Lamont-Doherty Earth Observatory
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The Pinatubo Gulp: Immediate and long-lasting impacts on ocean oxygen and carbon

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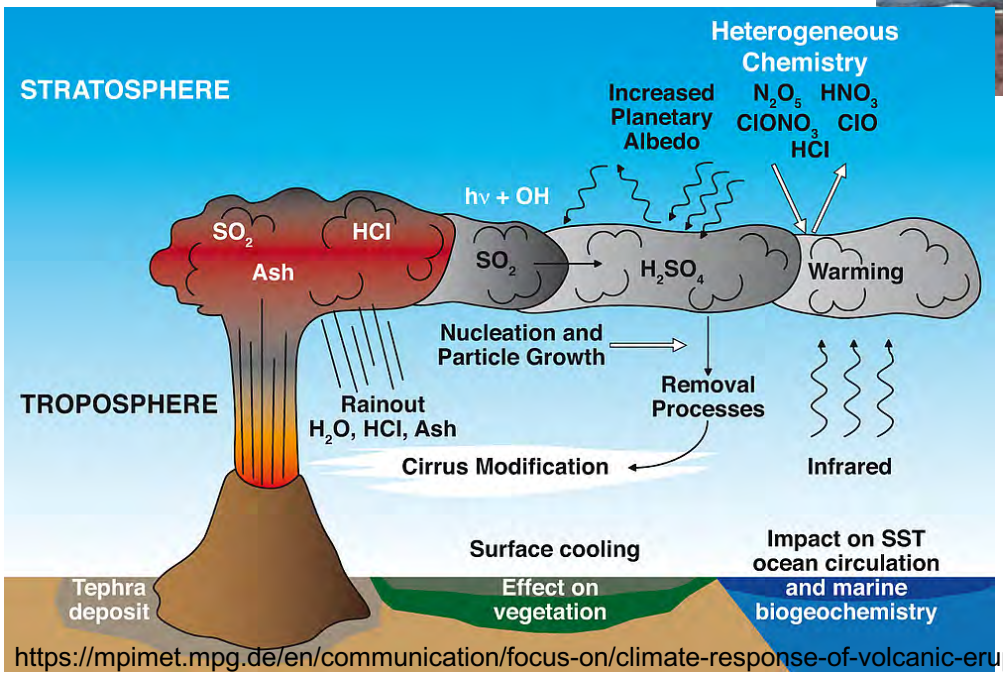
Mount Pinatubo

Volcanic eruptions affect climate in two main ways:

1. Warming the atmosphere through release of carbon dioxide
2. The cloud of ash, dust, and SO_2 enters the stratosphere. These aerosols reflect sunlight and encourage cloud formation, and have a cooling effect

By Dave Harlow, USGS - CVO Photo Archives - Pinatubo, Philippines, https://commons.wikimedia.org/w/index.php?curid=545011



https://mpimet.mpg.de/en/communication/focus-on/climate-response-of-volcanic-eruptions

This cooling effect outweighs the warming contribution from carbon dioxide, causing an overall cooling that tends to lasts for about two years after a major eruption.

Model Design

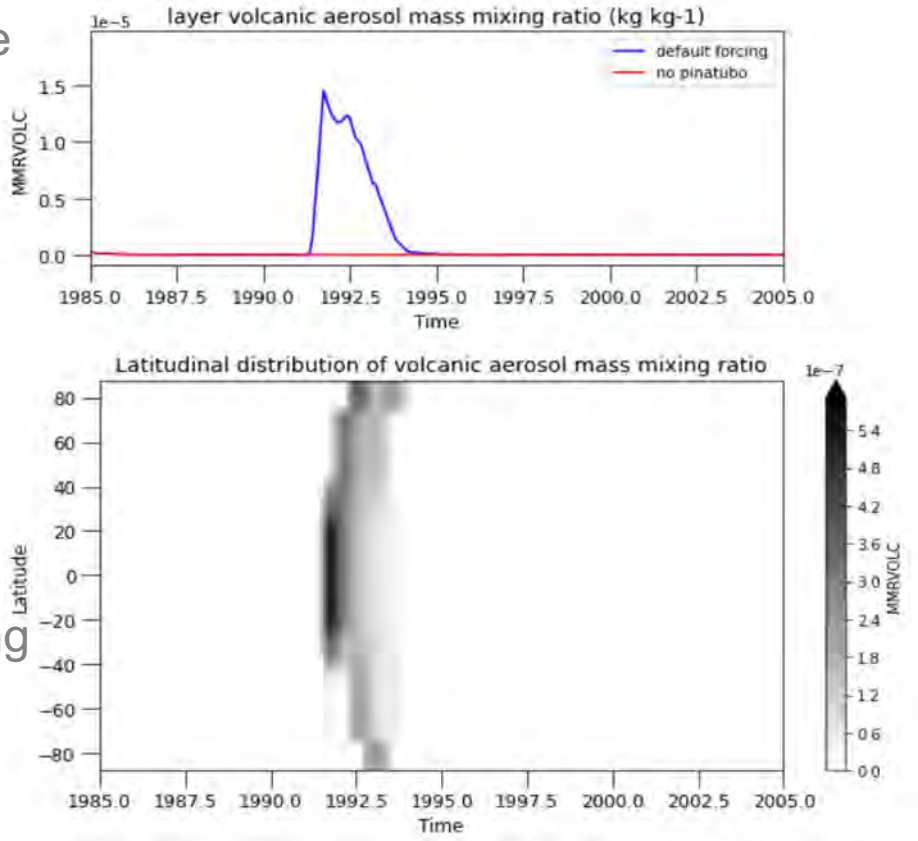
CESM1-Large Ensemble [Kay et al. 2015]
Historical / RCP8.5 Simulations
CAM5 atmosphere model and POP2 ocean model

CESM-LE

- Re-run for years 1990-2025 for 29 ensemble members
- Because of a transition to a new supercomputer (Yellowstone -> Cheyenne) we found that the computer and compiler change caused differences that were non-trivial for our comparison

CESM1-LE, No Pinatubo Experiment

- CESM-LENS, 29 ensemble members, run with 1991-1995 volcanic aerosol mass mixing ratio replaced with 1986-1990 values to simulate non-eruption conditions.

