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Atmospheric Measurement Techniques Discussions

Interactive comment on "MAMAP – a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: instrument description and performance assessment" *by* K. Gerilowski et al.

Anonymous Referee #1

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The manuscript provides a description of a new airborne instrument to measure the absorption of CO2, CH4 and O2 in the shortwave infrared region which is used to measure the emission plume of localized CO2 or CH4 emission sources. The manuscript provides a detailed assessment of the signal-to-noise ratio and precision from theoretical considerations and measurements and they find that for homogenous scenes theoretical and experimental estimates agree well and are in the range of 1% or better. For inhomogeneous scenes, the estimated precision increases to values of 2.8%.

Furthermore, the manuscript describes different airborne measurements over localized sources which demonstrate that plumes from power plant or land fill can be observed with the instrument. This manuscript deals with a highly relevant topic which will be of high interest to the readership of AMT. However, I have a series of comments that should be addressed before publishing the manuscript in AMT.

Major comments: The manuscript is very long and it would clearly benefit from shortening the text and removing unnecessary details. There are many sections that appear very repetitive. In particular the introduction section with 9 pages appears to be unnecessary long and it discusses several publications from other authors in great detail. At the same time, several figures and the details shown in the figures are too small (Fig 5 to 11)

The manuscript really only deals with an assessment of the precision for the CO2/CH4 ratio and the authors argue that this is the most relevant quantity for estimating sources of hot spots. Of course it is true that using the CO2/CH4 ratio will significantly reduce most biases, but it can still be expected that the assumption of the retrieval, instrument calibration or atmospheric variations can cause significant biases that can vary on scales of kilometres e.g. due to the coupling with surface albedo. When attempting to estimate emission strength, it is of critical importance that the uncertainty of the estimate is well characterized and traceable. The last section of section 6 goes into this direction, but is very brief and incomplete. I would suggest that the authors include a critical discussion of the different error sources and the expected effect on the final product. In addition, it needs to be pointed out clearly that the described approach will either give CO2 or(!) CH4 columns, but not both. The instrument has the potential to deliver both, but this would require a very different retrieval approach and the presented performance assessment would not be valid in this case. Furthermore, as mentioned in the text, the instrument would be very interesting for satellite validation, but this would require that this observations from this instrument itself are validated.

Minor Comments: Title: '...performance assessment' It is not clear to me what is meant

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by performance assessment. The manuscript really only deals with SNR and precision.

Abstract: ... in-situ local point measurements from micro sites... ->What do you mean by micro-sties. Are there in-situ macro-sites ?

...for these scenes the CH4 and CO2 column retrieval precisions are typically about 1% ->This manuscript only deals with CO2/Ch4 ratios and not with simultaneous CH4 and Co2 column observations. You should make this point very clear.

The measurements by the MAMAP sensor enable estimates of anthropogenic, biogenic and geological emissions of localized intense CH4 and CO2 sources ->... could enable...

Introduction:

This arises in part because of the difficulty in estimating the highly variable natural and anthropogenic atmospheric source emissions in space and time -> This arises in part because of the difficulty in estimating the highly spatially and temporally variable natural and anthropogenic atmospheric source emissions.

Up to now, flux estimates of CH4 and CO2 in current global... -> Up to now, flux estimates of CH4 and CO2 based on current global...

...on precise atmospheric in-situ... -> on precise and accurate atmospheric in-situ

...of the surface observation site network... ->...of the surface observation network...

The footprint of the Tanso-FTS instrument is 10 km... -> The footprint of the Tanso-FTS instrument has a diameter of 10 km...

...as they combine range with high spatial resolution. ->... as they combine coverage with high spatial resolution.

Until recently, few airborne instruments have had the capability of measuring CH4 atmospheric columns with the high spatial resolutions... -> Until recently, few airborne

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instruments have had the capability of measuring CH4 atmospheric columns with high spatial resolutions...

....reach a threshold sensitivity during flight at typical flight... -> ...reach a threshold sensitivity during flights at typical flight...

