Model constraints on the anthropogenic carbon budget of the Arctic Ocean

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Introduction

Background: The Arctic Ocean is one of the most vulnerable regions to ocean acidification, but only one study[1] has addressed how much anthropogenic carbon (C_{ant}) is stored in the Arctic Ocean.

Objectives:

- Simulate C_{ant} in a global ocean model with sufficient resolution to properly assess the Arctic C_{ant} budget and understand the mechanisms controlling it.
- Quantify the influence of model resolution on the Cant budget
- Quantify the change in acidification due to changes in Cant

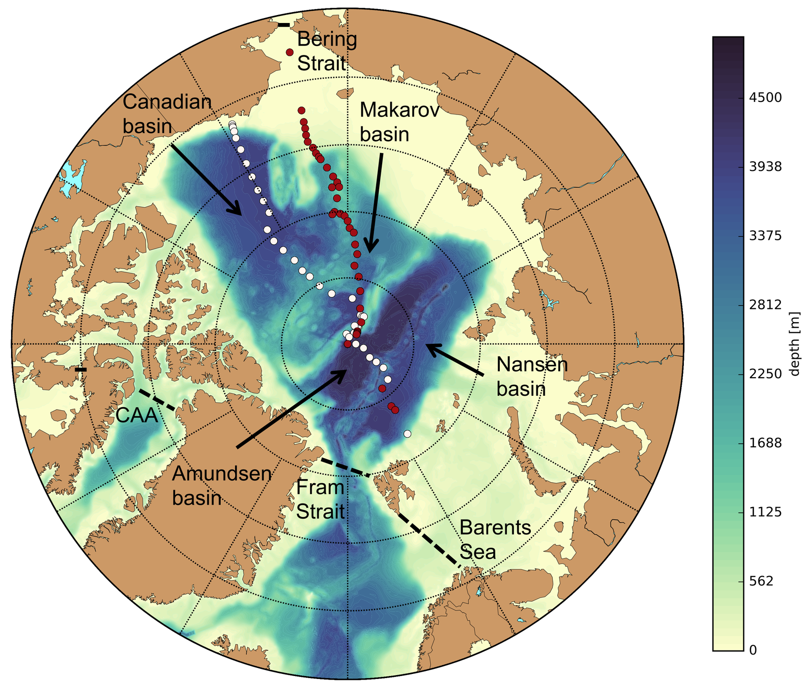


Fig 1: CFC-12 stations occupied during the AOS94 (red) and Beringia 2005 expedition (white). The filled-color scheme indicates the bathymetry of the Arctic Ocean, while the four dashed lines show the boundaries used in this study.

[1]Tanhua, T. et al. Ventilation of the Arctic Ocean: mean ages and inventories of anthropogenic CO2 and CFC-11. J. Geophys. Res. 114, doi:10.1029/2008JC004868 (2009)

Methods

We use the ocean carbon cycle model NEMO-PISCES and perform simulations over 1870-2012. We use the ORCA configuration at three different nominal resolutions (2°, 0.5° and 0.25°) and 46 depth level, which range from 6 m at the surface to 250 m at the bottom of the ocean. The model fields were initialized with data for DIC, ALK and nutrients and, with results from a 3000 years spin-up for Fe and DOC. From 1870 to 1958, control and historical simulations were made with ORCA05 (0.5°) model. That simulation was continued until 2010, while ORCA2 (2°) and ORCA025 (0.25°) were initialized with output from ORCA05 in 1958. All versions of these models were forced with the same atmospheric reanalysis (DRAKKAR Forcing Set): winds, humidity, temperature, radiation, and water fluxes. The anthropogenic component is the difference between the historical and control simulation. As our simulations are starting in 1870, and not at the beginning of the anthropogenic perturbation in 1765, we underestimate the amount of anthropogenic carbon. While it is not year clear, which difference that makes for the Arctic Ocean, Bronselaer et al. (2017) showed that CMIP5 simulations starting in 1850 (instead of 1765) underestimate Cant by around 25%.

