Anonymous Referee #2 (Referee's comments in black, our responses in red)

The paper aims to examine the limitations of the wind extraction from trace gas measurements using a 4D-VAR assimilation system. However, there are different points which are not yet very clear. The authors must address the following points before accepting the paper for publication.

Major comments:

The paper is generally divided into two parts: the first part is more pedagogical and qualitative in which the authors used a 1D model to highlight the limitations of wind extraction from the assimilation of trace gas measurements. The second part is a more realistic application of the methodology using a 3D model with a more complete 4D-VAR system.

1) The first part uses a 1D model in an idealized case with many simplifications. The conclusions (page 32997, lines 22-29; and page 33000, lines 1-9) from this model study which constitutes an important part of the paper have been already reported in the literature (see for example: Daley, 1995; Riishøjgaard 1996; Peuch et al, 2000; Semane et al., 2009). I expected from this part an added-value from this model different from that reported in the literature. I am wondering what is the benefit of this part for the scientific community. I would like the authors highlight better that benefit if existing.

We believe that the pedagogical approach using a 1-D simulation would be helpful for highlighting some of the fundamental aspects of the problem (as Referee #1 commented) before showing the full 4D-Var solutions. The approach is unique relative to the other works in that the analytic solution to a discrete problem is derived, showing the explicit form of the TLM, adjoint, cost function, and analysis increments. This therefore compliments the previous studies that used numerical solutions for systems of varying complexities. The 1-D model nicely demonstrates several of the limitations of the wind-extraction problem in a highly controlled system. The influence of the specification of background errors in terms of partitioning the increments between wind and tracer is a new aspect that was not highlighted in the previous studies. In addition, we emphasize the importance of correctly specifying the observation error standard deviation to avoid statistical degradation of the wind.

2) The second part constitutes the body of the paper and it is much more realistic because it uses a 3D model coupled with a 4D-VAR assimilation system. However, in this realistic case, the authors have used only ozone as a trace gas. Nevertheless, the title of the paper refers to all tracers! To give a meaning to the paper with respect to the title, it would be nice to use other tracers in the assimilation system and which are available from MLS instrument for example. This will confirm the hypothesis of the conclusion (page 33010, lines 7-8) which states that the assimilation of other tracers in addition to ozone may supplement the wind extraction.

Although the paper was meant to be general, we do only show results using a single trace gas, ozone, in the 4D-Var system. We agree to change the title, as suggested in this referee's earlier comments, to "Limitations of Wind-Extraction from 4D-Var Assimilation of Ozone." We are reserving the assimilation of other tracers to future work.

3) In the same direction, note that no discussion concerning the effect of the trace gas vertical distribution is undertaken in the paper. I recommend that the authors address this issue and examine the impact of the analyzed wind as a function of the vertical structure of the tracer if existing. For example, is there a relationship between the vertical gradient of the tracer and the analyzed wind? Can we quantify this impact regardless to the tracers?

In principle, the vertical gradient of the tracer may play a role due to the vertical advection term in the TLM (w' dq/dz), where w' is the perturbation vertical wind and dq/dz is the background vertical tracer gradient. In practice, the vertical advection is very small in the stratosphere over the 6-hour window, so the advection is dominated by the horizontal terms. The wind extraction process can thereby be assumed (to first order) to depend on the horizontal tracer gradients, rather than the vertical gradients. We will comment on this in the revised version.

4) Again, the interpretation of the results in the paper is generally based on the RMS reduction which is statistically good. However, no comparisons are done in terms of wind before and after the tracer assimilation. it would be very useful that the authors make a direct comparison of the wind before and after the tracer assimilation with respect to the altitude. Figures showing the vertical distribution of the wind at different regions before and after the tracer assimilation will be welcome.

If we understand correctly, you are suggesting that we examine the mean wind errors in addition to RMS. We have made a new figure comparing the mean zonal and meridional wind differences for the first case (see uploaded Figure 7). In the NH, the analyzed mean zonal wind error is smaller (in absolute value) than the background error over the entire range from 200 to 1 hPa, with maximum improvement of ~2 m/s around 6 hPa. The impact on the mean meridional wind in the NH is weaker, with slight improvement from ~78 to 5 hPa and slight degradation from ~5 to 2 hPa. That zonal winds in the NH are influenced more than the meridional winds is likely due to the larger background zonal wind errors combined with significant background tracer gradient in the zonal direction caused by the splitting of the vortex during the major warming (see Figure 3a). In the tropics and SH, the impact of ozone assimilation on the mean winds is very small relative to the RMS differences (Figure 4), with regions of both slight improvement and slight degradation.

specific comments:

-Page 32987, Line 11 : ...extremely expensive. I suggest you provide a reference.

We will include reference to National Research Council decadal survey, which lists DWL mission in the "large cost" category (>$600 Million). This cost estimate is for a demonstration version only, not a fully operational mission.

-Page 32990, Line 5 : Error variance diagnostics -> Error variance reduction diagnostics

We will make this change.

-Page 32990, line 7-13 : What about IASI data onboard Metop-A and Metop-B ?

We will include a comment that tracer-wind extraction is also possible using ozone-sensitive channels from IR radiances. Dragani and McNally (QJRMS, 2013) have recently examined assimilation of ozone-sensitive IR radiances in the ECMWF system, but state that the dynamical coupling is currently not included in ECMWF.

-Page 32991, line 7. Please remove the last sentence.

We will remove this sentence.

-Equation 2 : it seems that there is a missing term in the left-hand side : $u_b \frac{\partial q_b}{\partial \lambda}$. If this term is missing, please check the equation 3.

This non-linear term drops out during the TLM linearization process.

-Page 32992, line 15 : the non-dimensional wind U should be $U = udt/d\lambda$

We will change this to $U = u\Delta t/\Delta\lambda$, where Δt is the model time step and $\Delta\lambda$ is the model grid spacing.

-Page 32992, line 16 : in 1D approach, I don't know if: $\mathbf{M}_{t_{n-1}\to t_n} = dx'(t_n)/dx'(t_{n-1})$, please check?

Yes, this is true for the 1D approach, but the notation may be confusing to some readers (partial derivative of vector with respect to another vector), so we will leave it out.

-Equation 5 and in the following : Please replace σ_v by σ_u, otherwise what is σ_v?

We will replace σ_v by σ_u in all cases. Thank you for catching this error.

-Page 33004, line15 : I would suggest 'distributions' instead of 'conditions'.

This change will be made.

- Another section dealing with the limitations due to the vertical structure of the tracer if existing will be welcome.

As discussed earlier, the wind-extraction process is to first order a horizontal (2-D) process that requires a horizontal tracer gradient. The second-order effects, which will be more difficult to discern, may be interesting in their own right, but they are beyond the scope of this particular paper.