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THE DYNAMICS OF CO_2 AND CH_4 EMISSIONS AND ABSORPTION BY LAND AND OCEAN SURFACES IN THE 21st CENTURY: CURRENT ESTIMATES AND TRENDS

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Modern climate change is characterized by a rapid increase in global mean temperature, which has already risen by approximately 1.3–1.5°C compared to pre-industrial levels. Alongside this warming, the frequency and intensity of extreme weather events, including heatwaves and heavy precipitation, have increased significantly. Although climate variability is influenced by natural factors such as orbital forcing, solar activity, volcanic eruptions and ocean circulation, increasing atmospheric concentrations of greenhouse gases (GHG), primarily CO_2 and CH_4, are recognized as the main drivers of current climate change. This study analyses the dynamics of CO_2 and CH_4 emissions and uptake by terrestrial and oceanic ecosystems in the 21st century, focusing on recent estimates, spatial and temporal variability, and major trends. Particular attention is given to methods for assessing GHG fluxes and to the role of climate mitigation and adaptation strategies. The IPCC inventory methodology applies a bottom-up approach based on statistical data on land use, agriculture, industry and energy consumption combined with standardized emission factors. Biogeochemical models, including CESM, LPJ, ORCHIDEE and JULES, simulate interactions between vegetation, soils, oceans and the atmosphere. Inversion modelling uses satellite observations from OCO-2, GOSAT and TROPOMI together with atmospheric transport models to estimate surface GHG fluxes. Machine learning approaches are increasingly used to identify non-linear relationships between GHG fluxes and environmental drivers using large observational datasets. Modern GHG monitoring systems combine observations across multiple spatial scales. Local-scale measurements of CO_2 and CH_4 fluxes are obtained using eddy covariance techniques, chamber methods and UAV-based observations, providing essential data for model calibration and validation. Regional and global estimates are derived using biogeochemical and inversion modelling approaches based on satellite observations. Integrating ground-based measurements, remote sensing and modelling significantly improves our understanding of GHG exchange between the atmosphere, terrestrial ecosystems and the oceans. According to the Global Carbon Budget, the global ocean absorbed approximately 2.2–3.0 *GtC* per year of anthropogenic CO_2 between 2006 and 2023, while terrestrial ecosystems absorbed on average 2.5–3.5 *GtC* per year, although with much higher interannual variability related to climate conditions, disturbances and land-use change. This study emphasizes the importance of nature-based solutions, including the protection and restoration of forests, wetlands and grasslands, for climate mitigation and carbon sequestration.

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