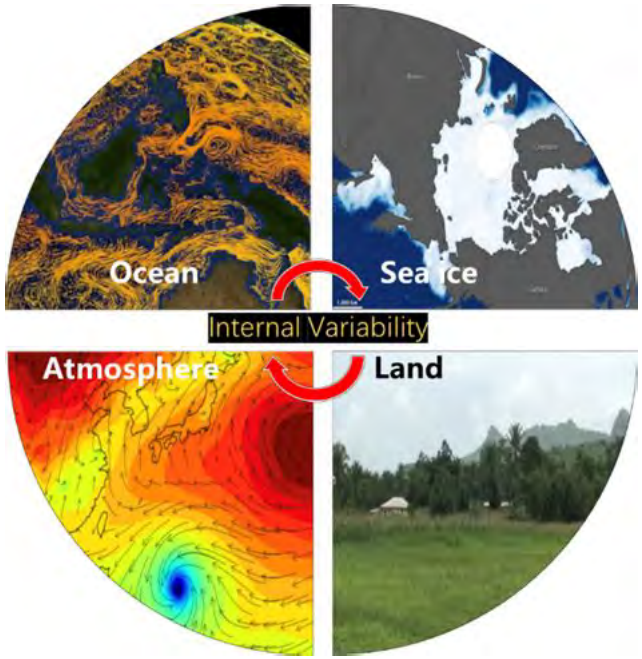


Model Design

CESM1-Large Ensemble [Kay et al. 2015]
Historical / RCP8.5 Simulations
CAM5 atmosphere model and POP2 ocean model

CESM-LE

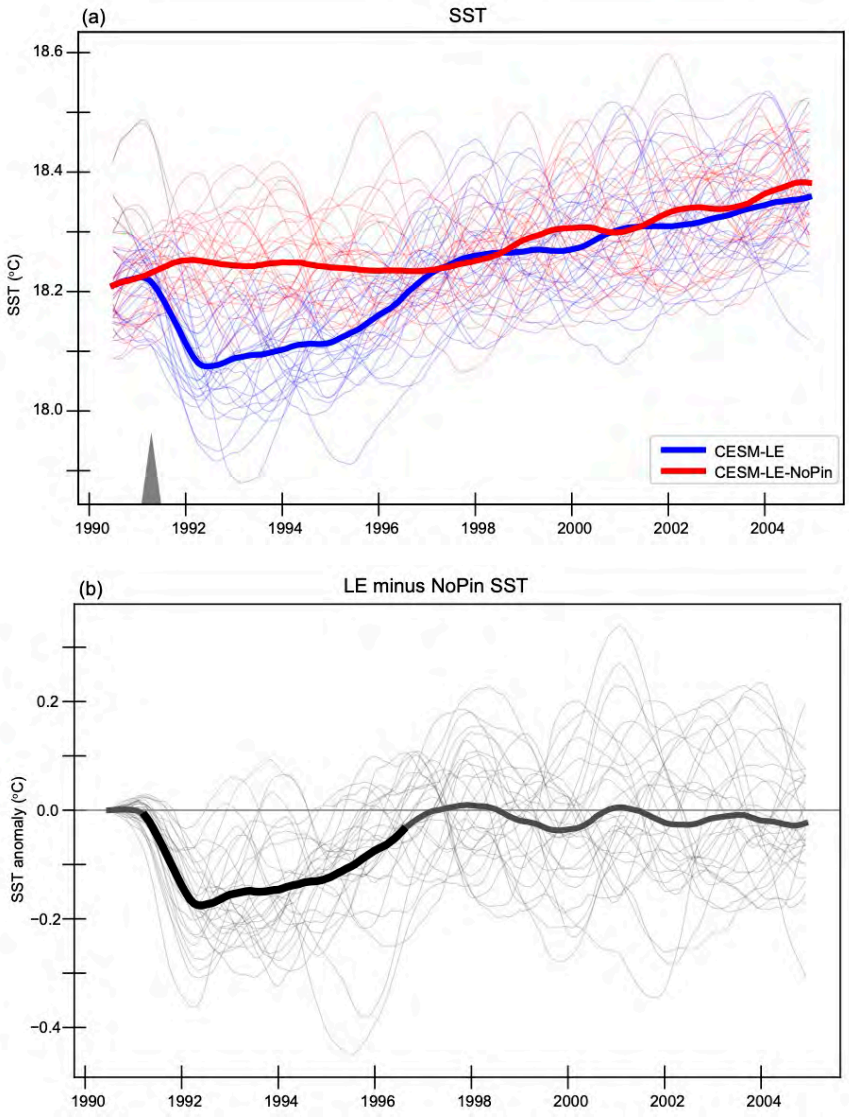
- Ensemble of 29 members were run on Cheyenne for years 1990-2025 in the exact same model set up as the original CESM1-LENS. Preliminary analysis on impacts from the compiler/computer change were on the scale of what we see within members of a large ensemble.
- We are focused on BGC results here, but model output is saved on campaign storage for all variables at 6-hourly, daily, and monthly resolution. One exception is that we omitted a handful of variables from the monthly CAM output to stay within our disk quota.



