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Development of an Integrated Observation and Analysis System for Monitoring Greenhouse Gas Sources and Sinks

SAIGUSA Nobuko
National Institute for Environmental Studies (NIES)
16-2 Onogawa, Tsukuba-City, Ibaraki 305-8506, JAPAN
E-mail: n.saigusa@nies.go.jp
With cooperation from: Meteorological Research Institute (MRI), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Chiba University

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The Paris Agreement established a long-term goal of achieving a balance between anthropogenic emissions and removals of greenhouse gases (GHGs) by sinks. To evaluate the impacts of climate change measures, accurate knowledge of emission trends and reliable GHG inventories are essential. However, owing to uncertainties in models and limited observational data coverage, estimates of GHGs sources and sinks still contain high degrees of uncertainty. This study aimed to develop an integrated observation and analysis system by combining data with advanced analysis systems including "top-down" (with inverse models) and "bottom-up" (with surface flux and emission data) methods to provide timely scientific knowledge to policymakers.

We firstly enhanced atmospheric carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO) concentration observations based on a commercial airliner-based measurement project (CONTRAIL) over Asia which is normally only sparsely monitored for atmospheric GHGs. Bottom-up CH_4 emission inventories were also intensively developed from statistical analyses of activity data and country-specific emission factors where high uncertainties had been detected particularly in coal mining and livestock.

To integrate those datasets, a new inverse system of atmospheric CH_4 was developed based on NICAM-TM 4D-Var. Using a state-of-the-art data assimilation technique, the system is capable of estimating spatially high-resolution fluxes. A function of using CO as a proxy for combustion sources was also newly incorporated in the system, whose utility was demonstrated by a CO_2-CO joint inversion for Indonesian biomass burning events in 2015.Long-term inverse analyses of CH_4 and CO_2 were also conducted. The derived high-resolution fluxes, which were consistent with atmospheric observations, improved our understanding of flux mechanisms of CH_4 and CO_2.

We then performed regional inverse modeling of atmospheric CO_2 and CH_4 at monthly time intervals for the period of the 1990s-2010s using MIROC4-ACTM. Natural (non-fossil fuel) CO_2 fluxes were analyzed for hemispheric and global budgets for land and ocean regions, while subcontinental scale CH_4 emissions were analyzed for sectorial emission changes. Finally, we conducted a thorough comparison of CO_2 budgets at multiple scales using multiple methods to assess the current state of the science in estimating CO_2 budgets. Our set of atmospheric inversions and biosphere models showed a high level of agreement for global and hemispheric CO_2 budgets in the 2000s. Regionally, improved agreement in CO_2 budgets was notable for North America and Southeast Asia. Our results show a dominance of anthropogenic CH_4 emissions over the loss of CH_4 for driving a growth rate decrease in the 1990s, quasi-equilibrium in the early 2000s, and regrowth in the late 2000s through 2016. Both the CO_2 and CH_4 emission and uptake datasets have contributed to various national and international research studies and assessments, including the IPCC AR6 and Global Carbon Project.

By integrating all efforts by the sub-groups, we analyzed inter-decadal variations in the terrestrial CO_2 budget across Southeast Asia and globally to test the robustness of each single method and to present the current best understanding of terrestrial CO_2 budgets. In Southeast Asia, both top-down and bottom-up approaches showed strong sensitivities of the CO_2 budget to temperature variations. We also analyzed inter-decadal variations in terrestrial CO_2 fluxes at the global scale and found that both approaches consistently estimated the largest land CO_2 sink in the 2000s among the past 100 years (Fig. 1). The largest CO_2 sink was attributed to recovery from past land-use changes. Finally, land CO_2 budgets were assessed at the sub-continental scale using top-down and bottom-up approaches, and both estimations approached each other if we filled the gaps in the definition of the CO_2 budget (Fig. 2).

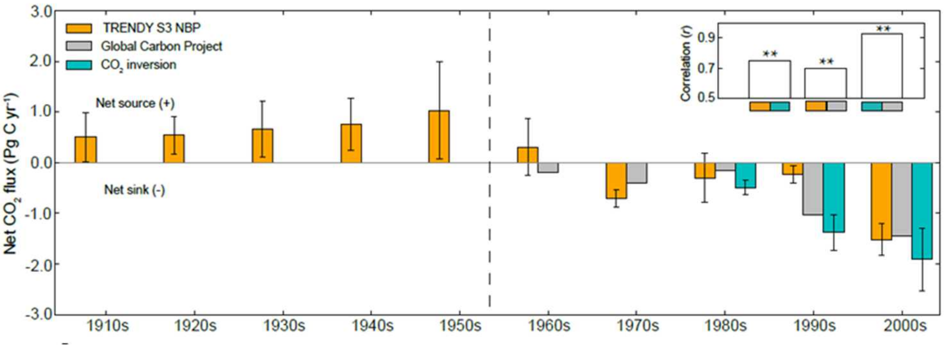

Fig. 1 Decadal variability in global net CO_2 flux from the ensemble mean of the bottom-up methods (orange), top-down methods (cyan) and residual method (gray). (Kondo et al., 2018)

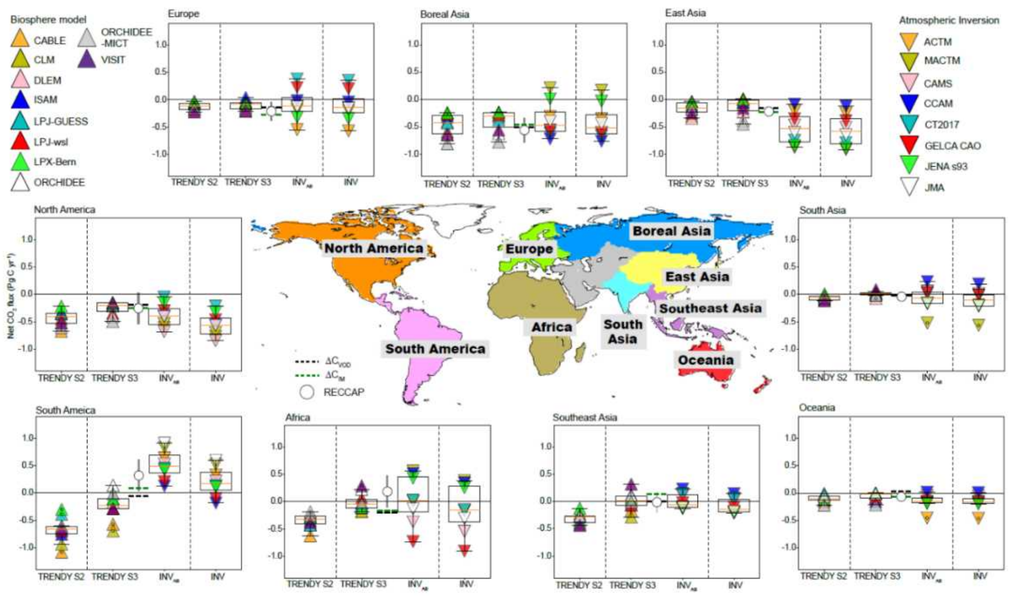

Fig. 2 Regional CO_2 budgets for the 2000s indicated by biosphere models (bottom-up methods; upward triangles) and atmospheric inversions (top-down methods; downward triangles). (Kondo et al., 2020)

References

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