Title: Eddy variability contribution to regional sea level change

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Sea level rise is one of the most direct consequences of the actual global warming. Over the 20th century, global mean sea level rises at a rate of 1.5-2 mm. yr^{-1} (Fox-Kemper et al., 2021). Since the beginning of the 1990s, satellite altimetry measure the changes of sea level with a near global coverage (from 66ºS to 75ºN). Global mean sea level rise over this period shows a linear rate of 3.3 mm yr^{-1} suggesting a possible acceleration in this global rise (WCRP Sea Level Budget Group, 2018). The use of satellite altimetry has, for the first time, highlighted large regional variability in sea level trends that significantly differ from the global mean estimate (Cazenave and Llovel, 2010; Llovel et al., 2018; 2022). If global ocean warming and land ice melting (mountain glaciers and ice sheets from Greenland and Antarctica) are the main processes explaining the observed global mean sea level rise, at regional scales, other processes are at play such as salinity change, ocean circulation and dynamics, air-sea flux interactions.

Currently, 267 million people worldwide live on land less than 2 meters above sea level. By 2100, with a 1 meter sea level rise and zero population growth, that number could increase to 410 million people (Hooijer and Vernimmen, 2021). This is precisely this regional sea level change that matters for coastal societies. Therefore, investigating regional sea level change is mandatory for potential socio-economic impacts.

Sea level projections used in IPCC reports are based on coupled climate models. Current projections are based on climate models in which ocean-eddy variabilities are parameterized and results deviates from observations especially in the Southern Ocean (van Westen and Dijkstra, 2021). Mesoscale processes transport heat/freshwater over very large distances in the ocean (both horizontally and vertically). They also regulate energy, moisture and carbon exchanges between the oceans and the atmosphere via coupling. Understanding these processes and how they might change in the future is critical for portraying robust global and regional sea level change.

Recently, new generations of climate models have been integrated with ocean-eddy variability partly resolved with a spatial resolution of ¼° and 1/12°. Understanding these processes and how they might change in the future is critical for portraying robust global and regional sea level change. The goal of this thesis is therefore to characterize and better understand the eddy variability contribution to regional ocean heat/freshwater content changes and their contribution to regional sea level changes over 1950-2050.

The thesis is fully funded by the Horizon Europe project **European Eddy-RIch Earth System Models** (EERIE). Its main ambition is to build a new generation of Earth System Models (ESMs) that are capable of explicitly representing a crucially important, yet unexplored regime of the Earth system – *the ocean mesoscale variability*.

Methodology

The selected candidate will take advantage of a collection of simulations based on HadGEM3-GC3.1 climate model at different spatial resolutions (from 250 km / 100km to 50km/8km for the atmosphere/ocean, respectively). These outputs are freely available from the H2020 PRIMAVERA project (https://www.primavera-h2020.eu/). This dynamical downscaling will be valuable to assess the contribution of eddy variability (parameterized or resolved) by ocean model at 1°, ¼° and 1/12° and its impacts on regional (halo/thermo)-steric sea level change.

The first part of the thesis will be dedicated to evaluate the realism of these simulations against remote and in situ observations (i.e., satellite altimetry data and Argo-based gridded products) on (multi)decadal time scales.

Then, in a second part, regional (halo/thermo)-steric sea level change will be investigated as a function of depth over several decadal time scales. The use of the control runs (names piControl) will be valuable to assess the internal climate variability on (mutli)decadal trends. Therefore, investigations on the (halo/thermos)-steric sea level change from the historical simulations will be compared to the internal climate variability and a focus will be done on the eddy variability. Close collaborations with Matt Palmer at the Metoffice will be valuable throughout the 3-year thesis.

References:

- Cazenave and Llovel, 2010, Contemporary Sea Level Rise, Annual Review of Marine Science, Vol. 2:145-173, 2010.
- Fox-Kemper, B., H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.L. Edwards, N.R. Golledge, M. Hemer, R.E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I.S. Nurhati, L. Ruiz, J.-B. Sallée, A.B.A. Slangen, and Y. Yu, 2021: Ocean, Cryosphere and Sea Level Change. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362, doi: 10.1017/9781009157896.011.
- Hooijer, A., Vernimmen, R. Global LiDAR land elevation data reveal greatest sea-level rise vulnerability in the tropics. *Nat Commun* **12**, 3592 (2021). https://doi.org/10.1038/s41467-021-23810-9
- van Westen and Dijkstra, *Sci. Adv.* 2021; **7** : eabf1674
- Williams, K., and 28 Coauthors, 2018: The Met Office Global Coupled model 3.0 and 3.1 (GC3.0 & GC3.1) configurations. JAMES, 10(2) 357-380. https://doi.org/10.1002/2017MS001115
- Kuhlbrodt, T., Jones, C. G., Sellar, A., Storkey, D., Blockley, E., Stringer, M., et al. (2018). The low-resolution version of HadGEM3 GC3.1: Development and evaluation for global climate. Journal of Advances in Modeling Earth Systems, 10, 2865–2888. https://doi.org/10.1029/2018MS001370.
- Llovel, W., Penduff, T., Meyssignac, B.,Molines, J.-M., Terray, L., Bessières, L., &Barnier, B. (2018). Contributions ofatmospheric forcing and chaotic oceanvariability to regional sea level trendsover 1993–2015.Geophysical ResearchLetters,45, 13,405–13,413. https://doi.org/10.1029/2018GL080838
- Llovel W. *et al* 2022 *Environ. Res. Lett.* **17** 044063. https://doi.org/10.1088/1748-9326/ac5f93
- Menary, M. B., Kuhlbrodt, T., Ridley, J., Andrews, M. B., Dimdore-Miles, O. B., Deshayes, J., et al. (2018). Preindustrial control simulations with HadGEM3-GC3.1 for CMIP6. Journal of Advances in Modeling Earth Systems, 10, 3049–3075. https://doi.org/10.1029/2018MS001495.
- Roberts, M. J., Baker, A., Blockley, E. W., Calvert, D., Coward, A., Hewitt, H. T., Jackson, L. C., Kuhlbrodt, T., Mathiot, P., Roberts, C. D., Schiemann, R., Seddon, J., Vannière, B., and Vidale, P. L.: Description of the resolution hierarchy of the global coupled HadGEM3-GC3.1 model as used in CMIP6 HighResMIP experiments, Geosci. Model Dev., https://doi.org/10.5194/gmd-12-4999-2019, 2019.
- WCRP Global Sea Level Budget Group: Global sea-level budget 1993–present, Earth Syst. Sci. Data, 10, 1551–1590, https://doi.org/10.5194/essd-10-1551-2018, 2018.