Results

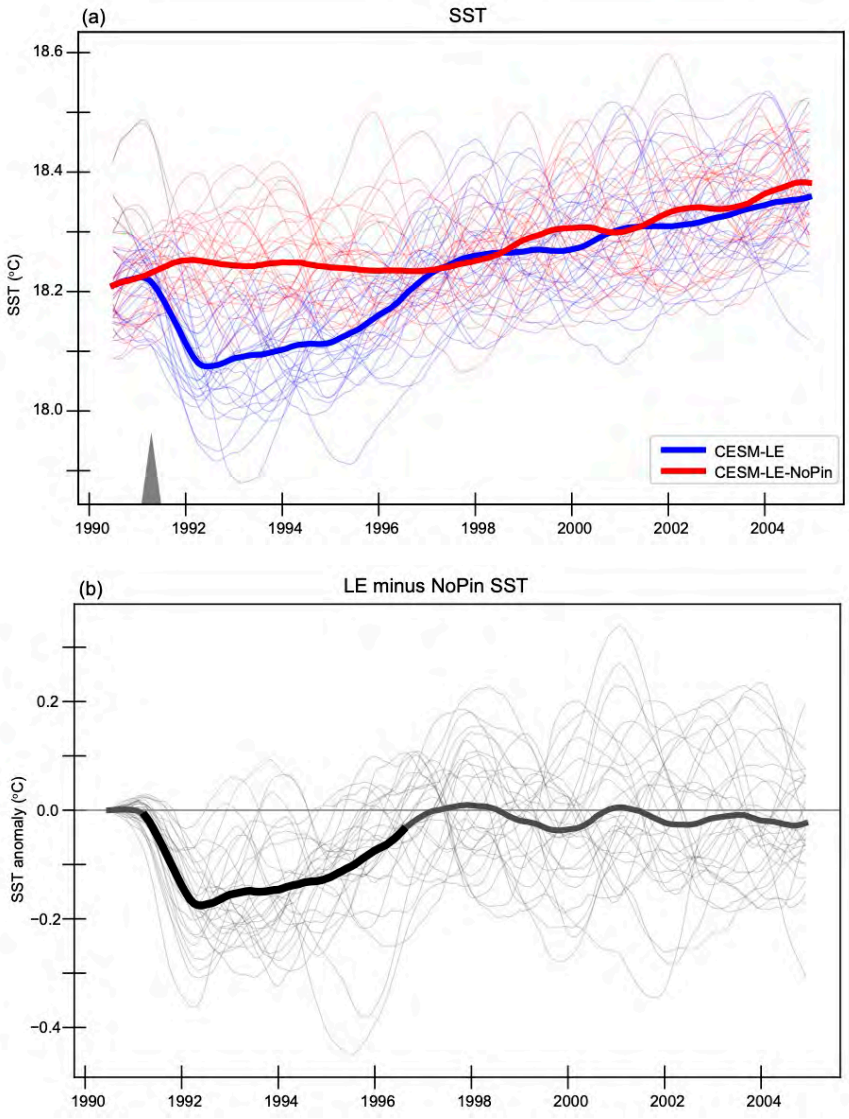
- Two initial-condition large ensembles are used to quantify the ocean physical and biogeochemical response to the 1991 eruption of Mt. Pinatubo for the period 1990-2025.
- The physical state and surface fluxes respond quickly post-eruption, while changes in the interior are long-lasting.
- Oxygen is immediately injected into the upper ocean and then transits to depth where it permanently increases the interior inventory by 60 Tmol.
- The global ocean carbon sink increases by 0.29 ± 0.14 PgC yr^{-1} in 1992, a magnitude consistent with observations

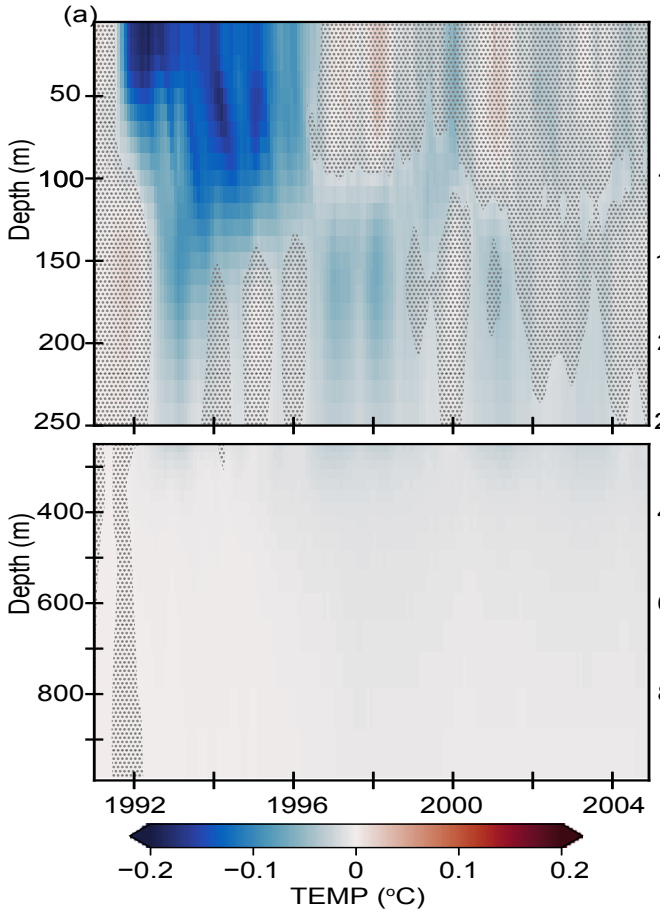
Physical response to Pinatubo



- Global SST declines by 0.2°C in 1992 in the forced signal and surface cooling persists for 5 years post eruption in the ensemble mean.
- The ensembles are statistically different through 1996, showing a significant forced cooling due to the eruption.

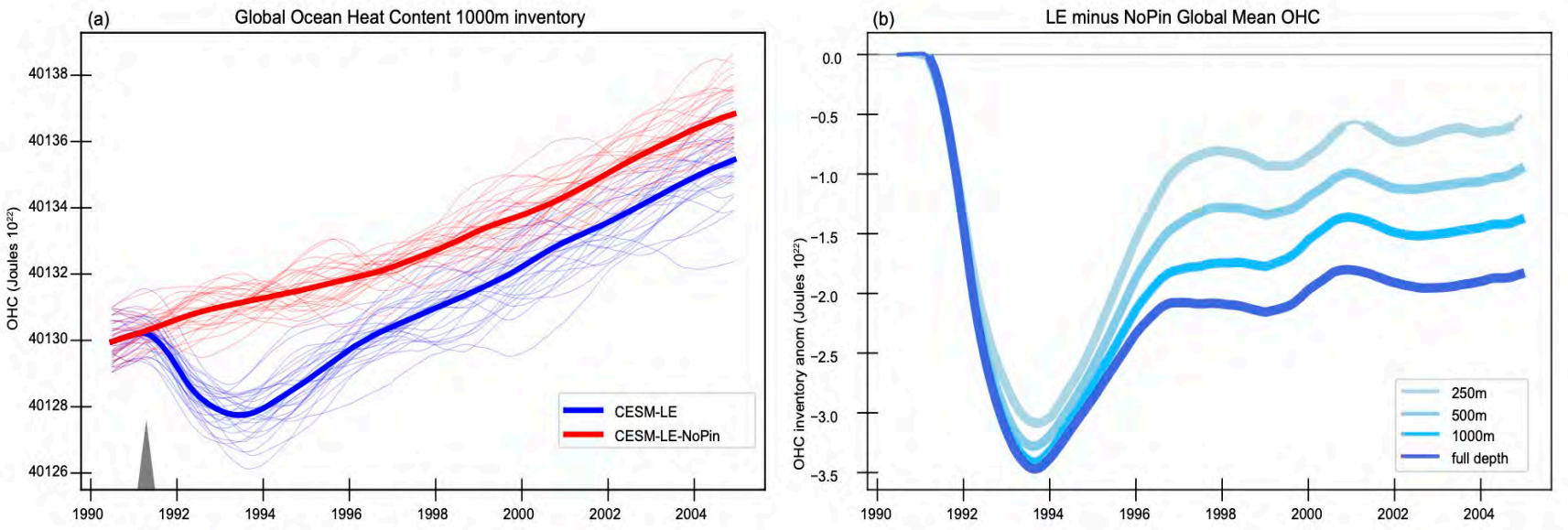
Physical response to Pinatubo





Cooling is concentrated in the top layers of the ocean immediately following the eruption, but the anomaly slowly spreads to deeper depths.

