be interpreted as the combination of two successive linear trends with a trend change in early 2012
- Trend shifts around 2010-2012 have been reported in different climate variables, e.g.: Terrestrial water storage (Buzzanga et al., 2025), Sea level in South China Sea (Cheng et al., 2023), Monsoon rainfall (Subrahmanyam et al., 2025), North Pacific Sea Surface Temperature (Xiao and Ren, 2023), as well as in many several others…
- Two hypotheses for explaining the observed climate shift around 2012:
  - Natural (internal) climate variability (change in phase of the Pacific Decadal Oscillation combined with a strongly negative North Atlantic Oscillation)
  - Increase in radiative forcing (Forster et al., 2022) due to aerosols emission reduction in the early 2010s (Jenkins et al., 2022) (especially in China, Liu et al., 2024), possibly combined with additional mechanisms (cloud & sea ice feedbaks) (Merchant et al., 2025).

More details in Leclecq et al., " Abrupt trend change in global mean sea level and its components in the early 2010s", in revision in *Communications, Earth and environment, 2025.*

References:

Buzzanga, Brett, Ben Hamlington, John Fasullo, Felix Landerer, and Athina Peidou. 2025. "Interdecadal Variability of Terrestrial Water Storage since 2003." Communications Earth & Environment 6 (1): 1–9. https://doi.org/10.1038/s43247-025-02203-6.

Cazenave, Anny, Yvan Gouzenes, Florence Birol, Fabien Leger, Marcello Passaro, Francisco M. Calafat, Andrew Shaw, et al. 2022. "Sea Level along the World's Coastlines Can Be Measured by a Network of Virtual Altimetry Stations." Communications Earth & Environment 3 (1): 117. https://doi.org/10.1038/s43247-022-00448-z.

Cazenave, Anny, Julia Pfeffer, Mioara Mandea, Véronique Dehant, and Nicolas Gillet. 2025. "Why Is the Earth System Oscillating at a 6-Year Period?" Surveys in Geophysics, February. https://doi.org/10.1007/s10712-024-09874-4.

Cheng, Xuhua, Mingyu Zhao, Wei Duan, Long Jiang, Jiajia Chen, Chengcheng Yang, and Yifei Zhou. 2023. "Regime Shift of the Sea Level Trend in the South China Sea Modulated by the Tropical Pacific Decadal Variability." Geophysical Research Letters 50 (7): e2022GL102708. https://doi.org/10.1029/2022GL102708.

Forster, Piers M., Christopher J. Smith, Tristram Walsh, William F. Lamb, Robin Lamboll, Mathias Hauser, Aurélien Ribes, et al. 2023. "Indicators of Global Climate Change 2022: Annual Update of Large-Scale Indicators of the State of the Climate System and Human Influence." Earth System Science Data 15 (6): 2295–2327. https://doi.org/10.5194/essd-15-2295-2023.

Horwath, M., Gutknecht, B.D., Cazenave, A., Palanisamy, H.K., Marti, F., Marzeion, B., Paul, F., Le Bris, R., Hogg, A.E., Otosaka, I., Shepherd, A., Döll, P., Cáceres, D., Müller Schmied, H., Johannessen, J.A., Nilsen, J.E.Ø., Raj, R.P., Forsberg, R., Sandberg Sørensen, L., Barletta, V.R., Simonsen, S.B., Knudsen, P., Andersen, O.B., Ranndal, H., Rose, S.K., Merchant, C.J., Macintosh, C.R., von Schuckmann, K., Novotny, K., Groh, A., Restano, M., Benveniste, J., 2022. Global sea-level budget and ocean-mass budget, with a focus on advanced data products and uncertainty characterisation. Earth System Science Data 14, 411–447. https://doi.org/10.5194/essd-14-411-2022.

Jenkins, Stuart, Adam Povey, Andrew Gettelman, Roy Grainger, Philip Stier, and Myles Allen. 2022. "Is Anthropogenic Global Warming Accelerating?" Journal of Climate 35 (24): 7873–90. https://doi.org/10.1175/JCLI-D-22-0081.1.

Leclercq, L., Dieng, H.B., Cazenave, A., Birol, F., Oelsmann, J., Passaro, M., Jevrejeva, S., Bergsma, E., Connors, S., 2025. Spatio-temporal changes in interannual sea level along the world coastlines. Global and Planetary Change 253, 104972. https://doi.org/10.1016/j.gloplacha.2025.104972.

Leclercq, L., Cazenave, A., Oelsmann, J., Passaro, M., Jevrejeva, S., Connors, S., Legeais, J.-F., Birol, F., Rio, R.A. del, 2025. Regime Shift in Global Mean Sea Level and Its Components in the Early 2010s. https://doi.org/10.21203/rs.3.rs-6647897/v1.

Liu, Lei, Zhang Wen, Sheng Liu, Xiuying Zhang, and Xuejun Liu. 2024. "Decline in Atmospheric Nitrogen Deposition in China between 2010 and 2020." Nature Geoscience 17 (8): 733–36. https://doi.org/10.1038/s41561-024-01484-4.

Merchant, Christopher J, Richard P Allan, and Owen Embury. 2025. "Quantifying the Acceleration of Multidecadal Global Sea Surface Warming Driven by Earth's Energy Imbalance." Environmental Research Letters 20 (2): 024037. https://doi.org/10.1088/1748-9326/adaa8a.

Subrahmanyam, Kandula V., Prashant Kumar, Narendra Reddy Nelli, Sampelli Anoop, M. V. Ramana, M. Rajeevan, and Prakash Chauhan. 2025. "Regional Shift in the Peak Time of Maximum Indian Summer Monsoon Rainfall in Recent Decades." Geophysical Research Letters 52 (6): e2024GL112697. https://doi.org/10.1029/2024GL112697.

Xiao, Dong, and Hong-Li Ren. 2023. "A Regime Shift in North Pacific Annual Mean Sea Surface Temperature in 2013/14." Frontiers in Earth Science 10 (January). https://doi.org/10.3389/feart.2022.987349.

Zhao, K., Wulder, M.A., Hu, T., Bright, R., Wu, Q., Qin, H., Li, Y., Toman, E., Mallick, B., Zhang, X., Brown, M., 2019. Detecting change-point, trend, and seasonality in satellite time series data to track abrupt changes and nonlinear dynamics: A Bayesian ensemble algorithm. Remote Sensing of Environment 232, 111181. https://doi.org/10.1016/j.rse.2019.04.034.