In order to improve our understanding of CH4 and CO2 sources (and sinks) and their variability at micro and meso scales by using top-down constraints and to validate space-based measurements on meso and synoptic scales (i.e. from SCIAMACHY and GOSAT), new measurement systems are needed. These must be capable of measuring CH4 from high altitudes (>7 km) over different surface types at high horizontal resolution (<250m) over areas <10 km up to 200 km and yield a precision and accuracy equal or better than the accuracy achieved by current and planned sensors, i.e. with a precision and accuracy of equal or better than about 1–2% (Breon and Ciais, 2010) -> I don't think that the cited publication talks about requirements for airborne systems and I am wondering how there requirement have been inferred. A requirement on precision and accuracy of 1-2% is very large and I would argue that a regional bias of 2% will make it impossible to learn anything on CO2 fluxes.

Description of the MAMAP instrument

I am surprised that not more details are provided here. How is the ILS measured and how does it change across the detector. Has there been any attempt to measure absolute calibration? Do you measure the non-linearity of the system? Is there straylight in the system?

The O2-A-band NIR spectrometer

Since this manuscript only deals with CO2/CH4 ratios, the details of the O2 A Band detector and how it will be used together with the SWIR instrument are somewhat less relevant. Nevertheless, how is co-boresighting of both spectrometers achieved and how well can it be characterised.

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MAMAP retrieval algorithm and the determination of data products

There are several approaches to estimate the dry air column needed for the conversion of the greenhouse gas columns into column-averaged mixing ratios: ->Method (II) is exclusively used here and this should be pointed out clearly and thus only CO2/CH4 ratios are retrieved and CO2 and CH4 cannot be determined simultaneously. An alternative approach for the determination of XCH4 at least in regions where diurnal or spatial 5 CO2 variations are small is to assume that the CO2 is effectively constant and well mixed compared to CH4 ->Usually it is not assumed to be constant but a modelled CO2 is used.

...the path of the electromagnetic radiation is approximately identical... -> the path of the electromagnetic radiation is similar...

In summary all three methods can be used for MAMAP. The method, which performs best, depends on the target and the validity of the assumptions and the effort made to account for cloud and aerosol within the retrieval algorithm. -> ...all three methods could... Method (III) is not really applicable as it would require knowledge of surface pressure on a scale of a few meters. Method (I) would require at least very good co-boresighting of both spectrometers and some level of absolute calibration to obtain estimates of surface albedo.

...obtained in the SWIR (1.6 nm) ->... obtained in the SWIR (1.6 micron)

... with respect to a change of atmospheric parameters (mainly scaling factors for the CH4, CO2 and H2O vertical profiles and temperature profile shift) ->please provide a complete set of all retrieved parameters In addition to the geophysical fit parameters, a low order polynomial in the spectral domain is used to account for all smoothly varying spectral parameters, which are not explicitly modelled or inadequately known. These parameters include, for example, the MAMAP absolute radiometric calibration function, aerosol scattering, and absorption parameters and the surface spectral reflectance. ->It needs to be pointed out here that these assumptions can be made because only

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CO2/Ch4 ratios are considered here and it is assumed that biases introduced by these assumptions will ratio out. But even in this DOAS approach, you need to make some assumptions about surface albedo and aerosol loading for the radiative transfer calculations. This is currently attributed to wavelength calibration... ->How is the wavelength calibration carried out? Do you fit shift and stretch?

Inspection of the averaging kernels (Fig. 6)... ->please define averaging kernels

SCIATRAN accounts for this path doubling in the weighting functions for each layer ->I would assume that you cannot simply double the path, but you need to use 1+1/cos(SZA) as a factor

Hence a column averaged PSF will always overestimate the real concentrations in the total column, because the averaged weighting functions are smaller than the weighting functions below the aircraft. ->I have real difficulties to comprehend why such an approach has been chosen, e.g. the new BESD retrieval would clearly be much better suited for the analysis of the data. The correction factor c will surely depend on more than altitude, SZA and albedo. What about the vmr profile shapes, the aerosol loading, the water vapour column, temperature profile or potential cloud coverage above the aircraft altitude? Where is the surface albedo taken from? Finally, what it the estimated uncertainty of this parameter c?

