TECHNICAL COMMENT

CARBON CYCLE

Comment on “Contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño”

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Liu *et al*. (Research Articles, 13 October 2017) inferred carbon flux anomalies in tropical continents with enough confidence to constrain the driving carbon-exchange processes. I show that they underestimated their error budget and that more effort must be invested in the satellite concentration retrievals and in the atmospheric transport models before such precision can be achieved.

The monitoring of CO_2 concentrations from space addresses a growing demand for improved information about the carbon emissions over the globe and about the absorption of some of these by oceans and terrestrial ecosystems. Several satellites have been specifically designed for that purpose, including the Japanese Greenhouse Gases Observing Satellite (GOSAT) and NASA’s second Orbiting Carbon Observatory (OCO-2), respectively launched in 2009 and 2014 (*1*). More spaceborne instruments are being prepared in the United States, Japan, China, and Europe. Given the relatively small space-time variations of CO_2 over the globe and the fact that CO_2 has no chemical sink in the atmosphere, the processing chains that estimate the carbon surface fluxes from these satellite measurements are particularly complex: They have to analyze some subtle details in each measured spectrum in the global context of the atmospheric flow. Various algorithms have been designed by the scientific community and most of them have participated in intercomparison exercises. Results so far have revealed a large uncertainty in the estimated carbon fluxes and in their interannual variability (*2*–*5*). The estimation process still appears to be subjective and is much dependent on technical choices and on expert judgment about the underlying physical and statistical models.

Liu *et al.* (*6*) explain that they have addressed these challenges with GOSAT and OCO-2 measurements to the point that they can confidently quantify the anomalies in the carbon fluxes that occurred in the three tropical subcontinents in 2015 as compared to 2011: They find source differences (i.e., source anomalies) of 0.9 ± 0.22 gigatonnes of carbon (Gt C; estimate ± SD) over tropical America, 0.8 ± 0.29 Gt C over Africa, and 0.8 ± 0.28 Gt C over Asia, for a total of 2.5 ± 0.34 Gt C. The relatively narrow confidence intervals suggest a leap forward in the remote sensing of carbon fluxes and, with additional satellite observations of solar-induced chlorophyll fluorescence, allow the authors to quantify the constituent carbon fluxes of these anomalies.

To illustrate the challenge represented by isolating a tropical continental flux anomaly of a similar amplitude within the global carbon budget, I used an atmospheric transport model (*7*) to simulate the impact of an anomalous source of 2.5 Gt C over the tropical continents together with a compensating source of the same amount in the rest of the world for 2015. To do so, I spread a regular source of 0.27 g C per square meter per day (g C m^{-2} day^{-1}) to the atmosphere over the tropical continents as defined by Liu *et al.*, and a regular sink of 0.01 g C m^{-2} day^{-1} elsewhere. I looked at the impact of this change on the column-averaged CO_2 dry-air mole fraction (X_{CO_2}) satellite retrievals used by Liu *et al.* for 2015, everything else being equal. I then repeated the exercise for an even source of 0.9 Gt C in either tropical America, tropical Africa, or tropical Asia within a fixed tropical carbon budget.

Figure 1 shows the scatter of the resulting change in X_{CO_2}. In all four cases, this change is essentially within ±0.5 parts per million (ppm). The largest values are seen in the case of the three tropical continents aggregated together, but still only 1.5% of the sounding perturbations exceed 0.5 ppm in that case. Consistent with previous studies (*8*, *9*), the figure suggests that subcontinental-scale systematic errors of a few tenths of ppm in the retrievals and in the modeled transport processes may severely distort the estimated tropical carbon flux anomalies. Yet the biases found between the OCO-2 retrievals used by Liu *et al.* and reference validation measurements at 17 surface stations of the worldwide Total Carbon Column Observing Network (*10*) were scattered with a standard deviation as large as 0.8 ppm and a median of 0.6 ppm; some of their patterns correlate with surface brightness, and thus with the target flux signal (*11*). The systematic errors of the GOSAT retrievals are not smaller (*6*). Some of these biases would cancel out when comparing two different years, but only partially because the biases depend on time-varying surface and atmospheric properties. In addition, the reference measurements themselves are tuned against internationally recognized standards at the 0.4-ppm level only (*12*, *13*), whereas only a few measurements support the development of CO_2 transport process models. I therefore argue that the uncertainties stated by Liu *et al.* much underestimate the actual flux error budget. Realistic values would reflect our current difficulty with X_{CO_2} retrievals to reliably discriminate between the anomalies in the three tropical continents and even to isolate some anomaly in the tropical continental budget within the global budget, irrespective of the quality of the satellite instruments themselves.

Monitoring carbon surface fluxes from space is still an emerging technology. An ambitious multimodel approach is needed to distinguish what is robust in current results from what is not. To make better use of existing and of future measurements, more research is needed to make the processing chains robust, in particular through further

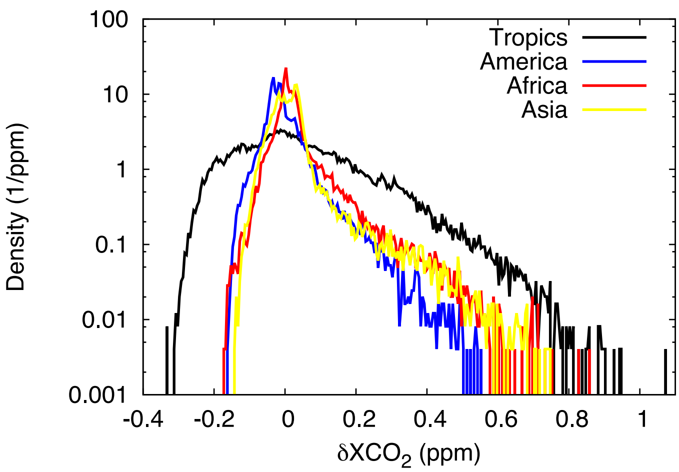

Fig. 1. Density function, in log scale, of the X_{CO_2} perturbations induced by perturbations of the carbon budget of 2.5, 0.9, 0.9, and 0.9 Gt C evenly spread over the tropical continents, over tropical America, over tropical Africa, and over tropical Asia, respectively. Each source is compensated with a sink of the same amplitude outside the tropical continents or in the same latitude band, including the oceans. X_{CO_2} values are simulated at the location of the OCO-2 retrieval used by Liu *et al.* The vertical weighting specific to each retrieval has been applied.

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development and refinement of the X_{CO_2} reference ground-based network and of measurement programs dedicated to the transport of tracers in the column.

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