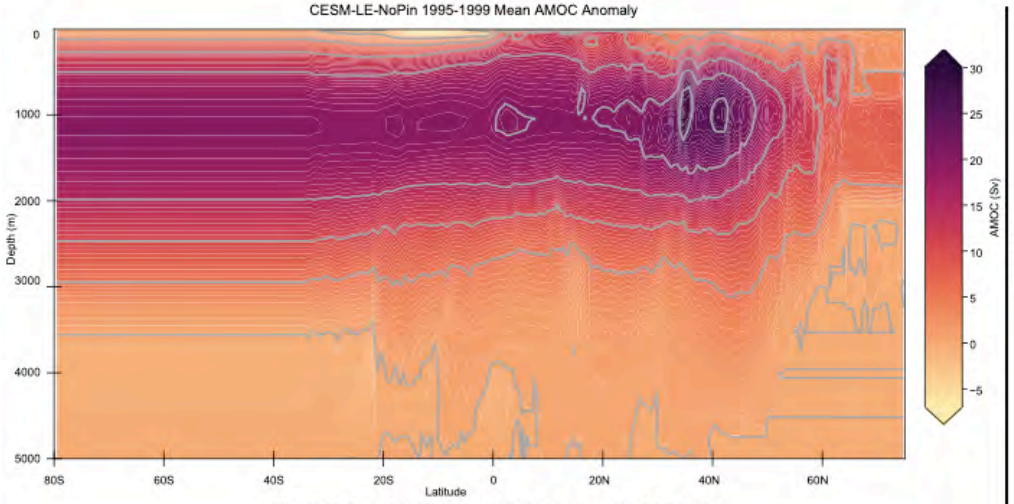
Physical response to Pinatubo

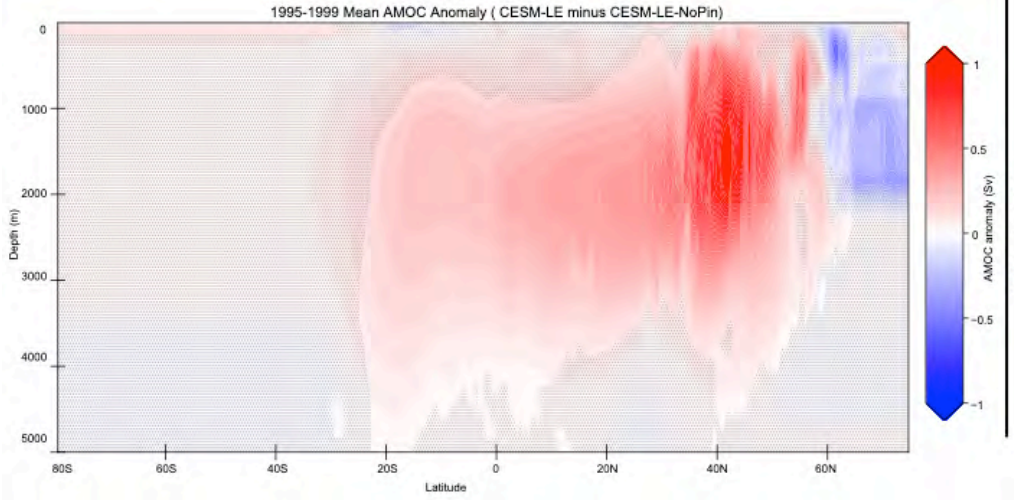


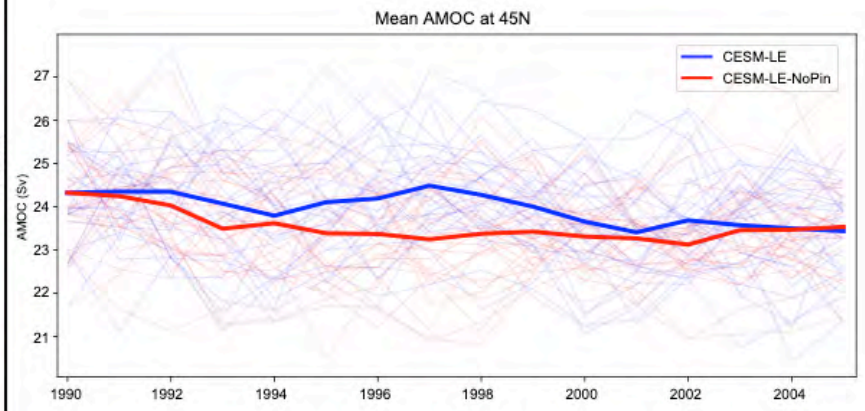
- Ocean heat content is significantly reduced in response to the eruption of Pinatubo
- Below 1000m, the eruption permanently reduces the interior heat content, with an ensemble mean reduction of 2 x 10^{22} Joules which persists through the end of the model run in 2025.

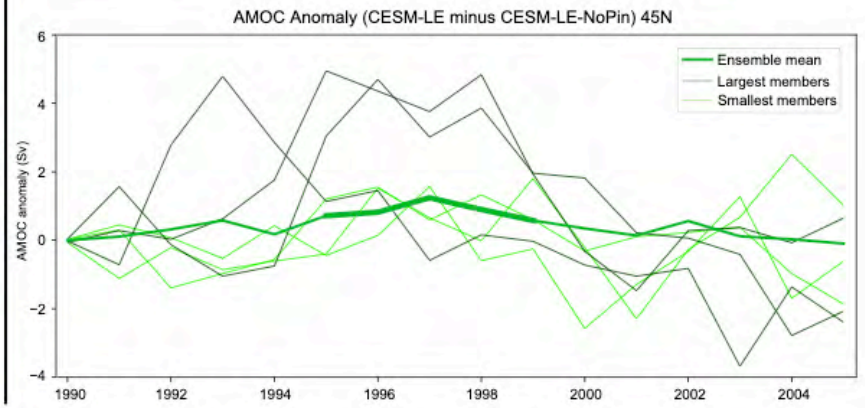
So much more to look at!

