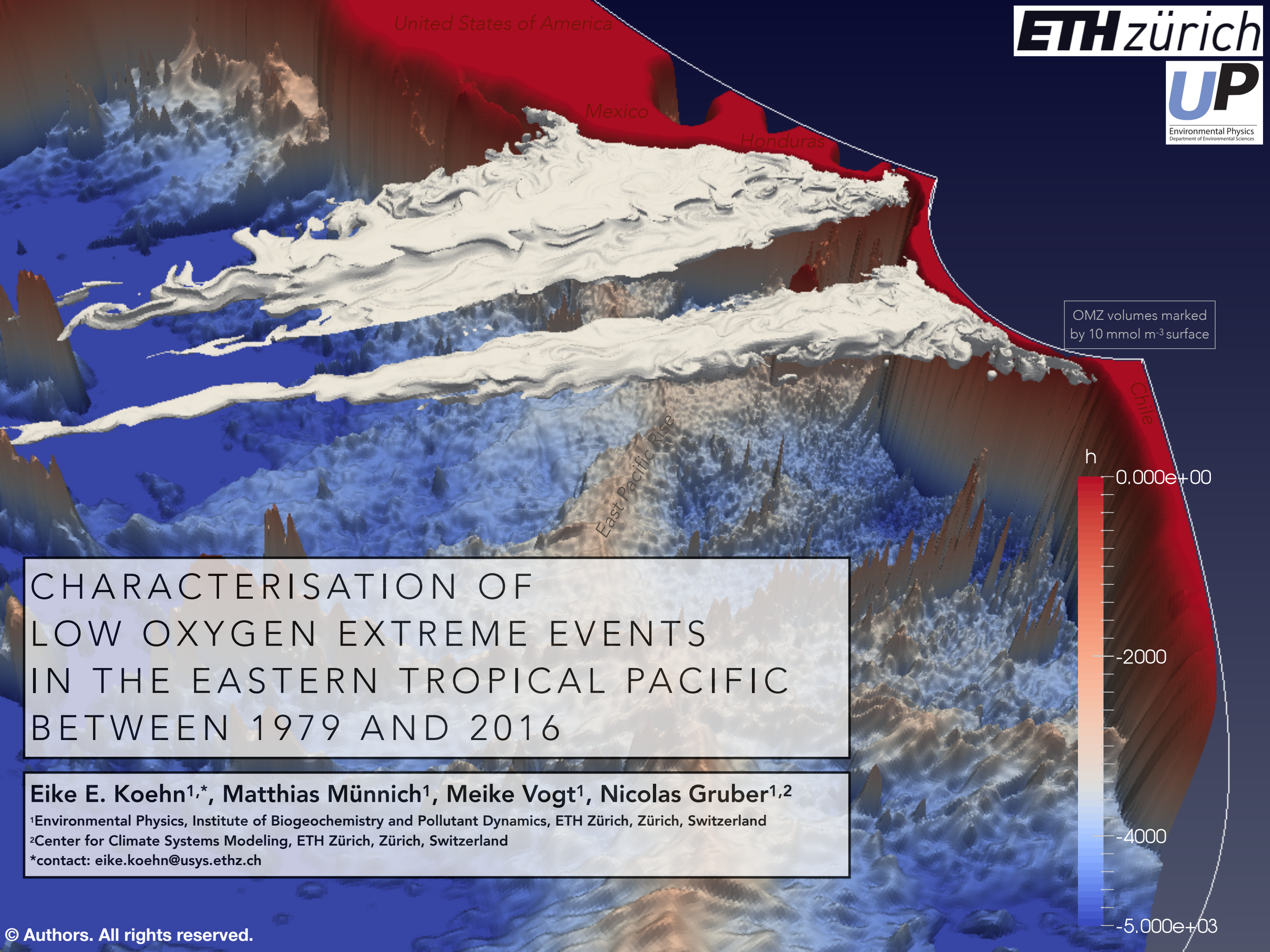

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CHARACTERISATION OF LOW OXYGEN EXTREME EVENTS IN THE EASTERN TROPICAL PACIFIC BETWEEN 1979 AND 2016

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- The subsurface oxygen minimum zones compress the vertical habitat of many marine heterotrophs[1,2]
- The oxygen-based potential habitat of large marine predators, such as tuna, is projected to decrease by the end of the century under the RCP8.5 scenario[3]
- Extreme transient shoaling events of the upper boundary of the oxygen minimum zones can lead to drastic habitat compression events much earlier

Research Questions

- When and where is the shoaling of the Eastern Pacific Oxygen Minimum Zones most extreme?
- What are the characteristics of such extreme OMZ shoaling events?
- What are the drivers behind these extreme events?

