# Toward a long-term global inversion of atmospheric $CO_2$ for elucidating seasonal and interannual variations of natural carbon fluxes

*Yosuke Niwa[1]

1. National Institute for Environmental Studies

A number of ground-based stations have been performing atmospheric measurements of $CO_2$ for several decades and have observed notable interannual variations of the growth rate of the atmospheric $CO_2$, which suggests that the natural $CO_2$ flux at the earth surface have been varying in conjunction with some climate key parameters (e.g., El Niño Southern Oscillation index). Furthermore, distinct seasonal variations of atmospheric $CO_2$ observed by those measurements give evidence of dynamic photosynthesis and respiration activities of terrestrial biospheres. However, the mechanisms underlying those natural $CO_2$ flux variations are not fully understood and that gives significant uncertainties in the global warming prediction by earth system models equipped with carbon cycle feedbacks. An atmospheric observation-based estimate of surface $CO_2$ fluxes, i.e., so-called top-down analysis, would improve our understanding of the surface $CO_2$ flux mechanisms. An atmospheric inverse analysis in which a transport model is used to connect surface fluxes with atmospheric mole fractions is a prominent method in that it gives spatiotemporal variations of surface fluxes. In order to give implications of surface flux mechanisms, we should conduct a long-term inverse analysis with a high spatial resolution. In this study, we first use a simple box model that emulates integration of the global atmospheric $CO_2$ and apply it to a long-term inverse analysis with a variational method. In that experiment, we investigate how surface flux estimation is optimized along iterative calculations. Furthermore, we extend the inverse analysis to a more realistic problem with a sophisticated inverse system name NICAM-TM 4D-Var (Niwa et al., 2017a,b), in which a global three-dimensional model is employed. By using synthetic data with a current observational network, we elucidate uncertainties behind coming inversion results from NICAM-TM 4D-Var with real observations.

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