AMOC

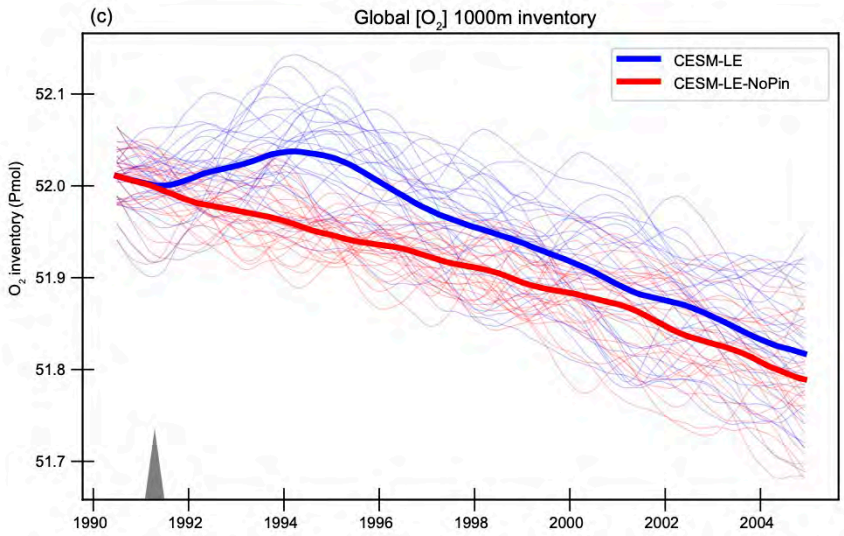


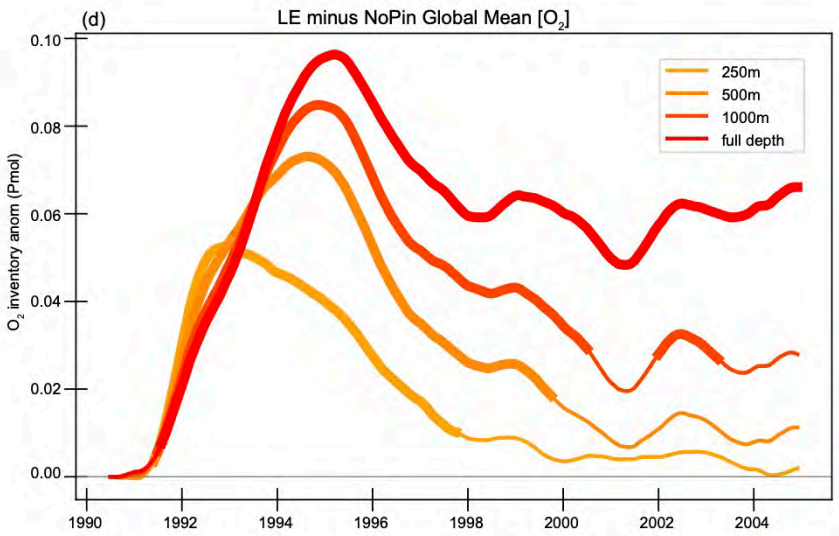


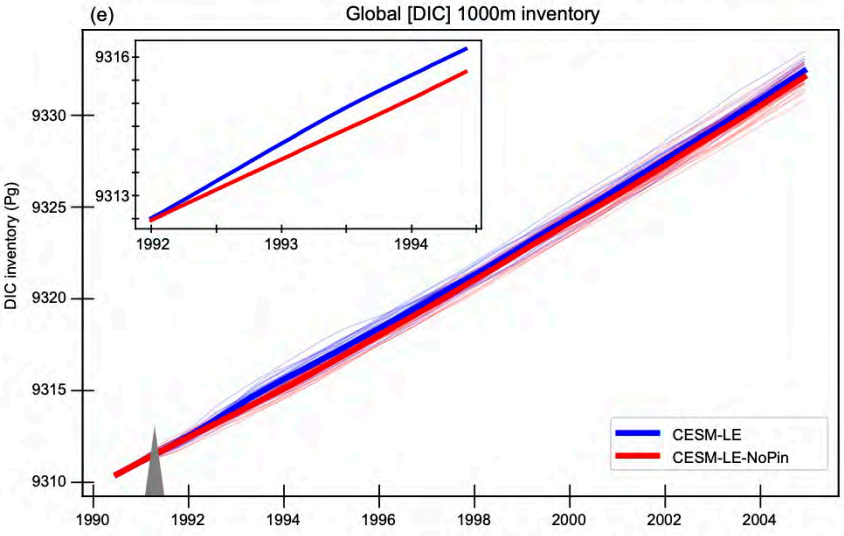


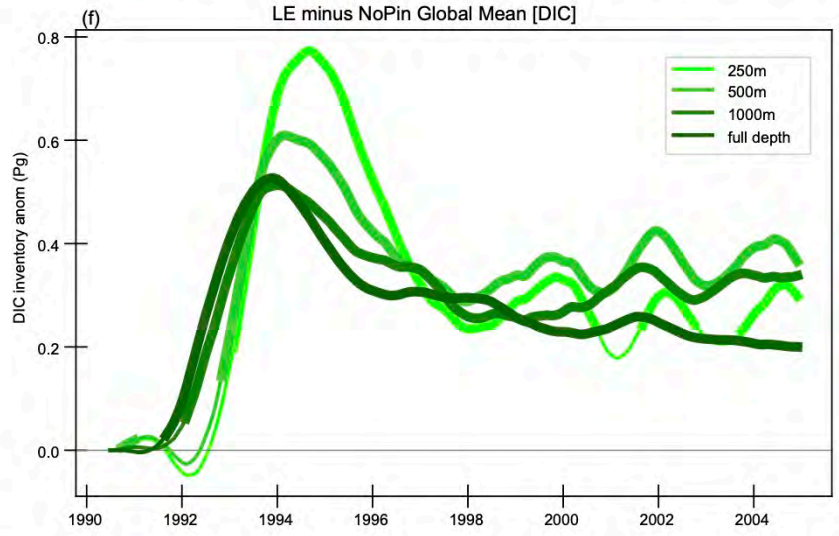


Biogeochemical response to Pinatubo



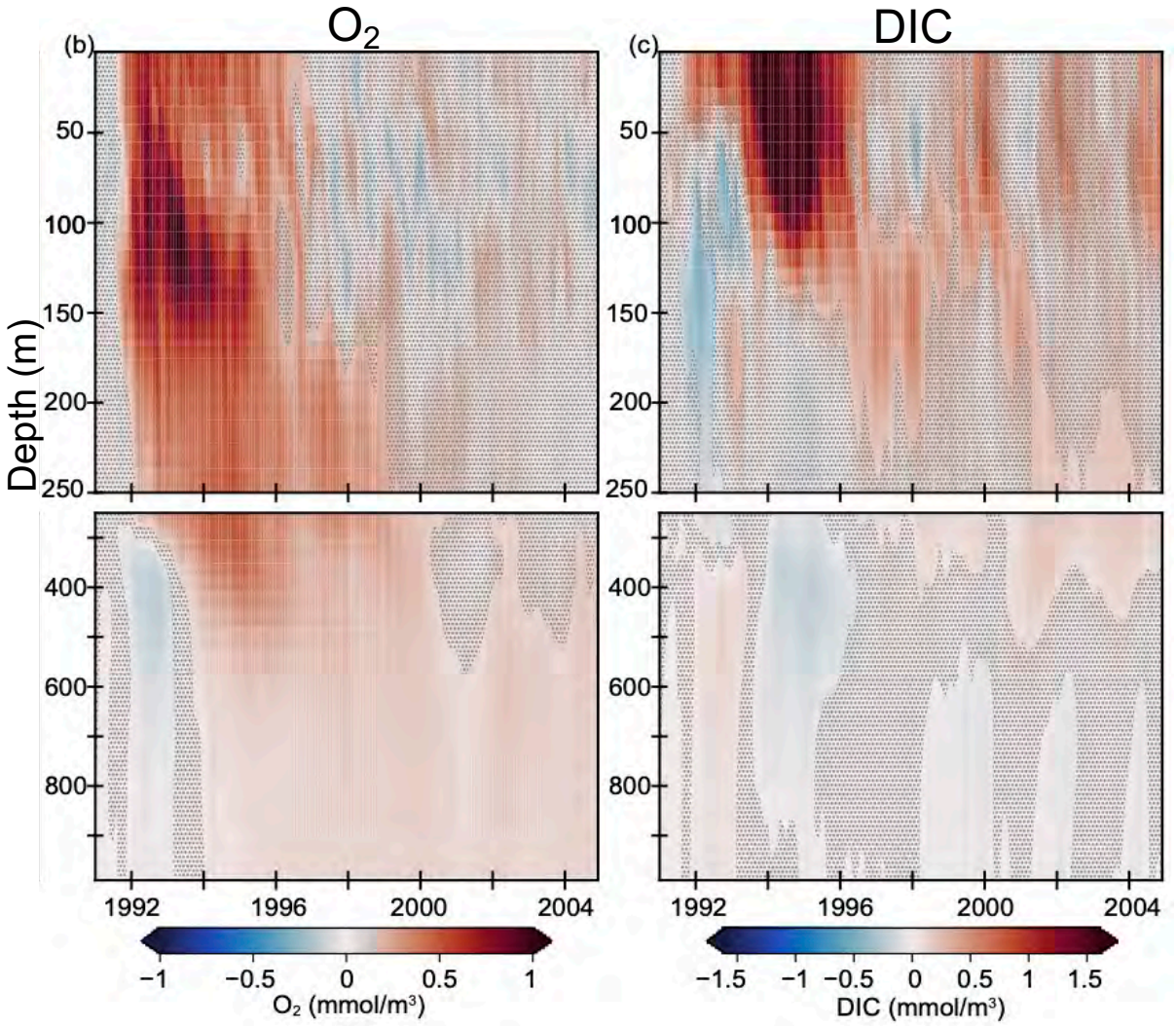