1 **Stramma, L., Prince, E. D., Schmidtko, S., Luo, J., Hoolihan, J. P., Visbeck, M., Wallace, D. W. R., Brandt, P. & Körtzinger, A. (2012).** Expansion of oxygen minimum zones may reduce available habitat for tropical pelagic fishes. *Nature Climate Change*, *2*(1), 33-37.

2 **Prince, E. D. and Goodyear, C. P. (2006)**. Hypoxia-based habitat compression of tropical pelagic fishes. *Fisheries Oceanography, 15(6), 451-464.*

3 **Mislan, K. A. S., Deutsch, C. A., Brill, R. W., Dunne, J. P., Sarmiento, J. L. (2017)**. Projections of climate-driven changes in tuna vertical habitat based species-specific differences in blood oxygen affinity. *Global Change Biology, 23, 4019-4028*

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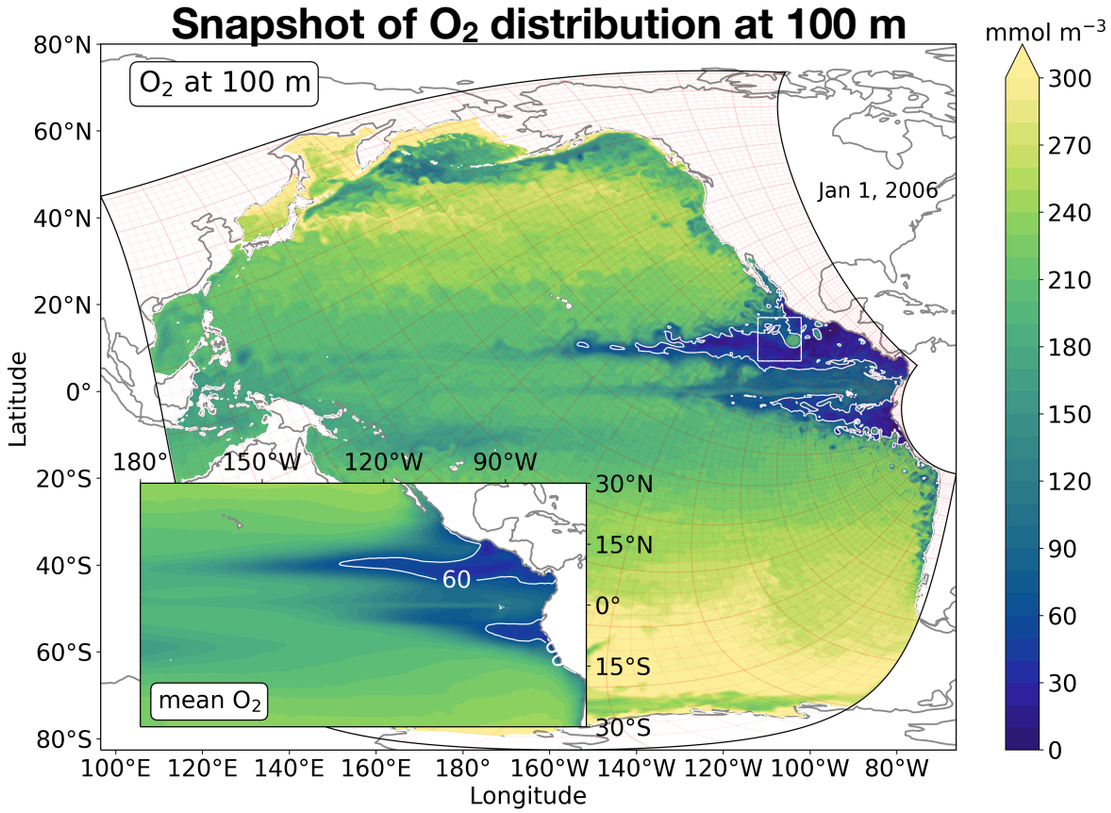
Model hindcast (1979-2016) using ROMS-BEC

