

Interactive comment on “The evolution of AMULSE (Atmospheric Measurements by Ultra-Light Spectrometer) and its interest in atmospheric applications. Results of the Atmospheric Profiles Of Greenhouse gasEs (APOGEE) weather balloon release campaign for satellite retrieval validation” by Lilian Joly et al.

Lilian Joly et al.

lilian.joly@univ-reims.fr

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Review#1

The evolution of AMULSE (Atmospheric Measurements by Ultra-Light Spectrometer) and its interest in atmospheric applications. Results of the Atmospheric Profiles Of

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Greenhouse gasEs (APOGEE) weather balloon release campaign for satellite retrieval validation

Anonymous Referee #1

Received and published: 15 November 2019

OVERVIEW: This paper describes the ongoing development of a novel new greenhouse gas (GHG) measurement system designed for deployment on standard meteorological balloons using an ultralight (< 3 kg) mid-IR spectrometer. Because in situ trace gas profile measurements are of high value for atmospheric chemistry, transport models, climate change studies, and satellite validation, this topic is of interest to, and suitable for, publication in AMT.

Thank you very much for your interest in our work. I warmly thank the Reviewer for his valuable comments which enabled us to improve this article.

RECOMMENDATIONS:

Reconsidered after major revisions.

GENERAL COMMENTS

1) While the paper’s topic is of high interest for reasons cited above, major revisions will be needed to bring the manuscript to publication quality.

2) Certain sections (detailed more below) would benefit from additional expository, where other sections are questionable as to the scope of a single paper. Additional content will be necessary to link the work with the large quantity of current and previous related work.

3) Linkage to current/previous work (e.g., other trace gas measurement systems and satellite validation) is essential as the paper seeks to identify itself as of something of “interest in atmospheric applications,” but then falls woefully short of pointing out specific applications with appropriate citations to existing/previous work (some given

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below). Previous work includes retrieval algorithm validation work from the AIRS and CrIS instruments and other in situ greenhouse gas measurements. The AIRS instrument isn't even mentioned in the submitted paper, nor campaigns such as HIPPO or ATom, nor well-established networks such as TCCON, which is a glaring oversight given the paper's original stated goal of "interest in atmospheric applications and satellite validation." This needs to be corrected in the revision.

I agree, a link with other chemical measurement instruments (e.g. AIRCORE) and with other measurement campaigns and satellite validation is missing. Changes have been made in the article to correct this deficiency.

4) There are numerous issues with grammar throughout (e.g., spelling errors, problems with singular/plural usage, etc.); I have identified out some corrections below, but not all of them.

SPECIFIC COMMENTS

1) Title: IMO the title could be shortened (the entire second part could be deleted) and modified. A suggestion is as follows: "The development of the Atmospheric Measurements by Ultra-Light Spectrometer (AMULSE) greenhouse gas profiling system and its interest in atmospheric applications"

Corrected

2) P. 1 a) Line 5: Rewrite "under weather and tethered balloons" as "via standard weather and tethered balloons"

Corrected

b) Line 8: replace "tethered balloon campaign and for a balloon campaign" with "two experiments"

Corrected

3) P. 2 a) Line 7-8: rewrite as "During the last decades, evidence has been accumulated

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that this climate change is directly related to the human activities" and include the 2019 IPCC Report and 2019 AMS State of the Climate citations.

b) Line 21: Here and elsewhere, plural/singular usage needs to be corrected. I do not have time point out every occurrence here in a formal review – it is systematic throughout the document and needs to be corrected. In this case, "many informations" should be replaced simply with "information" – "information" is already both singular and plural – there is no such word as "informations".

Corrected

4) P. 4 a) Line 26: "meters' " should be simply "meters".

Corrected

b) Line 27: Pertaining to plural usage, replace "lots of preparations" with "a lot of preparation"

Corrected

5) P. 5 a) Line 2: "The specificity of the balloons, to be able to access the profiles" – meaning not clear.

b) Line 11: "resolution of few meters" – needs to be more quantitative, e.g., "1-5 meters" (or something like that)

Corrected

c) Line 21: "atmospheric sensing" is much too vague – rewrite as "measuring atmospheric gas concentrations"

Corrected

d) Line 28: "Lambert Beer's law" is usually referred to either as "Beer-Lambert law" or "Beer's Law"

Corrected

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6) P. 6 a) Line 13: What is meant by “meteorological fields”? Such terminology usually refers to an analysis or model of a particular set of state parameters, but I don’t think that’s what you’re talking about with an Iridium module.

Corrected

b) Line 14: “computer fixed at 400 m” – what does that mean or how is it relevant?