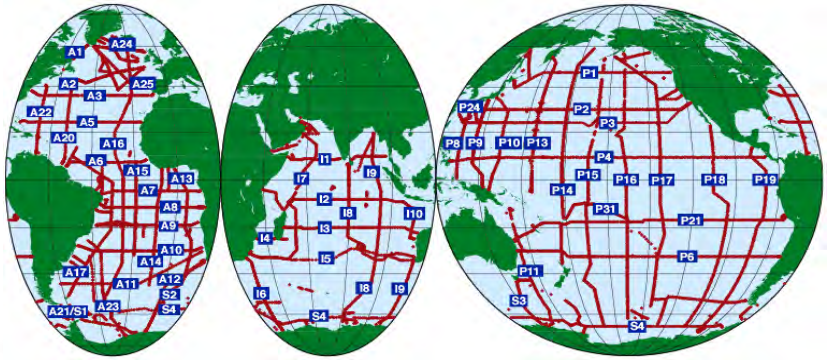
Biogeochemical response to Pinatubo

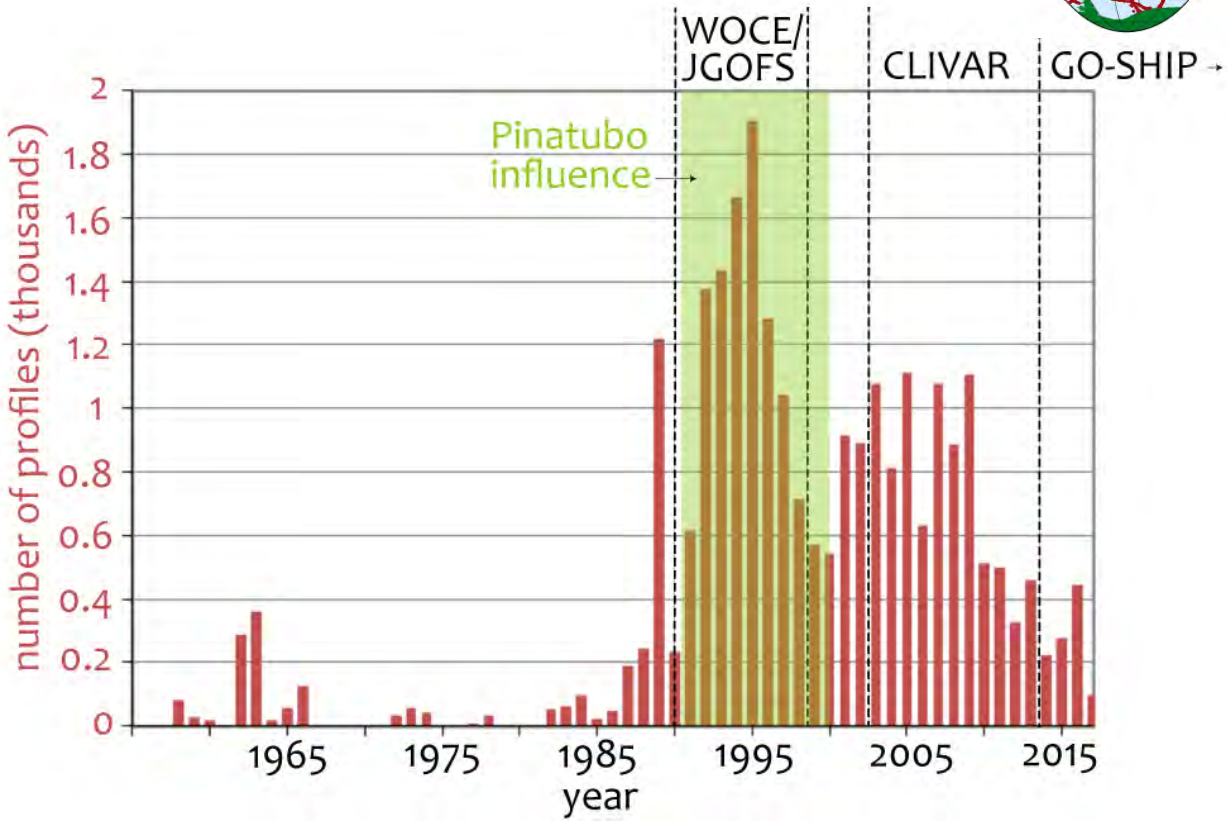
CESM-LE minus CESM-LE-NoPin anomalies



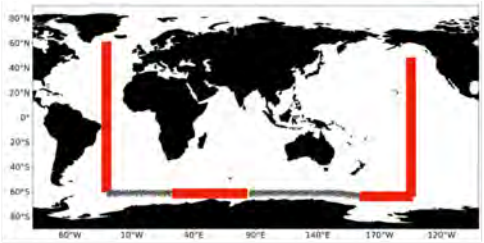
- Increased oxygen with a quick response