- UCLA-ETH version of **R**egional **O**ceanic **M**odeling **S**ystem[1] (ROMS) coupled to the **b**iological **e**lemental **c**ycling (BEC) model[2]
- telescopic model grid with pole over South America
  -> horizontal resolution increases gradually towards the Peruvian coast (~4 km off Peru, ~40 km off Japan)
- forced with ERA-Interim atmospheric reanalysis[3] and increasing atmospheric pCO_2 (from 1979 to 2016)
- 20 years spin-up from WOA2013 data (10 years of pure physics and 10 years of coupled physics-biogeochemistry)
- daily output for 38 years from 1979-2016



1 **Shchepetkin, A. F. & McWilliams, J. C. (2005)** The regional oceanic modelling system (ROMS):
A split-explicit, free-surface, topography-following-coordinate oceanic model. *Ocean Model.*, 9(4), 347-404
2 **Moore, J. K., Lindsay, K., Doney, S. C., Long, M. C. & Misumi, K. (2013)** Marine ecosystem dynamics and biogeochemical cycling in the Community Earth System Model [CESM1(BGC)]:
Comparison of the 1990s with the 2090s under RCP4.5 and RCP8.5 Scenarios, *J. Clim.*, 26(23), 9291-9312
3 **Dee, D. P. et al. (2011)** The ERA-Interim reanalysis: Configuration and performance of the data assimilation system, *Q. J. R. Meteorol. Soc.*, 137(656)

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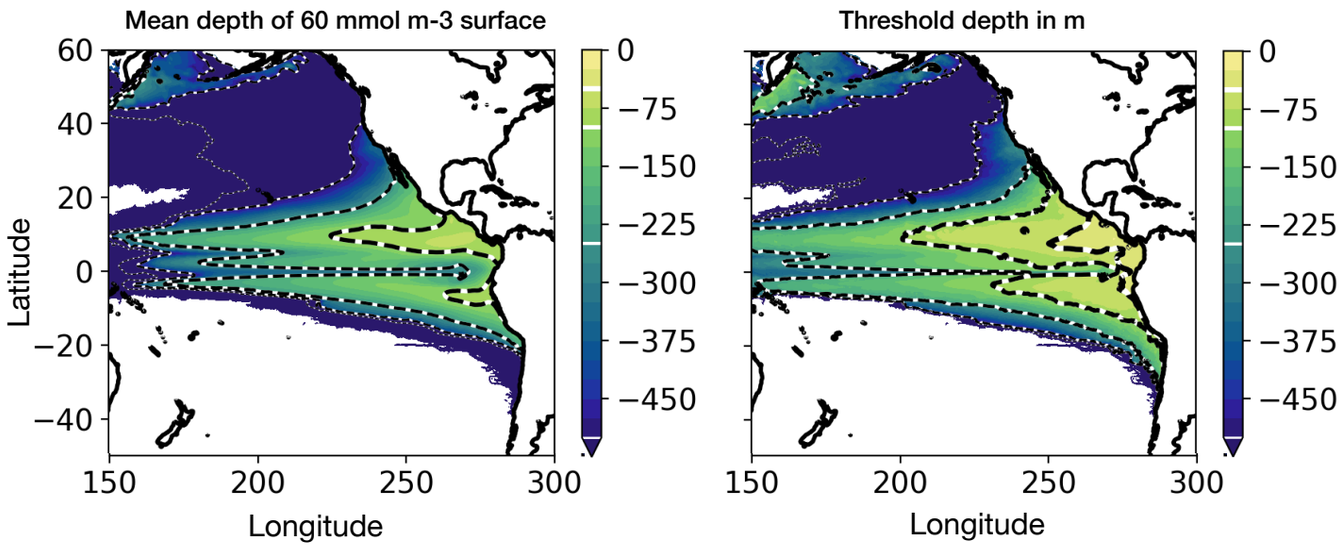
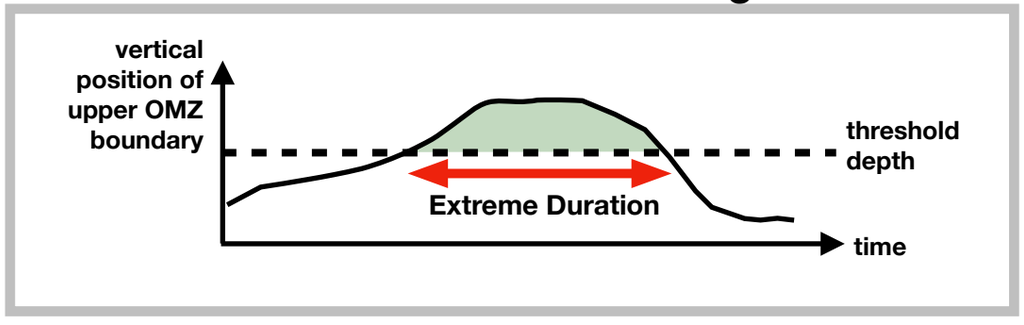
Detection of extreme shoaling events of the upper OMZ boundary