Corrected

c) Line 16: Capitalize acronym “AMULSE”

Corrected

d) Line 18, Table Caption: Delete “This table illustrates” and begin simply with “Evolution (between 2015 and 2018. . .)” Corrected

7) P. 7 a) Lines 1-2: Please give the fractional differences (%) as well.

Corrected

b) Figure 1 Caption: capitalize AMULSE and don’t refer to the insets as (a), (b), (c), which usually simply refer to the panels of a multi-panel figure. Instead simply refer to them as “insets”.

Corrected

8) P. 8 a) Line 5: Here and elsewhere, replace “captive balloon” with “tethered balloon” – “captive balloon” is not a standard terminology.

Corrected

b) Line 8: Here and elsewhere, I suggest replacing the word “campaign” with “experiment”, based upon the descriptions of said experiments. A “campaign” usually refers to a dedicated mission that deploys single or multiple moving platform aircraft (e.g., ATom or CalWater), ships, or a dedicated observing network spread over an area and working in coordination with one another over an intensive observing period. Perhaps

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the Authors haven’t fully described their mission or I have misunderstood, but what they describe otherwise sounds more a like an experiment.

Corrected

c) Line 9: replace “spatial” with “vertical” – spatial resolution refers to horizontal resolution.

Corrected

d) Line 10: to what point spacing are the data interpolated? X, Y, Z : [20, 100, 100]

Corrected

e) Lines 10-13: Need to comment/discuss the boundary layer evolution shown on the figure, or otherwise delete the figure.

Corrected

f) Figure 2: The H₂O is given in %, but % what? I presume it’s not RH. Corrected

9) P. 9 a) Line 1: Reiterate what APOGEE stands for, and more details on where and when it was conducted.

APOGEE (Atmospheric Profiles Of Greenhouse gasEs) is the name of a French scientific project which has funded this project. Date included

b) Line 9: What does “GSMA” stand for? Corrected

c) Line 10: sentence needs period.

Corrected

10) P. 10 a) Figure 3 caption: Rewrite “connected in order to send” with “connected which measures and transmits”

Corrected

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b) Figure 4: Is this the “GSMA” site? More details are needed in the caption. Corrected
11) P. 11 a) Table 2: Either insert commas “,” in the altitude numbers (e.g., 19,121) or rewrite in km (e.g., 19.121).

Corrected

b) Line 3: “photosynthesis phenomenon”? How does photosynthesis “enrich” CO₂?

During the day, plants take advantage of photosynthesis. They release more oxygen than CO₂. During the night, there is no more photosynthesis, the plants breathe. They only emit CO₂. Corrected → plant respiration →

c) Line 6: insert “the year” before 2020 for clarity.

Corrected

12) P. 12 a) Section 5.1.2 Radiative Transfer Model: To my knowledge, greenhouse gases (or greenhouse gas channels) are minimally assimilated into NWP models – these models assimilate thermodynamic sounder channels (e.g., temperature/moisture) for forecasting. So it is not clear to me what the ultimate relevance of this section is to the paper, which ought to be more focused on the new (and novel) in situ gas sampling system.

Currently, most of the channels used in data assimilation for Numerical Weather Prediction are the CO₂ sensitive channels in the infrared spectrum to retrieve temperature profiles, H₂O sensitive to retrieve humidity profiles and some window channels. This is why a realistic consideration of a CO₂ prior profile is preferable at the input of Radiative Transfer Models in order to improve the quality of the simulated channels sensitive to this greenhouse gas as shown in the [Engelen et al., 2014] work. Finally, several meteorological centres are beginning to assimilate channels sensitive to ozone and methane for example (this is the case of the IFS model at the ECMWF) in order to extract information on temperature and humidity, but also on the molecules themselves in the case where the latter is also modified during the assimilation process.

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b) Line 6: “a prior” should be “a priori”

corrected

c) Line 11: “The differences between observations and simulations are called innovations.” – I am unfamiliar with the terminology “innovations”.

Innovation is the term used in the data assimilation community [Ide et al., 1999] can also be called first-guess departure. → innovation → has been replaced by → first-guess departure →.

d) Line 15: Capitalize TIROS.

corrected

13) P. 13 a) Line 14: insert “near the surface” between “high sensitivity” and “to window channels”

corrected

b) Line 15: Here and elsewhere: Use decimal points to separate the unit and tenth decimal places – at first I was completely confused when I saw 1.080 to 1.150 cm⁻¹, thinking these were near-IR to microwave channels when talking about an IR instrument. Please rewrite simply as “1080 to 1150 cm⁻¹”

corrected

14) P. 14 a) Last line: What does “ARPEGE” stand for?

