Inverse modeling with aircraft observations for constraining CO2 flux estimates in Asia

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Estimates of carbon dioxide (CO_2) fluxes at the earth surface (e.g., between atmosphere and terrestrial biospheres/oceans) have significant uncertainties, which limits our understanding of the carbon cycle. Especially, uncertainties of the flux estimates for the Asian regions are considerable because human activities such as fossil-fuel consumption and land-use changes and frequent biomass burnings complicate the problem.

Globally distributed observations of atmospheric CO_2 have been used to constrain estimates of surface CO_2 fluxes and a statistical estimation has been often performed by a Bayesian inversion analysis, which employs an atmospheric transport model that links surface fluxes with the atmospheric observations. However, there are many challenges to perform a reliable inversion analysis; for instance, it requires an accurate transport model, a dense observation network, and a sophisticated inversion scheme.

Toward an accurate transport simulation, we have developed the atmospheric transport model NICAM-TM (Nonhydrostatic ICosahedral Atmospheric Model-based Transport Model), which has promising capabilities for mass conservation and a high-resolution simulation. In the inversion analysis with NICAM-TM, we leverage aircraft observation data from the CONTRAIL (Comprehensive Observation Network for Trace gases by Airliner) project to fill the gaps of the conventional surface observation network. Since 2005, CONTRAIL has been continuously operating in-situ measurements of atmospheric CO_2 onboard commercial aircraft. Owing to the observations on international flights, its observation network is worldwide and ranges from the boreal high latitudes to the austral mid-latitudes including many parts of Asia. Furthermore, in order to fully exploit a number of CONTRAIL data, we have newly developed an inversion system, named NICAM-TM 4D-Var, by combining the four-dimensional method with NICAM-TM. This system provides high resolution flux estimates with nearly no limitation in the number of observations it can accommodate.

In the inverse modeling with the CONTRAIL data, we have demonstrated great utility of those aircraft data for constraining Asian flux estimates. Especially, the impact of the data is noteworthy for South and Equatorial Asia, where the surface observation network is quite sparse. Over those regions, flux signals are uplifted by convective vertical transport and they are more efficiently captured by the aircraft than by remote surface stations. In 2015, which is the one of the biggest El Niño years for the last two decades, large-scale biomass burnings occurred at Equatorial Asia. Anomalies of the CO_2 fluxes induced by those biomass burnings were clearly captured by the high-resolution inversion analysis with NICAM-TM 4D-Var. This study could provide valuable insights on the mechanism of the CO_2 fluxes in Equatorial Asia, where a large amount of carbon is stored in tropical rainforests and peatlands and disturbances on those reservoirs have strong impacts on the growth rate of the global atmospheric CO_2.