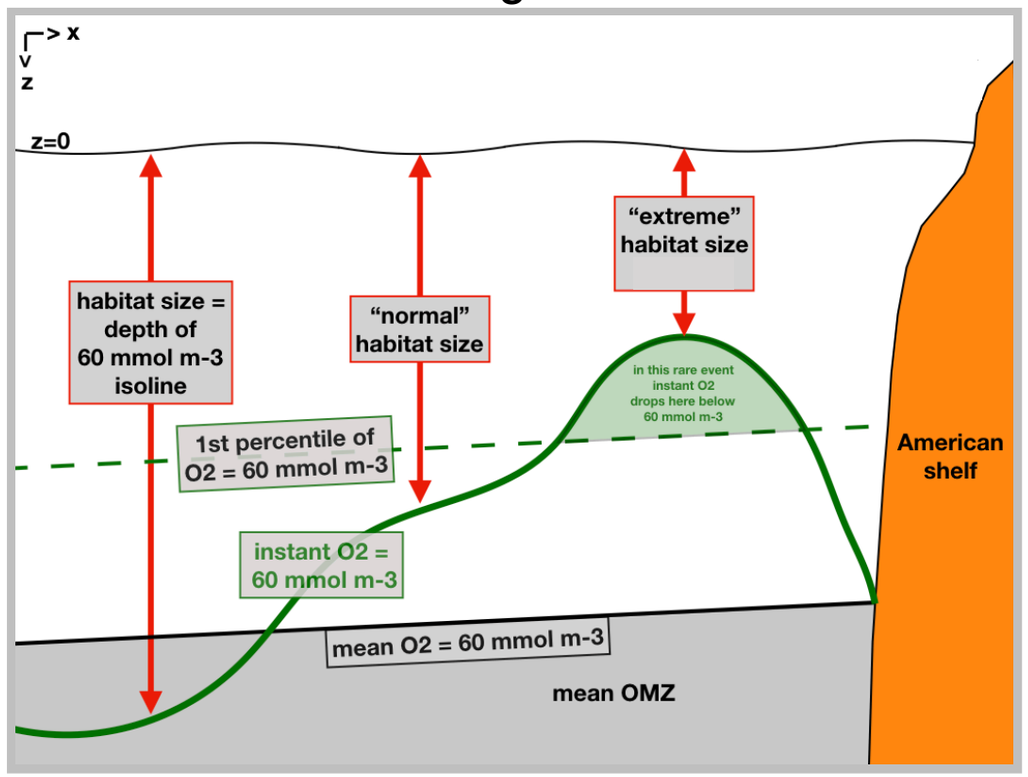
- consider oxygen levels of 60 mmol m^{-3} to define upper OMZ boundary (also called “oxycline” hereafter)
- define the threshold depth as the depth where the 1st percentile of local oxygen distributions (1979-2016) equals 60 mmol m-3
- take Eulerian perspective and identify extremes as periods, where the local, instantaneous 60 mmol m^{-3} oxygen surface shoals above the threshold depth
- stipulate a minimum duration of 5 days for extreme shoaling events. Shorter events will be discarded.



