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Monitoring the CO_2 surface emissions and surface sinks from space

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The space-time variations of the carbon budget at the Earth's surface are highly variable and quantifying them represents a major scientific challenge. A prominent strategy consists in inferring the carbon surface fluxes from the gradients of the carbon concentrations in the atmosphere. This method has been established in the 90s based on the (sparse) atmospheric measurements from conventional surface networks. With the advent of atmospheric composition remote sensing in the 00s, this method can now be applied to tentatively monitor the carbon surface fluxes over long periods from space.

For CO_2 flux inversion, the requirements on the relative accuracy of the atmospheric products, like those from AIRS and GOSAT, are particularly stringent. Similarly, uncertainties in atmospheric transport modeling also hampers the inversion of the carbon fluxes. Satellite products with little or no sensitivity to the boundary layer, like those of AIRS, combine the difficulty of a small signal to capture and that of a large contribution of the transport model needed to interpret them in terms of surface fluxes. The generation of products from CO_2-dedicated instruments, like GOSAT, with some sensitivity to the boundary layer, is still at an early stage and is complicated by the ambiguity of the measured short-wave infrared radiation with respect to CO_2, aerosols and thin cirrus clouds at once.

Within the European GEMS project and its follow-on MACC, LSCE has been developing a variational inversion scheme to extract the information from the satellite sounders about the surface fluxes. This system is one of the few that processes satellite soundings individually (i.e. large observation vector), while preserving the high spatial resolution of the expected inversion flux increments (i.e. large state vector). It has been applied to products from AIRS and from GOSAT and to the conventional surface measurements for the estimation of time-varying CO_2 surface flux maps at the global resolution of $2.5° \times 3.75°$ (latitude, longitude). In this paper, we describe the inversion system and show the comparison and the evaluation of the three sets of inverted fluxes. Complementary comparisons are provided from the reference surface network of Total Carbon Column Observation Network (TCCON) and from a state-of-the-art and observation-free model simulation of CO_2. It is shown that the model simulation is already in agreement within 1-2 ppm with individual TCCON retrievals at TCCON sites. This result sets the bar high for satellite CO_2 products in general. Our evaluation indicates that the satellite products tested still have not outperformed the surface network so far and do not bring new insights about the carbon fluxes yet. We conclude by synthesizing the strengths and weaknesses of the current satellite observing systems for surface flux monitoring and make some recommendations for future developments.