It is the global NWP model at Météo-France as describe in Section 4.2.2.

15) P. 15 a) Last line: It should also be noted that there is a temporal difference in the overpass times between IASI and CrIS. Also, the Author should always be explicit as to what satellites they’re talking about. For IASI is it Metop-A, -B or -C? For CrIS is it SuomiNPP or NOAA-20?

As describe in Section 4.2.1, these are the MetOp-A and B satellites for the IASI in-

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strument and Suomi-NPP for the CrIS instrument. In the case of Figure 8, the IASI spectrum was measured from MetOp-B. Information added in the text.

16) P. 16 a) Equation 1: These equations could be expressed better. Why “EXP”? Is it possible to simplify the subscripts by abbreviating them to a simply letter (e.g., replace “simul” with “s”, “REF” with “r” or “b” for background, “AMULSE” with “o” for “obs”, etc.) Also, why are three variables in boldface?

Indeed, I have simplified the equation for a better clarity.

17) P. 17 a) Figure 9 caption: What does “,rp” mean?

“rp” is the abbreviation for respectively, which I replace here by “resp.”.

b) Lines 5-6: Please explain the relevance to the current paper.

As explained above, the CO₂-sensitive channels are used to retrieve the temperature. Thus, if these channels have a large first-guess departures, this can have a negative impact on the data assimilation process and temperature retrieval due to a degraded CO₂ prior profiles.

18) P. 18 a) Lines 8-10: It is not clear what relevance this has. Are simulations usually “validated” in this manner? Usually what is done is that radiative transfer model (RTM) “obs minus calc” are subjected to empirical bias correction “tuning” using observations such as this (where the RTM is then later used in retrieval algorithms), but that’s not “validation.”

We agree this is not validation as the number of cases is far too low. In this example, the comparison illustrates that the impact of switching from static CO₂, CH₄ and O₃ profiles to measured ones on simulations is rather small. This case study highlights the potential benefit of this kind of measurements if they were done on a more regular basis and for a wider network of measurement sites. The text has been modified accordingly.

19) P. 19: nothing

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20) P. 20: a) Line 14: include “AIRS, CrIS” along with IASI; Combine sentence fragments by replacing “.” with “,” before “which”.

corrected

b) Line 17: insert “level” after “pixel” and insert “or from cloud-cleared spectra as done by the AIRS and NUCAPS systems (Susskind et al., 2003; Smith and Barnett, 2019).” (References provided below)

corrected

c) Line 20: Replace “ozone analyses” with “ozone retrievals”

corrected

d) Line 23: Insert citation “(Nalli et al. 2018)” for the ozone retrieval validation connection.

corrected

e) Line 26: What does “restitutions” mean?

That’s a mistake, that’s the French word for retrievals.

21) P. 21 a) Line 2: What radiosondes?

radiosondes means in situ soundings made during the APOGEE campaign. I replaced all the “radiosondes” with “in situ soundings”.

22) P. 22: The Authors should provide a bit more information on their 1-D VAR retrieval algorithm and then should relate their results using this algorithm with results from established operational algorithms such as NUCAPS (as in the Nalli et al. Reference) and/or AIRS.

I described this algorithm in more details and compared it to what is done at other centres.

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23) P. 23 a) Figure 12: Because the Authors aren't even showing AMULSE measurements in these figures, it's important that they related it to their AMULSE work and also tie it back to other work on the subject of ozone validation using ozonesondes.

I have added references related to our work.

b) Figure 12d: Fix typo "Radiosondge" should be "Radiosonde"

Corrected and replaced by nothing.

24) P. 24 a) Figure 13 Caption: Simplify by rewriting as "As Figure 12, except for IASI. . ."

Corrected

b) How is "validating the quality of our simulations essential for NWP models"?

added in the article.

Indeed, as mentioned above, the a priori information of gases provided to RTTOV is invariant in time and space. In reality these gases such as CO₂, CH₄, O₃ or CO show significant variability, both temporarily and spatially in the atmosphere. In addition, carbon dioxide sensitive channels are often used to extract information on atmospheric temperature. However, the approximation of using a fixed CO₂ for the simulation of infrared satellite observations can have a negative impact on the quality of temperature retrieval as shown by the work of (Engelen et al., 2001) from the AIRS instrument. Finally, data assimilation systems have a bias correction method called VarBC (Auligne et al., 2007). However, this method can correct systematic biases that do not necessarily take into account the specificity of the variability of certain gases. Thus, it is preferable to correct biases at the source through an improvement of simulations in Radiative Transfer Models and will improve the analysis of temperature, humidity and wind in global model assimilations.