Definition of extreme shoaling events



Spatial conceptualisation of extreme shoaling events



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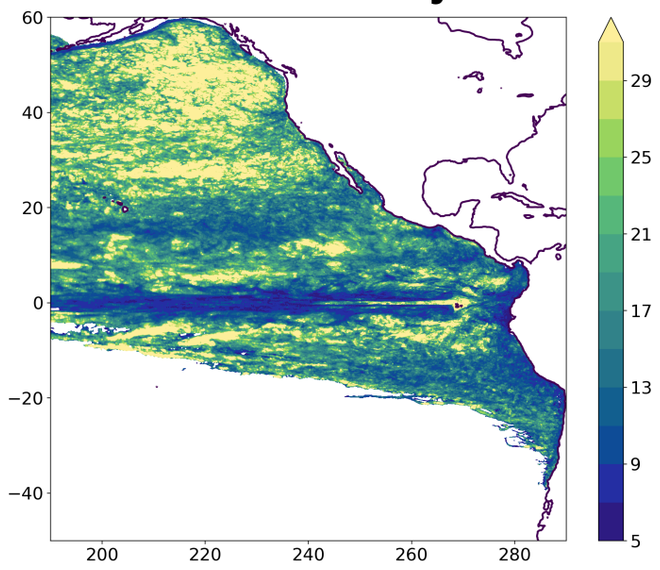
Characteristics of extreme shoaling events (for 60 mmol m^{-3} surface)

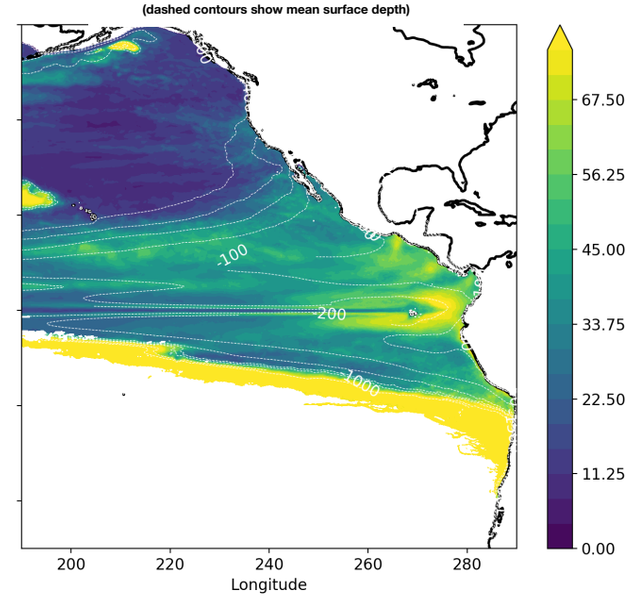
- many short extreme events in the Humboldt current system and the subtropical North Pacific
- bands of fewer, but rather long-lasting (>20 days) extremes between 5°-10°N and 5°-10°S
- locally, the 60 mmol m^{-3} surface can shoal during extreme events by more than 60% compared to the mean (e.g. southeast of Hawaii, in the Peruvian upwelling region, Gulf of Tehuantepec/ Papagayo
- within ~20°N/S the extreme oxycline shoaling events are associated with a shoaling of the thermocline/pycnocline bringing less oxygenated and more acidic water closer to the surface

Average extreme duration in days



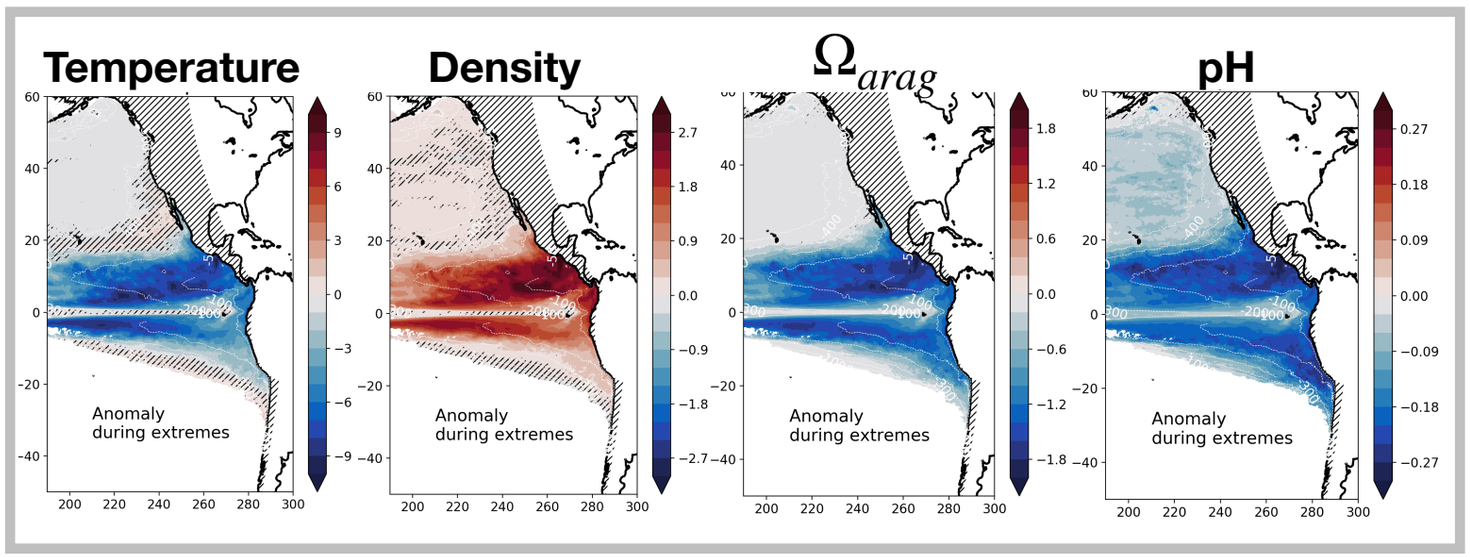
Average extreme intensity (% over mean depth)