Conclusions

1) The air-sea CO_2 flux contributes at most 25% of total C_{ant} input in Arctic Ocean
2) Simulated Cant storage (inventory) is 2.3 Pg C in 2005, a lower limited based on model-data CFC-12 comparison
3) Ocean Acidification Saturation Horizon shoaling increases with resolution from 50 m to 210 m

1 C_{ant} inventory increases with resolution

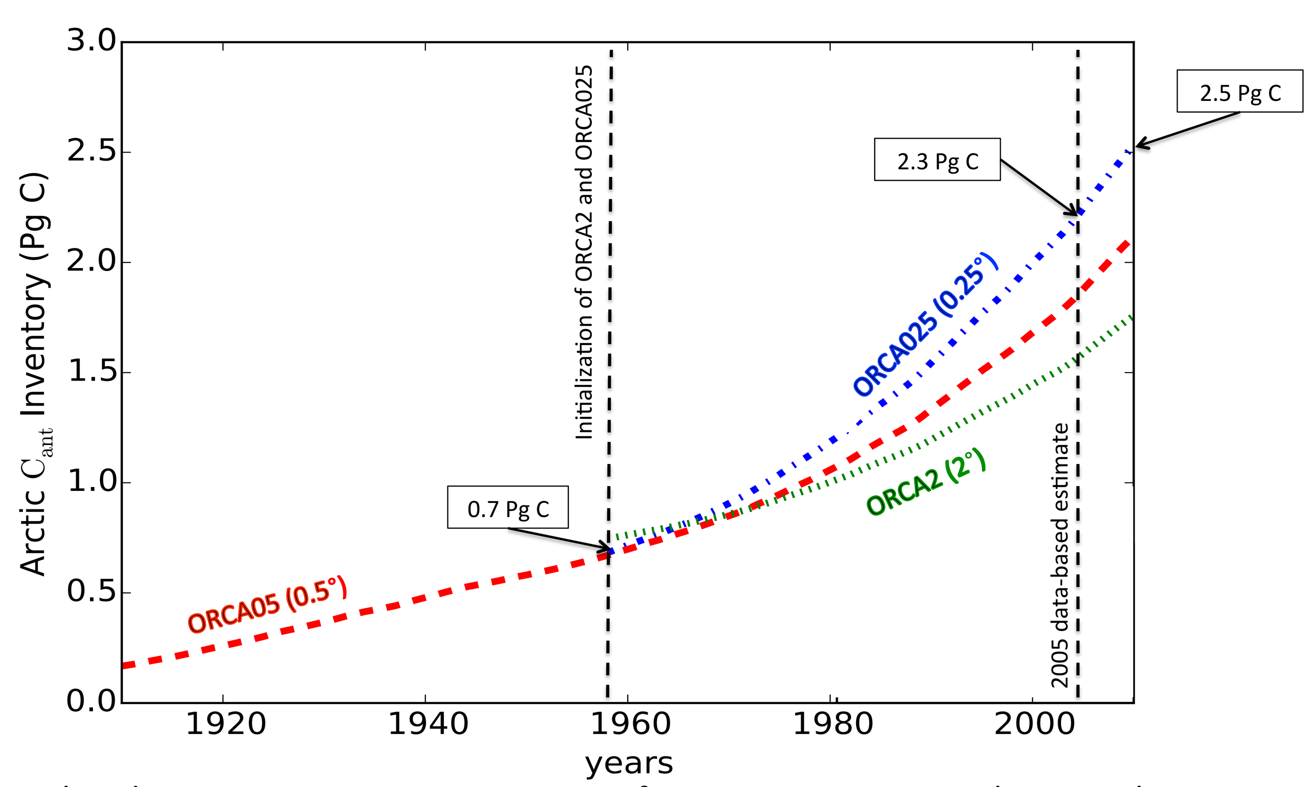


Fig 2: Simulated Arctic Ocean C_{ant} inventory from 1870-2010. Until 1958 the intermediate resolution model (ORCA05) was used. Between 1958 and 2010 three different resolutions, high (ORCA025), intermediate (ORCA05) and low (ORCA2) were used. The vertical line indicates the point of comparison to data (2005).

