Machine learning-based long-term spatial reconstruction of surface total alkalinity for the northern Indian Ocean

The scarcity of observations varying in time and space in the northern Indian Ocean (NIO) makes it difficult to understand the changes in surface total alkalinity (TA) in a changing environment. We collect ship-based observations of surface TA from different sources for the period 1978-2019 for the long-term spatial reconstruction of high-resolution surface TA. We assume that the changes in TA are a function of surface temperature (SST), surface salinity (SSS), and the mixed layer depth (MLD). This study uses a decision tree-based advanced machine learning algorithm (XGB) combined with an ensemble approach to predict the surface TA of the north Indian Ocean (NIO) from 1993 to 2020. The ensemble approach enables to develop the best estimates of high-resolution surface TA (known as INCOIS-TA) with an uncertainty map. We find that INCOIS-TA performs better than the two global ML-based TA products. The open ocean region of the Arabian Sea (AS) and the Bay of Bengal (BoB) show low uncertainties (<22 µmol/kg). The coastal regions and the southwestern region are found to have higher uncertainties, which could be attributed to a lack of sufficient observations. The TA values in AS are higher (~150-350 µmol/kg) than in the BoB. The northern BoB has the lowest TA values (~ 2050-2130 µmol/kg) in the NIO region, which is primarily controlled by low SSS. The northern AS has the highest TA values (> 2400 µmol/kg), which is controlled by both upwelling and convective mixing processes. We find that the MLD has a strong control on TA seasonality, however, both SSS and MLD dominantly control its trends. Normalized TA (nTA) shows that decreasing SSS in the north BoB (due to the increasing river discharge consisting of high alkaline waters) is increasing the nTA, which is essentially buffering the acidification trend in this region. We identify six zones having significant ($p < 0.1$) nTA trends. The analysis to study interannual variability indicates that both ENSO and IOD have an equal (r=-0.34 with DMI and –0.32 with Nino3.4) impact on the TA of BoB, whereas changes in TA are dominated by ENSO in the AS. Strong El-Nino and positive IOD years (1997 and 2016) show a decrease in TA for the NIO, and TA increases during La-Nina and negative IOD years (1998 and 2010). Observational efforts need to be enhanced in the high uncertain regions identified in this study.

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