(dashed contours show mean surface depth)



Composite anomalies at the threshold depth (extreme conditions minus mean conditions over hindcast)

hatched areas indicate where the standard deviation of anomalies across extreme events exceeds the mean anomaly



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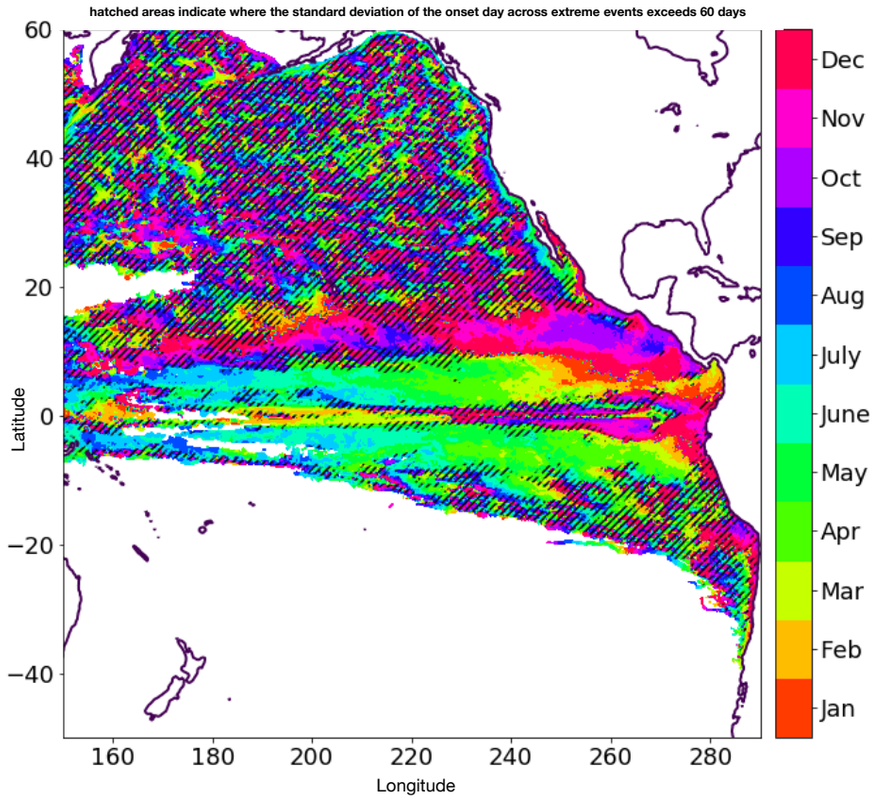
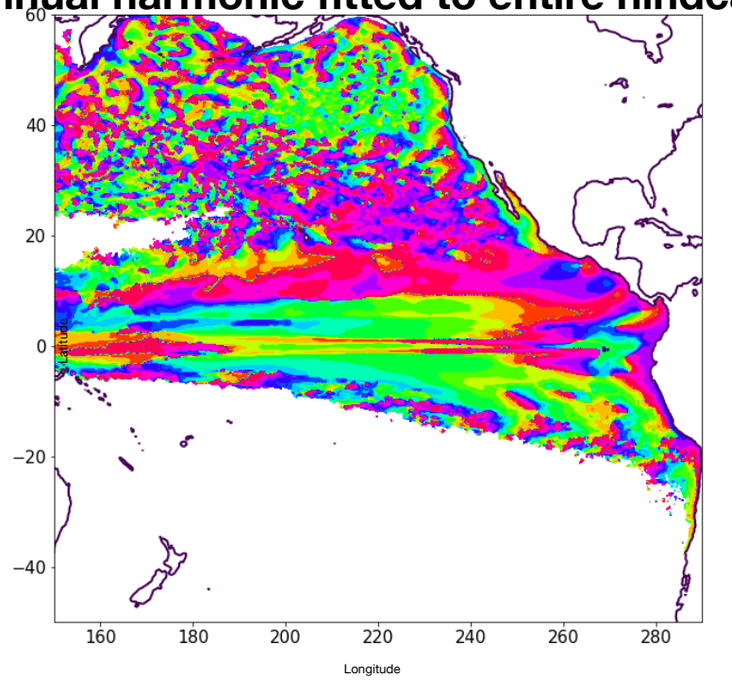
Seasonal cycle of the oxycline depth sets timing of extreme shoaling events