2 C_{ant} storage and flux increase with resolution

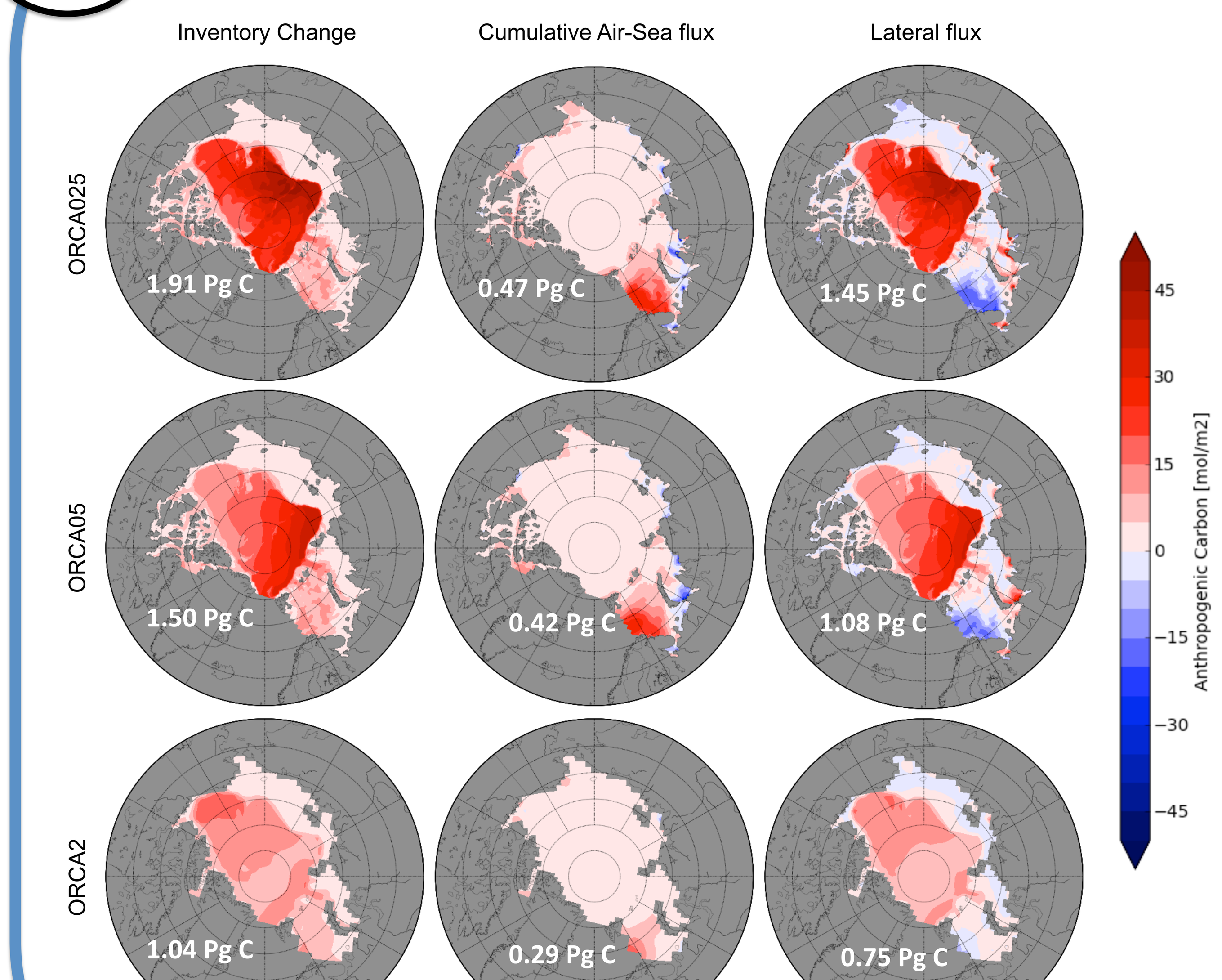
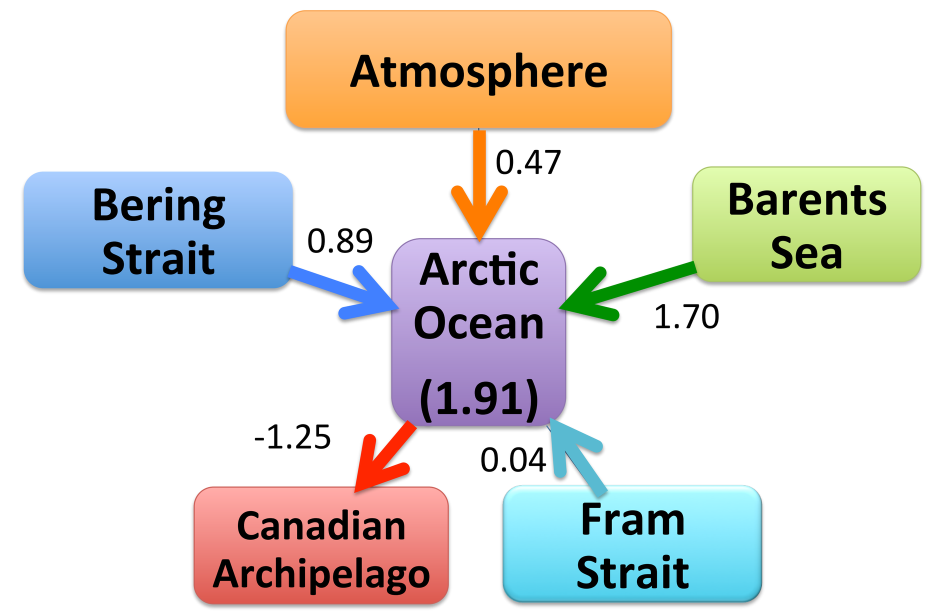


