Response to Anonymous Referee #2

We thank the reviewers for their constructive and helpful suggestions. We have provided our responses to the reviewers' comments and believe that our manuscript is much improved as a result.

The main paper improvements are:

- The abstract was rewritten.
- The goal of the study is formulated more clearly.
- The number of sites for validation of GELCA is increased.
- Proofreading and grammar check performed.

The reviewer's specific comments (shown in blue) are addressed below.

Response to Anonymous Referee #2

Received and published: 8 September 2015

Overview:

The manuscript "Adjoint of the Global Eulerian–Lagrangian Coupled Atmospheric transport model (A-GELCA v1.0): development and validation" by Belikov et al. describes the construction of a new coupled adjoint model based on GELCA, which is a coupled forward transport model based on the NIES Eulerian transport model and the Lagrangian transport model, FLEXPART. The methodology described in this manuscript provides an interesting development upon existing adjoint models, and may be used in future to supply high-resolution adjoint sensitivities at relatively low computational cost. The authors describe the applications of the model, before describing its development and providing examples of the adjoint model's accuracy in comparison with the forward model. Finally, a real-world example of use of the adjoint model is described.

Overall the manuscript is fairly clearly written, although there are a large number of technical corrections necessary before publication. Some of the descriptive sections are quite brief and lacking in necessary detail. The figures and tables are generally clear and well chosen. Although the performance of the forward coupled model compared with the Eulerian model is investigated to some extent, my biggest concern with the manuscript is that only a handful of sites are included in this analysis, all of which are in relatively close proximity to each other, in a region where surface fluxes are uncertain. However, from this limited perspective, the coupling does appear to improve the model performance. The adjoint model is shown satisfactorily to be accurate in comparison with the forward model, which is the most important aspect of the manuscript.

I recommend publication after these revisions have been carried out.

Comments:

5985.11: define 3-D for first use

Done

5985.20: Can you provide a more recent reference than Bovensmann et al., (1999) for this statement?

Replaced with (Karion et al., 2013; Tohjima et al., 2015)

2986.2-4: Rephrase: "Generally, there are the Eulerian and the Lagrangian method of modelling the atmospheric constituents transport"

Rewritten as "Generally, the atmospheric constituents transport may be described in two different ways: the Lagrangian and the Eulerian approaches."

5986.16: Rephrase the sentence beginning “The adjoint of the transport model. . .” as it is unclear.

Revised as: “The adjoint of the transport model is an efficient way to accelerate calculation of concentration gradient of the simulated tracer at observational locations (Kaminski et al., 1999).”

5986.24: The accompanying references to this sentence seem out of place here, as they relate to inverse modelling of CO and NOx, rather than the longer-lived species discussed in the rest of the manuscript.

Revised as follows: “Recent studies have used this method to constrain estimates of the emissions of CO_2 using retrieved column integrals from the GOSAT satellite (Basu et al., 2013; Deng et al., 2014; Liu et al., 2015).”

5987.3: You should mention recent work that has made use of nested grids together with inverse modelling methods in order to obtain high-resolution inverse results, such as Hooghiemstra et al., (2012).

Paper by Hooghiemstra et al., (2012) relates “to inverse modelling of CO, rather than the longer-lived species discussed in the rest of the manuscript.” Please see previous comment.

5988.19: Have you investigated the effect of changing the number of particles used in the Lagrangian model (both in terms of information content and computational time)? Perhaps you should mention how you settled on 1000 particles.

Added: “The number of particles has been chosen to optimize the computational cost without compromising the quality of modeling by Ganshin et al., (2013).”

More details are in paper by Ganshin et al., (2013): “One thousand particles were used in the calculations with our method, and this number was found to be optimal by comparing calculations using different numbers of particles. Increasing the number of particles by an order of magnitude (up to 10000) improves the results slightly but increases the required computer time many times. On the other hand, decreasing the number of particles to below 100 markedly worsens model data.”

5989.3: You should clarify what it means to have a coupling at the time boundary in the global domain, rather than at the spatial boundaries. I felt that this was unclear, and should be clearly explained in a development manuscript such as this one.

We revised section 2.1 and added short descriptions of coupling procedure to the text to clarify the sentences about the time boundary coupling: “The scheme of concentration calculation for the given location includes coupling of two model approaches. NIES TM calculates global concentrations for the selected time period (usually 1 year to exclude spin-up effect), but stops 7 days before the time of the observations. To obtain the concentrations for the observation time we transport the background concentrations from NIES TM gridbox to the location of observation point along the trajectory ensemble calculated by FLEXPART model and add contribution from surface sources. Therefore we have implemented the coupling at a time boundary in the global domain of the NIES transport model, while nested regional modeling systems such as one by Rodenbeck et al (2009) have to couple at both region boundary and time boundary.”

Detailed information may be found in original paper by Ganshin et al. (2012).

5989.25: You say that the model performs well in comparison with measurements, but you should further clarify this statement. Can you quantify the performance? Are there any major discrepancies in the model performance in (e.g.) interhemispheric exchange time or vertical mixing?

The text is revised as follows: “To ensure that this is the case, the NIES TM model has been evaluated extensively. Comparisons against SF_6 and CO_2 (Belikov et al., 2011, 2013b), CH_4 (Patra et al., 2011; Belikov et al., 2013b), and ^{222}Rn (Belikov et al., 2013a) measurements show the model ability to reproduce seasonal variations, interhemispheric gradient and vertical profiles of tracers." More details are in papers shown above.

5992.6: H is, by definition, already linear if it is a matrix.

Revised as follows: “Equation 2 has an analytic solution …”

5993.27-29: I do not think that this statement is supported by the values provided in Table 3. The high-resolution Eulerian model variously outperforms and is outperformed by the low-resolution coupled model at different sites. You should either remove or add qualifications to this line.