- between ~10°S and ~15°N and along almost the entire American coast extreme shoaling events tend to occur during phases of the climatologically shallowest oxycline
- around the Equator, the seasonal cycle is marked by the westward propagation of annual Rossby waves
- at 10°-15°N typical extreme event onset coincides with the seasonally shallowest oxycline/thermocline around October/November associated with wind stress curl and Rossby wave dynamics
- off-equatorial extreme events exhibit a westward phase propagation beginning at the coast around June (NH) and December (SH). Offshore, the phase coherence breaks down hinting towards mesoscale eddy driven extreme shoaling events

Average day of year @ extreme onset



Phase of shallowest oxycline depth of annual harmonic fitted to entire hindcast



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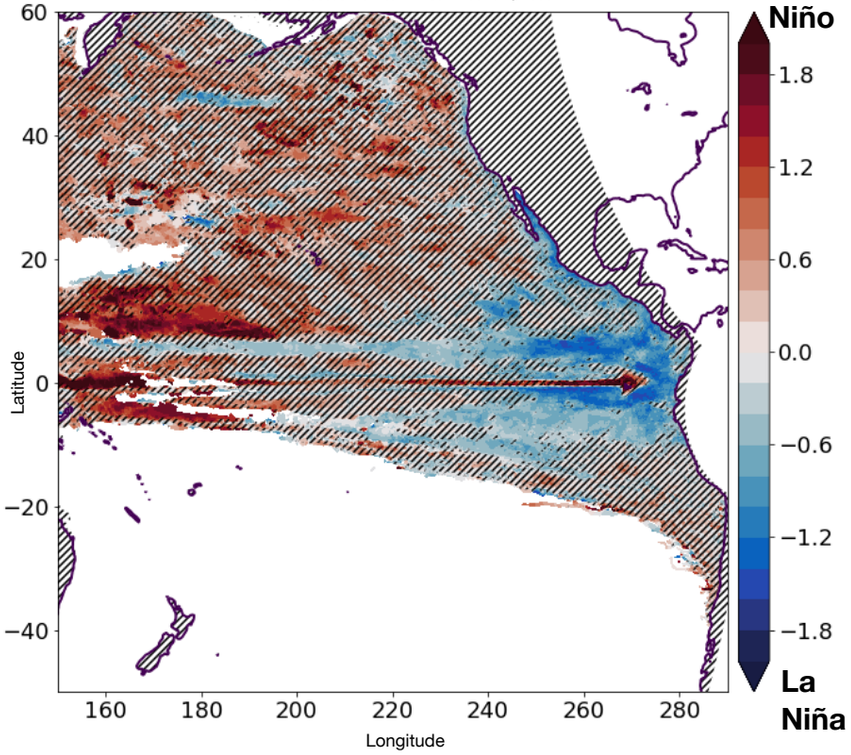
La Niña conditions precondition the Eastern Pacific for extreme shoaling events

- around the Eastern Pacific Equator and along the central American coast, extreme shoaling events occur predominantly during La Niña