Fig 4: The 1960-2012 change in C_{ant} inventory (left), the corresponding cumulative air-sea flux (center), and their difference (the lateral flux) (right). For the cumulative flux, positive values indicate a flux into the ocean. For the lateral flux, red indicates inflow of C_{ant} and blue outflow. Results are shown for ORCA025 (top), ORCA05 (middle) and ORCA2 (bottom).

- ➢ Increased resolution (2° to 0.25°) doubles C_{ant} inventory change
- ➢ Both the lateral flux and the air-sea flux increase with resolution

3 Lateral transport of C_{ant} dominates



- ➢ 75% of input from lateral fluxes
- ➢ 25% from air-sea fluxes

4 Evaluation of CFC-12 as incidcator for modeled C_{ant}

Modeled CFC-12 concentrations similar to observed

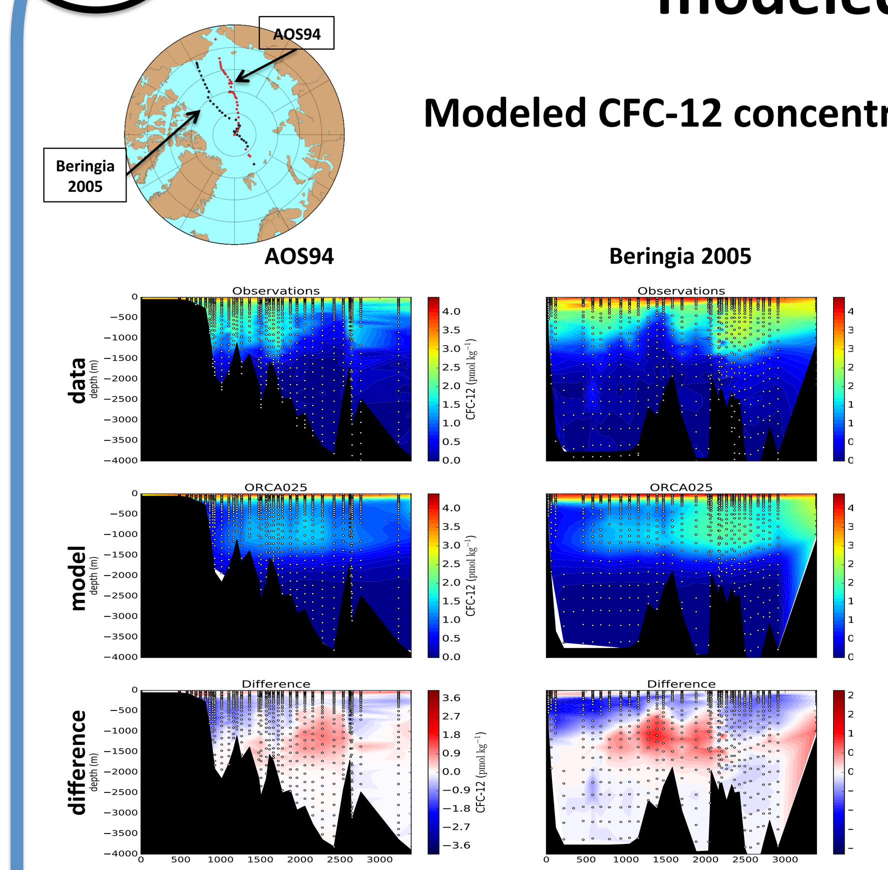