time and forced signal that penetrates down to 1000m by 1994.
- Global mean increase in DIC emerges in the upper 150m of the ocean during years 1994-1997

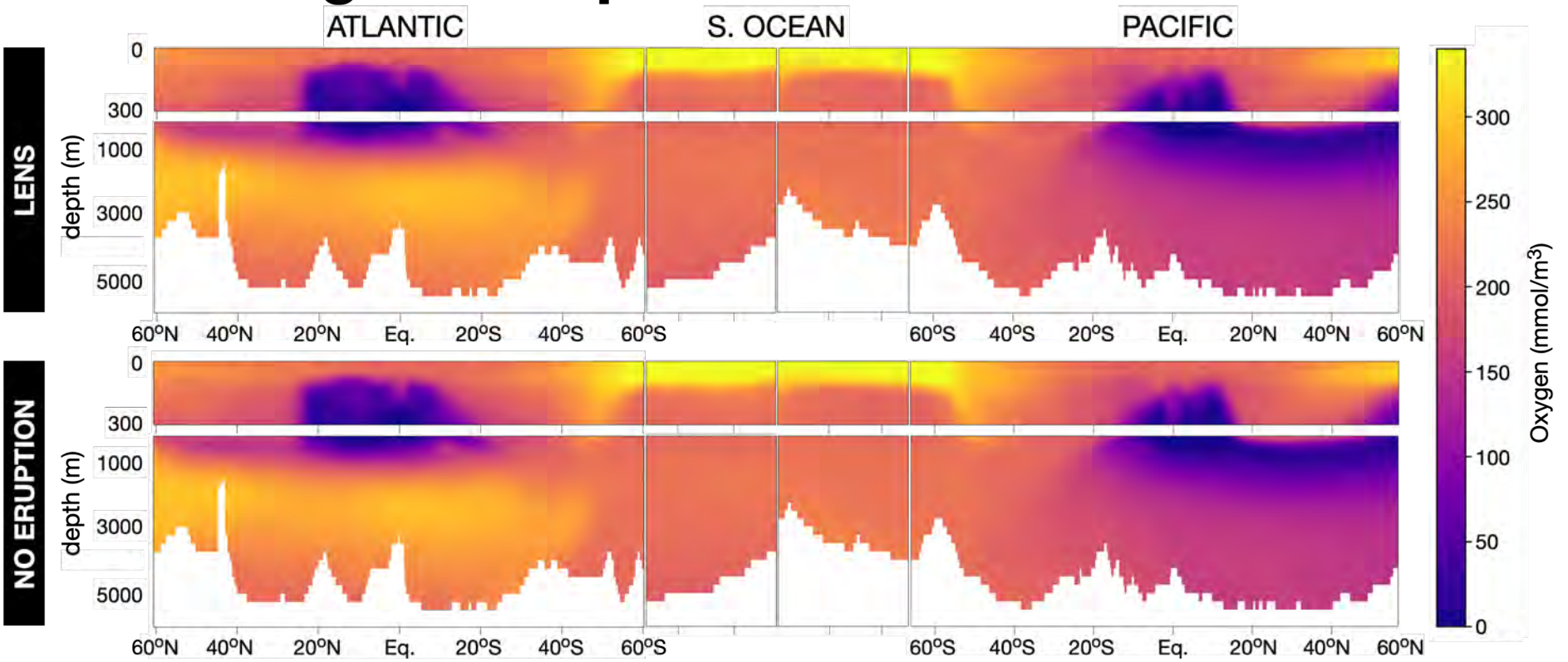
Ocean transect observations in a No Pinatubo world