Average Nino3.4 index @ extreme onset

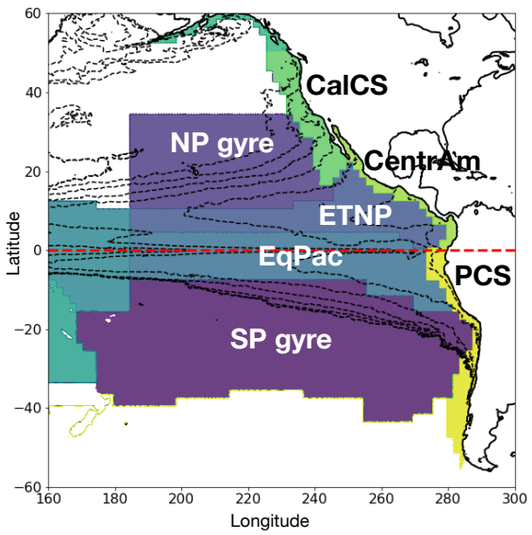
hatched areas indicate where the standard deviation of the onset Nino3.4 index across extreme events exceeds the mean Niño3.4 index amplitude



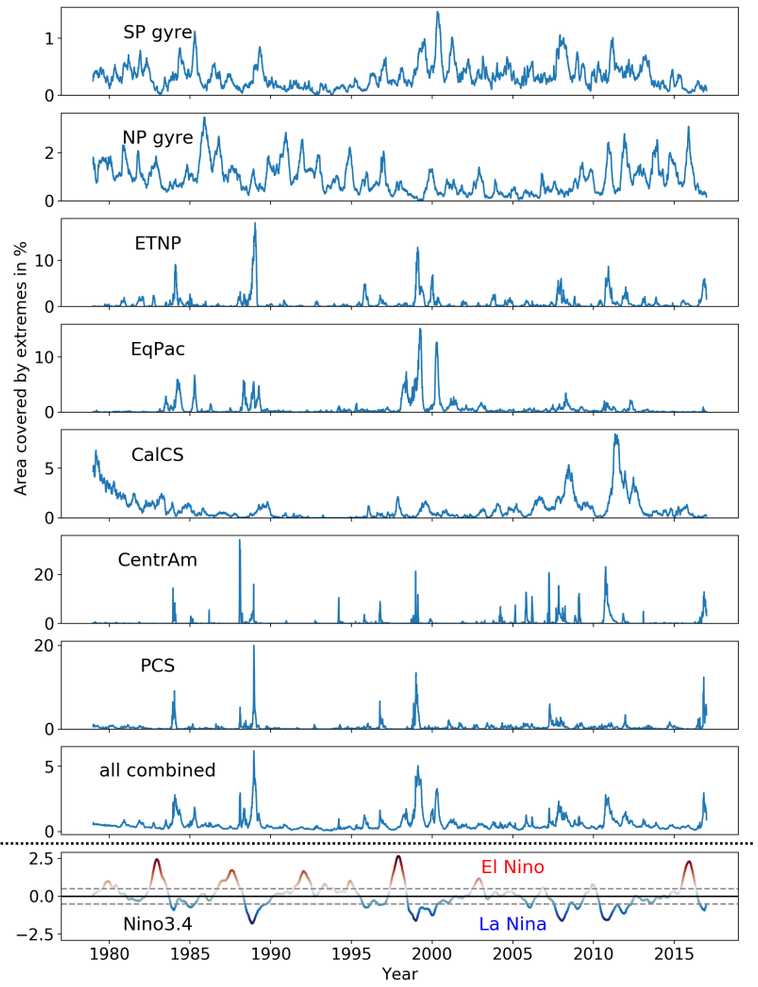
- up to 20-30% of the central American coast experience extremely shallow oxycline conditions during La Niña periods

- despite the well documented sensitivity of the vertical OMZ position off the Peruvian coast to ENSO, extreme shoaling events show no preferred ENSO state south of ~10°S

- large oxycline displacements associated with mesoscale eddies dominate instead in the Humboldt and California Current system



Time series of regionalised[1] extreme event coverages



1 **Longhurst, A. R. (2010)** Ecological geography of the sea. Elsevier.

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Summary

- using a hindcast ROMS-BEC model simulation from 1979 to 2016 we identify extreme shoaling events of upper Eastern Pacific Oxygen Minimum zone defined by the 60 mmol m^{-3} oxygen concentration surface
- between 10°S and 15°N the superposition of the seasonal cycle and ENSO dynamics lead to the predominant occurrence of extreme shoaling events during La Niña conditions.
- these extreme oxycline shoaling events are associated with heaving of the thermocline/ pycnocline
- poleward of 10°S/15°N the extreme shoaling events show no clear relation to ENSO and are rather dominated by mesoscale dynamics