An Overview of Ocean Climate Change Indicators: Sea Surface Temperature, Ocean Heat Content, Ocean pH, Dissolved Oxygen Concentration, Arctic Sea Ice Extent, Thickness and Volume, Sea Level and Strength of the AMOC (Atlantic Meridional Overturning Circulation)

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Abstract

Global ocean physical and chemical trends are reviewed and updated using seven key ocean climate change indicators: (i) Sea Surface Temperature, (ii) Ocean Heat Content, (iii) Ocean pH, (iv) Dissolved Oxygen concentration (v) Arctic Sea Ice extent, thickness, and volume (vi) Sea Level and (vii) the strength of the Atlantic Meridional Overturning Circulation (AMOC). The globally averaged ocean surface temperature shows a mean warming trend of 0.062 ± 0.013°C per decade over the last 120 years (1900–2019). During the last decade (2010–2019) the rate of ocean surface warming has accelerated to 0.280 ± 0.068°C per decade, 4.5 times higher than the long term mean. Ocean Heat Content in the upper 2,000 m shows a linear warming rate of 0.35 ± 0.08 Wm^{-2} in the period 1955–2019 (65 years). The warming rate during the last decade (2010–2019) is twice (0.70 ± 0.07 Wm^{-2}) the warming rate of the long term record. Each of the last six decades have been warmer than the previous one. Global surface ocean pH has declined on average by approximately 0.1 pH units (from 8.2 to 8.1) since the industrial revolution (1770). By the end of this century (2100) ocean pH is projected to decline additionally by 0.1–0.4 pH units depending on the RCP (Representative Concentration Pathway) and SSP (Shared Socioeconomic Pathways) future scenario. The time of emergence of the pH climate change signal varies from 8 to 15 years for open ocean

sites, and 16–41 years for coastal sites. Global dissolved oxygen levels have decreased by 4.8 petamoles or 2% in the last 5 decades, with profound impacts on local and basin scale habitats. Regional trends are varying due to multiple processes impacting dissolved oxygen: solubility change, respiration changes, ocean circulation changes and multidecadal variability. Arctic sea ice extent has been declining by −13.1% per decade in summer (September) and by −2.6% per decade in winter (March) during the last 4 decades (1979–2020). The combined trends of sea ice extent and sea ice thickness indicate that the volume of non-seasonal Arctic Sea Ice has decreased by 75% since 1979. Global mean sea level has increased in the period 1993–2019 (the altimetry era) at a mean rate of 3.15 ± 0.3 mm $year^{-1}$ and is experiencing an acceleration of ∼ 0.084 (0.06–0.10) mm $year^{-2}$. During the last century (1900–2015; 115y) global mean sea level (GMSL) has rised 19 cm, and near 40% of that GMSL rise has taken place since 1993 (22y). Independent proxies of the evolution of the Atlantic Meridional Overturning Circulation (AMOC) indicate that AMOC is at its weakest for several hundreds of years and has been slowing down during the last century. A final visual summary of key ocean climate change indicators during the recent decades is provided.

Author keywords
AMOC; Arctic sea ice; dissolved oxygen; ocean climate change indicators; ocean heat content; ocean pH; sea level; sea surface temperature