Performance assessment of the SWIR channel In the following sections the terms precision, accuracy and measurement uncertainty are used. ->accuracy is not considered in this manuscript

Theoretical retrieval precisions Eq (13): The Gaussian error propagation for a ratio a/b will yield: sqrt(var(a)/b2 + var(b)* a2/b4) To account for small systematic offsets caused by the fit procedure... ->What kind of systematic offsets do you mean?

Ground based measurements In a second on-ground set-up, scattered light zenith radiance measurements (measurements of the down-welling diffuse radiance) were performed... ->How is this data analyzed without knowing the aerosol load?

Airborne single readout measurements over inhomogeneous scenes

Effects such as small spectral features of the earthshine spectral reflectance can also not be completely excluded as reason. ->Which kind of effect is meant here? The same statement is repeated in the section 4.3.4.

For a background concentration 1774 ppb this corresponds to an enhancement oft 20.59 ppb of the total column. ->For a background concentration 1774 ppb this corresponds to an enhancement of 20.59 ppb of the total column.

Below 1%total column precision, the accuracy variation induced by atmospheric effects (i.e. light path differences for CH4 and CO2 caused by scattering and absorption of aerosols and clouds and variations of the albedo/SSR and refractive index of the atmosphere) start to dominate the overall uncertainty variation. ->This statement implies that the relative accuracy is better than 1%. I would assume that the c-factor alone is uncertain by more than 1%. Please add evidence for this statement since accuracy is not addressed in the manuscript.

MAMAP targets

Achieving 1–2% total column accuracy.... Nevertheless, such a performance puts limitations on the target emissions which are suitable to be detected with the actual MAMAP total column precision of 1%. ->Again, it is assumed that the accuracy of MAMP is much smaller than the precision without providing any evidence.

In addition assuming that aerosol and cloud are smoothly varying, any impact of slow systematic changes in the accuracy of the measured CH4/CO2 column mixing ratio can be minimised by high-pass filtering the data. ->I would argue that many biases will be on a similar scale than the plumes that are targeted by MAMAP, in particular effects of aerosols and clouds will vary with surface albedo which will vary on a range of different scales. Please show that data with and without this filter.

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Over the globe, many different sources exist with fluxes exceeding the above calculated detection limits. ->It is not really about the detection of emissions, but about measuring their emissions with more accuracy than is done already. Thus, the considerations on flux estimates from MAMAP need to have some realistic uncertainties.

The approach used above can also be applied to estimate the detection limits required for extended regions of less intense source emissions assuming that the region is sufficiently homogeneous. ->The assumptions of the presented methods in this manuscript will be poor for larger regions and I would expect that for larger regions, small biases will become the dominant error source.

First results from measurements over localized emissions sources

In order to test the MAMAP sensitivity to score emissions and validate the results obtained in Sect. 4.3.4 flights over localized targets have been performed ->I don't think that the result shown in this manuscript qualifies as validation.

Systematic effects in the measured columns caused by solar zenith angle changes and cirrus cloud variations are minimised by high-pass filtering the data ->Why does the solar zenith angle introduce biases. As already mentioned above, I don't think that high-pass filtering is appropriate and it would be beneficial to show the unfiltered result as well.

Figure12/13: Albeit the high-pass filter, the Co2/Ch4 ratio still shows significant variations outside of the expected plume. Do you attribute this to atmospheric variations, instrumental issues or retrieval algorithm issues? Can this be used as a measure of the accuracy?

... in agreement with the predicted values ->What is the predicted value?

To exclude albedo/SSR dependent offsets as origin of the CH4 column increase.... ->How good is the fit and the correlation coefficient? ->It would be interesting to do the same test for the other flights shown in figures 12 and 13. ->Does this explain all the

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variations in outside of the wind direction from the source?

Summary

In that case the MAMAP CH_4 total column uncertainty variation will no longer be limited by the precision of the instrument but by the relative accuracy ->Again, there is no evidence in the manuscript that this is the case.

MAMAP measurements can potentially be used for micro-, meso- and synoptic scale validation of daily CH_4 and CO_2 chemical transport model simulations, and for validation of satellite measurements... ->this manuscript only deals with CO2/Ch4 ratios and it will be a completely different story to obtain accurate, independent and simultaneous Co2 and CH_4 column data.

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 3199, 2010.