Section 4 was revised entirely.

5994.10: Although you have mentioned this in the text, I’m bothered by the fact that you have assessed the model performance at only a few sites in one region of the globe. There exist a number of observational datasets available for comparisons to model data, such as

those provided by the Global Monitoring Division of the National Oceanic and Atmospheric Administration. Can you examine the coupled model performance in tropical regions, for example?

Number of sites for validation of GELCA is increased. Section 4 was revised.

5996.12: This explanation of the model set-up for the accuracy test is a little unclear and should go into more detail. What do you mean by "perturbed by 1ppm per grid cell"?

There was misprint in this section.

The text was revised, as: "In the first test, adjoint simulations were carried out using an initial CO_2 distribution, zero surface flux for 2 days (1-2 January 2010) and a horizontal grid with resolution 2.5° × 2.5°. The adjoint gradient was then compared with that from the finite difference calculated using Eq. (3). This equation was selected in order to save CPU time by minimizing the number of forward model function calculations. For this test we used $\varepsilon = 0.01$."

5996.15: The sentence is unclear and needs rephrasing. How exactly are you saving CPU time here?

The sentence was revised as follows: "The adjoint gradient was then compared with that from the finite difference calculated using Eq. (3). This equation was selected in order to save CPU time by minimizing the number of forward model function calculations. For this test we used $\varepsilon = 0.01$."

In Eq. (3) evaluates perturbations at point $(x+\varepsilon)$. Eq. (4) evaluates perturbations at points $(x+\varepsilon)$ and $(x-\varepsilon)$. Thus, Eq. (4) requires a two times more simulations with forward model.

5997.17: This section needs more explanation. What simulations did you carry out here, exactly? What were your initial conditions for the adjoint model runs?

We added: "CO_2 initial conditions and fluxes were the same as those used for the CELGA forward simulations in Section 4"

We revised the section entirely.

6013-14: Keep the same order of cases from left to right when printing R, M and S in the plots (i.e. red-cs1, blue-cs2, green-cs3, not green, blue, red).

Done

Figures 4 – 7: It might be interesting to see panels showing the differences between the different results when using the different versions of the model, as it can be difficult to discern these differences by eye. Also, in Figure 5, are the left-hand and right-hand panels the same results, but aggregated onto different grids? I can see the logic of this, but it feels a little unnecessary to me to have both grids displayed. I'd consider showing only the results on the native model grid, as Figure 6 shows the combined results on the 2.5 degree grid anyway.

It is difficult to show differences between the different results when using the different versions of the model, because they have a different spatial extension. We tried to make the figures easier to compare and combined them. The section revised.

Technical corrections: Overall, the manuscript requires a thorough proofreading in order to make sure that there are no further technical corrections necessary. I have included all of the mistakes that I found.

Done

5984.7: tangent -> tangent linear

Revised

5984.11: As results -> As a result

Revised

5984.17: shown -> shows that

Revised

5984.20: demonstrates the high accuracy -> demonstrates high accuracy

Revised

5985.18: a density of observational network -> the densityof the observational network

Revised

5985.21: CO2 observation are not existing -> CO2 observations do not exist

Revised

5986.13: If tracer is a chemically inert -> if a tracer is chemically inert

Revised

5986.15: is running -> is run

Revised

5986.28: speeds -> speeds up

Revised

5987.10: To utilize of the strongest sides of both methods -> In order to exploit the advantages of both methods

Revised

5988.10: This may change in the font of the final manuscript, but the capital "I" and lower-case "l" appear identical in this equation. Maybe consider changing notation?

Revised. "L" and "l" are replaced with "S" and "s" correspondently.

5989.12: The model's employs -> The model employs

Revised

5989.16: we follows -> we follow

Revised

5989.22: ration -> ratio

Revised

5989.25: intercomparisons -> comparisons

Revised

5990.2: FLEXPART similar to other LPDMs consider … -> FLEXPART, like other LPDMs, considers ...

Revised

5990.4: sink and sources -> sinks and sources

Revised

5990.5: running -> tracking? following?

Revised

5990.6: no comma necessary here

Revised

5990.11: Gaussian grid T106 -> Gaussian T106 grid

Revised

5990.12: and in 6h time steps -> and 6-hourly time steps.

Revised

5991.2: 3-dimensional -> 3D

Revised

5991.6: driving -> driven

Revised

5991.8: “The” current version

Revised

5991.10: Remove extra ‘of’

Revised

5991.13: parameter estimation method used in different reanalysis dataset the use. . .

-> parameter estimation methods used in different reanalysis datasets, the use

Revised

5994.21: a construction of continuous adjoint -> construction of a continuous adjoint

Revised

5995.13: remoted -> remote (or distanced?)

Revised

5995.20: inpute -> input

Revised

5997.2: did not seriously changed -> did not significantly change

Revised

5997.8: the M in the denominator should be M’ (i.e. tangent linear)

Revised

6000.12: Performed in the paper analyses showed, that GELCA -> Analyses in this paper showed that GELCA. . .

Revised

6000.14: Decreasing of the Eulerian model resolution are not able to significantly distort. . .
-> Decreasing the Eulerian model resolution does not significantly distort. . .

Revised

6001.3: variation -> variational

Revised

6014: As Fig 2 -> As Fig 1

Revised

6015: Siberian observations towers -> Siberian observation towers

Revised

REFERENCES:

Hooghiemstra, P. B., M. C. Krol, T. T. van Leeuwen, G. R. van der Werf, P. C. Novelli, M. N. Deeter, I. Aben, and T. Röckmann (2012), Interannual variability of carbon monoxide emission estimates over South America from 2006 to 2010, J. Geophys. Res., 117, D15308, doi:10.1029/2012JD017758.