Fig 5: CFC-12 section for 1994 Arctic Ocean Section (AOS94) cruise (left) and Beringia 2005 expedition (right). The observations (top) are compared to the model results for the summer of the respective year (middle). The difference (model-data) is shown at the bottom.

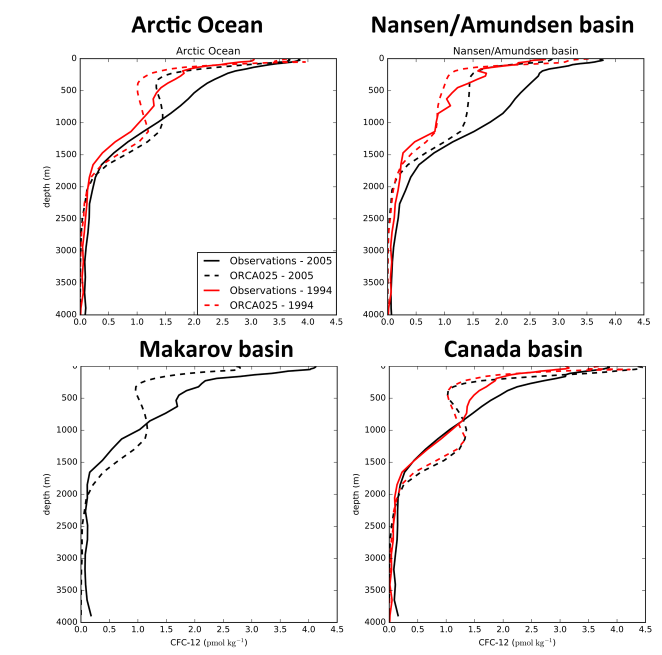


Fig 6: Vertical profiles (distance-weighted means) for observations and model output (ORCA025) along the sections AOS94 (red) and Beringia 2005 (black) for the total Arctic Ocean (top left), the Nansen and Amundsen basin (top right), the Canada basin (bottom left) and the Makarov basin (bottom right).

- ➢ Modeled CFC-12 close to observations
- ➢ Atlantic water too deep in the Arctic Ocean

5 *CMIP5 models differ greatly in Arctic inventories and fluxes*

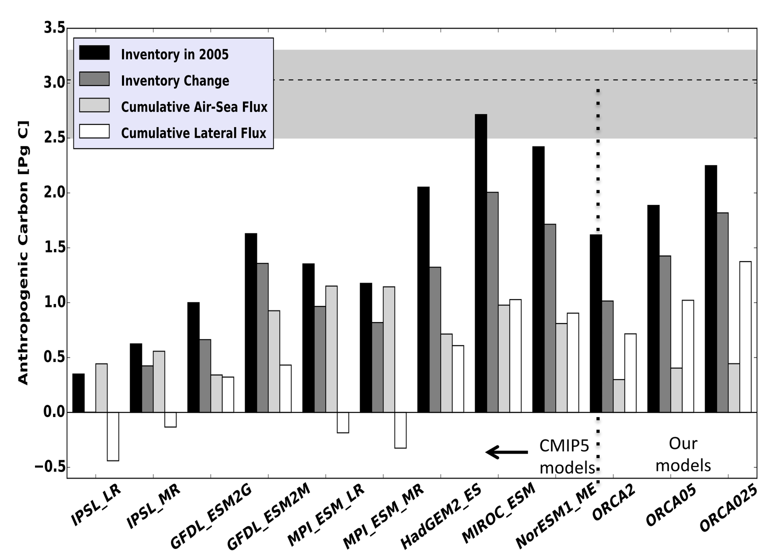
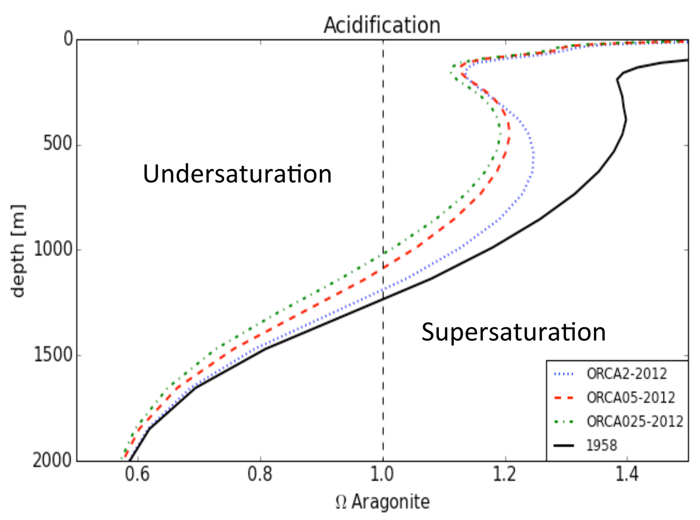