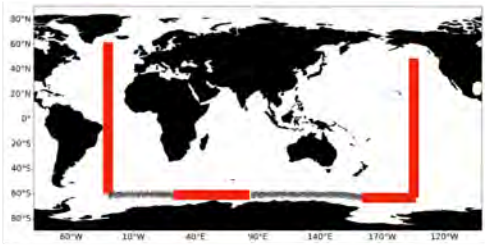


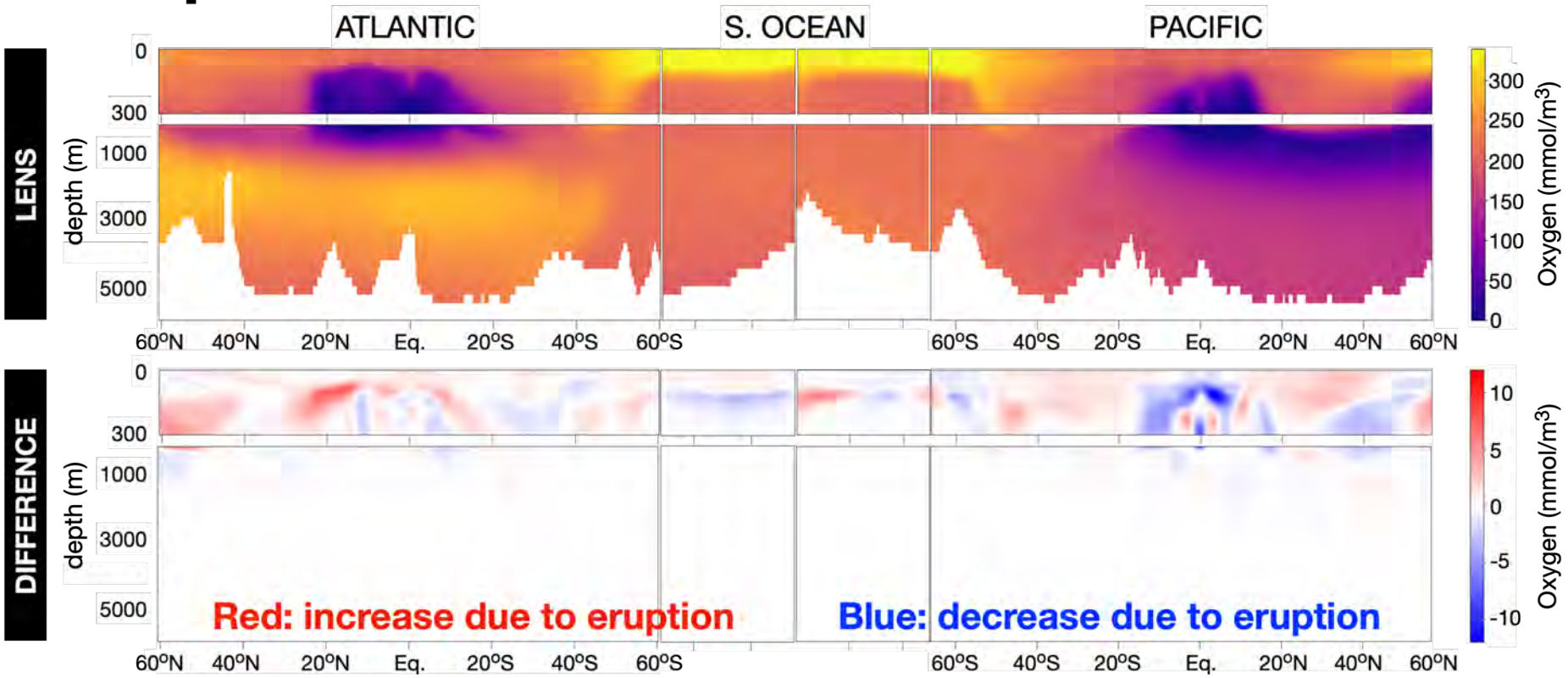
Oxygen in the second year following the eruption



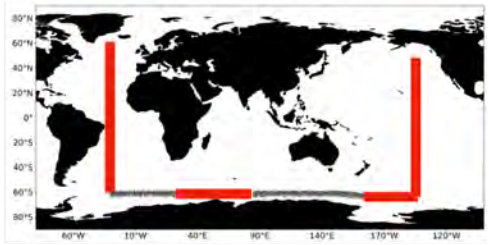


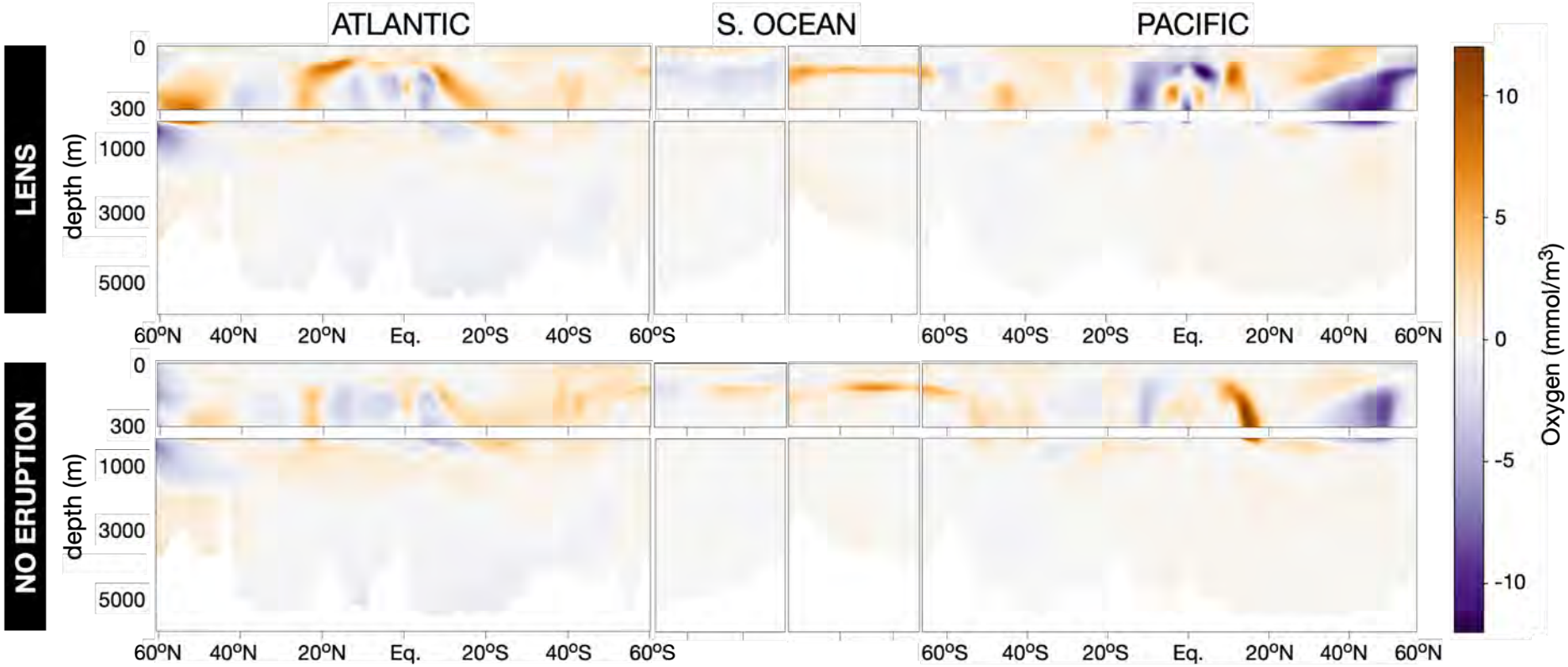
Oxygen: second year following the eruption





Total change in oxygen 7/1993 - 6/2003





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If you are interested in analyzing these experiments, (and we hope you are!) please contact Matt Long (mclong@ucar.edu)