25) P. 26 a) Line 13: Please provide full citation. REFERENCES (not all-inclusive –

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please feel free to include more if you have them, including specifically references to other in situ measurements such as HIPPO, Atom)

Blunden, J. and D. S. Arndt, Eds., 2019: State of the Climate in 2018. Bull. Amer. Meteor. Soc., 100 (9), Si–S305, doi:10.1175/2019BAMSStateoftheClimate.1.

Chahine et al., 2006: AIRS: Improving weather forecasting and providing new data on greenhouse gases, Bull. Amer. Meteorol. Soc, 87, 911-926.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Nalli, N. R., et al., 2018: Validation of atmospheric profile retrievals from the SNPP NOAA-Unique Combined Atmospheric Processing System. Part 2: Ozone, IEEE Trans. Geosci. Remote Sens., 56(1), 598-607, doi:10.1109/TGRS.2017.2762600.

Smith, N. and C.D. Barnet, 2019: Uncertainty characterization and propagation in the community long-term infrared Microwave Product System (CLIMCAPS), Remote Sens., 11, 1227, doi:10.3390/rs11101227.

Susskind, J., C.D. Barnet, and J.M. Blaisdell, 2003: Retrieval of atmospheric and surface parameters from AIRS/AMSU/HSB data in the presence of clouds, IEEE. Trans. Geosci. Remote Sens., 41, 390-409.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2019-335, 2019.

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The development of the Atmospheric Measurements by Ultra-Light Spectrometer (AMULSE) greenhouse gas profiling system and its interest in atmospheric applications

Lilian Joly¹, Olivier Coopmann², Vincent Guidard², Thomas Decarpentier¹, Nicolas Dumelié¹, Julien Cousin¹, Jérémie Burgalat¹, Nicolas Chauvin¹, Grégory Alborn¹, Rabih Maamary¹, Zineb Miffah El Khair¹, Diane Tzanos², Joël Barrié², Éric Moulin², Patrick Aressy², and Anne Belleudy²

¹GSMa, UMR CNRS 7331, Université de Reims, U.F.R. Sciences Exactes et Naturelles, Reims, France

²CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France (NWP team)

³CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France (Instrumentation team)

Correspondence: L. Joly, GSMa, UMR CNRS 7331, Université de Reims, U.F.R. Sciences Exactes et Naturelles, Reims, France (lilian.joly@univ-reims.fr); O. Coopmann, Météo-France, CNRM/GMAP/OBS, 42 Avenue Gaspard Coriolis, 31057 Toulouse Cedex, France (olivier.coopmann@umr-cnrm.fr);

Abstract.

We report in this paper the development of an embedded ultralight spectrometer (< 3 kg) based on tuneable diode laser absorption spectroscopy (with a sampling rate of 24 Hz) in the mid-infrared spectral region. This instrument is dedicated to in-situ measurements of the vertical profile concentrations of three main greenhouse gases: carbon dioxide (CO₂), methane (CH₄) and water vapour (H₂O) via standard weather and tethered balloons. The plug and play instrument is compact, robust, cost-effective, and autonomous. The instrument also has a low power consumption and is non-intrusive.

It was first calibrated during an *in situ* experiment on an ICOS (Integrated Carbon Observation System) site for several days, then used in a *two experiments* with several balloon flights up to 30 km altitude in the Reims-France in 2017-2018 in collaboration with Météo-France/CNRM Centre National de Recherches Météorologiques.

This paper shows the valuable interest of the data measured by AMULSE (Atmospheric Measurements by UltraLight Spectrometer) instrument during the APOGEE (Atmospheric Profiles Of Greenhouse gasEs) measurement experiment, specifically for the vertical profiles of CO₂ and CH₄, which remain very sparse. We have carried out several experiments showing that the measured profiles have several applications: for the validation of simulations of infrared satellite observations, for evaluating the quality of chemical profiles from Chemistry Transport Models (CTM) and for evaluating the quality of retrieved chemical profiles from the assimilation of infrared satellite observations. The results show that the simulations of infrared satellite observations from IASI (Infrared Atmospheric Sounding Interferometer) and CrIS (Cross-Track Infrared Sounder) instruments performed in operational mode for Numerical Weather Prediction (NWP) by the Radiative Transfer Model (RTM) RTTOV (Radiative Transfer for TIROS Operational Vertical sounder) are of good quality. We also show that the MOCAGE (Modèle de Chimie Atmosphérique à Grande Échelle) and CAMS (Copernicus Atmospheric Monitoring Service) CTMs modeled ozone profiles fairly accurately and that the CAMS CTM represents the methane in the troposphere well compared to MOCAGE. Fi-

Fig. 1.