Fig 7: Inventory change, cumulative-air sea flux and lateral transport of anthropogenic carbon in the Arctic from 1960 to 2010 and the inventory in 2005 for different CMIP5 models. The air-sea flux and inventory change were calculated directly from model results and the lateral flux was calculated as the difference between these two values. The horizontal black dashed line marks the best estimate by Tanhua et al. (2009) with the uncertainty range in grey using the TTD method. The vertical dotted line separates the CMIP5 models (left) from the three models used in this study (right).

- ➢ Only models with strong lateral transport can approach data-based estimates

6 *Acidifcation saturation horizon rises faster with resolution*

Fig 8: Mean state of Ω Aragonite in the Arctic Ocean for all three resolutions (2°, 0.5° and 0.25°) in 2012. The acidification in 1958 is shown as a reference point. The vertical dashed black line shows Ω Aragonite = 1, below which waters become corrosive towards aragonite



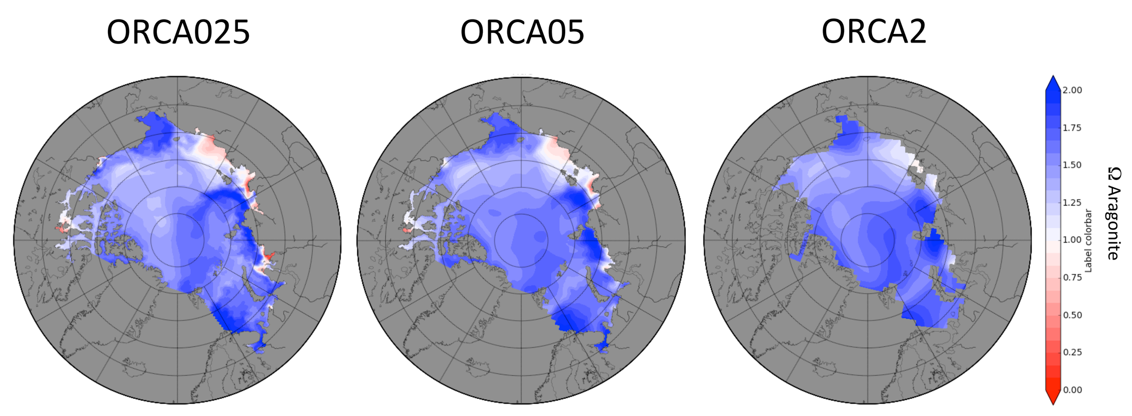


Fig 9: Surface ocean Ω Aragonite in the Arctic Ocean for all three resolutions (2°, 0.5° and 0.25°) in 2012. The acidification in 1958 is shown as a reference point. Red color indicates undersaturation of water, while blue shows supersaturated waters

- ➢ Acidification saturation horizon rises by 50 m (2°), 150 m (0.5°) and 210 m (0.25°) from 1960 to 2012
- ➢ Localized acid surface coastal waters only with higher resolutions