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Interactive comment on "A Lagrangian Approach Towards Extracting Signals of Urban CO_2 Emissions from Satellite Observations of Atmospheric Column CO_2 (XCO_2): X-Stochastic Time-Inverted Lagrangian Transport model ("X-STILT v1.1")" *by* Dien Wu et al.

Anonymous Referee #1

Received and published: 16 July 2018

This paper describes a new modification and application of the STILT model for total column measurements. This will allow X-STILT to be used to interpret satellite (and ground-based) total column abundances, and is a timely contribution, given the rapidly increasing number of satellite greenhouse gas total column measurements. The manuscript is thorough and technical, generally clear and well written, and suitable for this journal. I would recommend its publication after the following comments are addressed.

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Discussion paper

General Comments

Is X-STILT restricted to XCO2, or could it be applied to any total column tracer (e.g., XCH4, XCO, XN2O, etc.)? Could it also be applied to ground-based total column measurements? My understanding from reading this paper is that X-STILT could be applied more generally, and that you were showing a rigorous example of its functionality with OCO-2 XCO2. If this is true, its generality should be made more clear – perhaps with a more general title and introduction.

Specific Comments

P2L30-36. I don't think the current suite of CO2 satellites will completely fill in the gaps of the surface in situ networks, especially over specific locations such as cities. Certainly the future looks bright with OCO-3's "city mode", and the geostationary missions on the horizon, but I think you are overstating the impacts over cities as our satellite observing system currently stands.

Section 2.1.

I'm having trouble with your definition of the sensitivity of the satellite sensor: it seems incomplete. The column averaging kernel represents the change in the retrieved total column with respect to a perturbation in the abundance at a particular altitude. When the column averaging kernel is 0, the measurement is insensitive to changes at that altitude, and thus relies completely on the information in the a priori profile to construct the column. (Ref: OCO-2 ATBD, P58: https://co2.jpl.nasa.gov/static/docs/OCO-2%20ATBD_140530%20with%20ASD.pdf)

Weighting functions, which you mention on L33, at least to the retrieval community, refer to the Jacobian matrices, and while these are related to the averaging kernel matrices, they are not the same as the column averaging kernels (see P54 on the ATBD document above). I'd ask that this section is clarified further.

On P5, you mention the interpolation of the measurement onto the model levels. Why wouldn't you do the reverse: interpolate the model onto the retrieval grid? Your method requires that you make several assumptions that seem to complicate your analyses (i.e., these "scaling factors" you mention). Is there a compelling reason not to interpolate the model instead of the measurements? Please explain these "scaling factors" in more detail to walk the reader through Fig. 2.

Section 2.4

A recent paper by Nassar et al. (2017) would be relevant to cite in Section 2.4. They use OCO-2 data to quantify power plant emissions, and they choose an overpass-dependent background that would be interesting to compare with your method.

Ref: Nassar, R., T. G. Hill, C. A. McLinden, D. Wunch, D. B. A. Jones, and D. Crisp (2017), Quantifying CO2 emissions from individual power plants from space, Geophys. Res. Lett., doi:10.1002/2017GL074702.

Section 2.6

My (admittedly simplistic) understanding of the transport error issue is that it is still important for models to get the vertical transport right when assimilating or inverting total column measurements, because the vertical transport sets the altitude at which advection occurs, and thus the distribution of the gas around the planet. So while the total column measurements themselves are insensitive to the altitude of the molecule within the column, it is not necessarily the case that the models are better able to reproduce the column. Indeed, the abstract of Lauvaux and Davis cited in this paragraph seems to confirm that vertical transport errors are very important for calculating fluxes from column-integrated measurements. Please address this issue further.

Furthermore, there is little discussion about the atmosphere above MAXAGL ($\sim$450 hPa). While this is unlikely to be important for CO2 emissions over regional or smaller scales, it may be important for other tracers (e.g., CH4). Can you comment on how important the tropopause altitude, for example, might impact this work? Over what spatial and temporal scales would X-STILT properly represent the total column?

OCO-2 v7

You are using v7 of the OCO-2 data in this paper, but v8 is available and v9 will be available soon. V8 has significant improvements in the treatment of aerosols and throughput, which may be important for work over polluted urban regions. V9 will have improved pointing, especially important over topography. Please comment on whether your results will be robust against these changes to the OCO-2 data.

Technical Comments

In Section 2.1.1, I found myself wondering which version of OCO-2 data you were using, given the discussion about quality flags and albedo cutoffs, which is version-specific. I realize this is answered later in Section 2.2. I'd suggest either not mentioning the specifics of the quality filtering in section 2.1.1, or mentioning the data version in 2.1.1.

P10L14-7: I'm having trouble understanding these sentences, and I believe this wind correction may be an important step in X-STILT. Please explain in more detail.

P13L3-6: I believe you are saying that M2H is in general lower than M3. But can you say definitively that M3 is correct, and thus M2H has the bias? Also, 0.56 ppm is not small! This can be 25-50% of the enhancement.

There are several instances of omitted definite and indefinite articles, and a few typos here and there, but I assume that once this paper has been accepted, the copy editor will find and correct them more thoroughly than I have. However, I will list the ones I caught here. Between ** are the edits I suggest.

P2L17: top-down constrain*ts

P3L6-7: shed light** on CO2 emission** monitoring network*s*.

P4L18: Riyadh*,* with *a* population

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P4L20: Saudi Arabia has the largest CO2 emission*s* among...

P4L32: “apple*s*-to-apple*s*”

P4L33: weighted using *the* satellite’s *column averaging kernels*...

P5L17: at the same lat/lon as *the* satellite...

P5L21: compare ** overall modeled

P5L28: *The l*onger the time an air parcel..., *the* higher its footprint value...

P6L5: FFCO2 *are* derive*d* from...

P6L13: we binned ** the observed...

P6L16: estimate *the* increase in observed...

P6L22: 1x1 km resolution on ** monthly scale*s*... emission estimates by fuel type** from the...

specific ODIAC emission categories on *a* monthly basis...

P6L31: line sources and diffuse** sources...

P8L32: which are more straightforward** and efficient** than solely *relying* on...

P9L7: boundary of *the* city...

P10L19: more suitable sites *to* retrieve...

P10L25: get around ** the impact on...

P11L6: we fit *an* exponential variogram...

P12L11: which results in *an* overall smaller footprint... Yet, column footprint*s* cover**...

P12L14: an air column can be one or *a* few orders...

P12L18: regardless *of the* adopted meteorological fields.

P12L33: Here we emphasi*ze*...

P13L29: sensible → sensitive

P14L21: according to *the* OCO-2 Lite file...

P14L24: scatter*ed*

P15L36: latitudinal** integration ←this happens in other locations as well

P16L30: exceeding *a* certain averaged...

P17L8: emissions of *a* target city

P18L2: even large impact*s* on *the* posterior... can be caused by using *a* background derived from simplistic statistic*s*

P18L13: hampered ** due to...

P18L24: improves biospheric flux** estimation...

P20L10: for *a* few levels...

P21L17: These small changes *show* that our *latitude band integration*... a second peak or miss** large XCO2 enhancements.

P21L21: *widths*

P21L27: The word "benefit" seems out of place here.

P21L30: Based on three simpl*e* tests...

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