The authors thank the reviewers for the constructive comments which have helped to improve the paper.

Answer to Reviewer #1.

A sensitivity study to justify the rationale for not applying averaging kernels before comparisons with other satellite reference measurements was discussed in section 2. However, no such study was described for the comparisons with the MkIV interferometer or the cryosampler balloon profiles, and the figures and text do not imply that MIPAS averaging kernels (AK) were applied to the balloon measurements. These comparisons should be presented with both the measured profiles and the profiles smoothed by the MIPAS averaging kernels, and bias estimates should be computed with respect to the smoothed balloon profiles.

The paragraph of the Section 2 discussing the sensitivity study does state that this concerns the satellite instruments only; indeed, the sensitivity study was performed for MkIV profiles as well, and the conclusions (not more than 2% change in the middle of the profile, where MIPAS AK are close to 1, and a bias larger than 200 % at the lower altitudes, where MIPAS AK are close to 0.1) concerns MkIV profiles as well.

The vertical resolution of the MkIV balloon profiles varies between 2-4 km. Immediately below the balloon altitude, it is 2 km. At lower altitudes it is 4 km. All three flights took place in [30N,40N] latitude band. As one can see at the [30N,40N] stripe of the Figure 2 (old Figure 1), this corresponds to MIPAS CH4 vertical resolution, so it is not surprising that the application of the MIPAS CH4 AK degrades the profile, biasing the comparison.

In turn, the cryosampler measurements do not provide continuous profiles but a series of independent point measurements, which are used as they are and at the heights where they were measured, without any regridding. These measurements are taken between appr. 10 and 30 km heights, with 1-3 km step. As one can see at the [30N,40N] stripe of the Figure 2 (old Figure 1), this step corresponds to MIPAS CH4 vertical resolution in this latitude band as well. This is discussed in the text, in the Section 3.3 “Comparison with cryosampler profiles”

We changed the text into :
“To be on the safe side, sensitivity studies were performed to assess the impact of the application of the averaging kernels; this was done for all reference instruments providing continuous profiles of methane, i.e. all satellite instruments and MkIV”.
and moved the corresponding paragraph about the cryosampler measurements from the beginning of the Section 3.3 “Comparison with cryosampler profiles” to the Section 2, right before the discussion of the sensitivity study.

No description of the cryosampler measurements is given and the references were not especially helpful (Levin et al., 1999 doesn’t mention cryosamplers). The measurement technique needs to be described, at least briefly. Mk1V vertical resolution should also be given or included in the table (see comment below). The introduction has no description of why we care about stratospheric methane –there should be a brief discussion of the chemistry/climate role of methane at different altitude ranges to motivate our need to understand the measurement biases.

The introduction now contains a summary of the physics and chemistry of methane. Section 2 contains now the description of cryosampler and MkIV measurements.

Line 20: “27 tangent altitudes” – state the total altitude range
Done.

Line 24: “The analysis is restrained on the reduced resolution..” Do you mean “The analysis is limited to: : :”?
Yes. We changed “restrained” to “limited”.
Also, what do you mean by the “corresponding baseline”?
While the processing scheme of the IMK/IAA MIPAS research processor stays unchanged, different versions of the data corresponds to different calibration of its secondary parameters such as: selection of parts of the spectra from which the species is retrieved (so-called microwindows); spectroscopy used; heights at which continual absorption coefficients are fitted etc.

Table 1. It would be useful to see the vertical range for comparison and representative vertical resolution for all the reference datasets.
We added the vertical range of comparisons into the table. As to the vertical resolution, the representative number varies with altitude, and given in all details it would overload the table. It is discussed in details at the end of the Section 2.
Also, for the cryosampler, if you have collocation criteria and comparisons, why are there no #matches or time overlap given?
Done

For viewing geometry, you could list “balloon, in situ”
The definition of “in situ measurements” is ambiguous among the communities. In some communities air sampling measurements are called in situ, while other communities reserve the term 'in situ' for measurements which are analyzed immediately when the sample is taken. A third type of terminology does not use the term 'in situ' at all if a sample is taken. To avoid confusion we thus avoid the term `in situ' and use the more specific term `air sampling'.

Line 113: “artificial 300% bias appeared on the extremities” Are these parts of the profile excluded from the comparison? If either instrument AK is close to zero, then the comparison isn’t meaningful. This should be stated here and reflected in the table if comparison vertical ranges are listed.

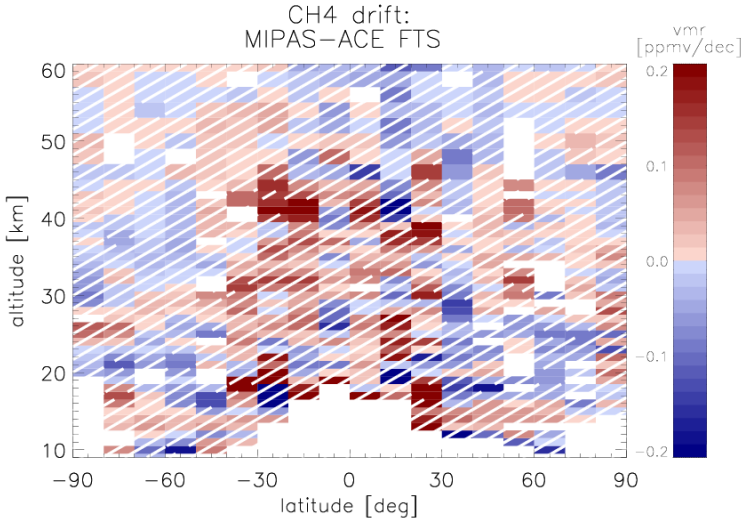
These parts of the profiles are not excluded from the comparison because we do not apply the averaging kernels. We now list in the table the vertical range of the reference instruments.

Line 227: very localized phenomena” Is this still there after applying the MIPAS AK?
Cryosampler measurements must not be seen as continuous profiles but as a series of independent point measurements. This means that not even smeared information about the atmospheric state between two sampling points is available. A regridding or application of AK makes no sense; instead, these data are used as they are and on the height where they were measured.
We changed the text so that this particularity of cryosampler measurements is pointed out.

Fig. 5: I can’t tell the difference between MIPAS seasonal mean and MIPAS mean collocated colors.
In order not to overcharge the plot, we removed the “MIPAS mean collocated” curve.

Fig. 6: Drift value should have associated error. Also, describe orange solid and dashed lines in figure caption.

Error associated are 2σ-uncertainties. Since most of drifts wrt ACE-FTS are insignificant, we decided to show rather the overall behavior of drift. We have replaced the example of a significant drift by the plot below.



Drifts of MIPAS with respect to ACE-FTS methane measurements as function of height and latitude. The bins where the significance is less than 2 sigma are hatched.

Fig. 7: Caption should say what you mean by ex-ante and ex-post (shouldn't have to search in text).

We added in the caption of the Figure a text explaining the terms ex-ante/ex-post.

Answer to Reviewer #2.

In the manuscript presented the authors wish to present to the scientific community the validation of the official MIPAS IAA/IMK methane product. This validation is performed via comparisons to other satellite and in situ measurements of methane using different comparative tools. The paper shows some interesting results however is lacking in many aspects:

first of all, I believe that the product should be presented in the beginning of the paper, maybe as a yearly zonal mean or whatever is more adequate and the physics of methane discussed. In this way, the reader will also be introduced to altitudes/seasons of importance to the rest of the text.

We have added a plot showing temporal evolution of methane at 12 km height; a discussion of the physics and chemistry of methane is also added .

Also, is this the only MIPAS CH4 product out there? How has it been compared to other products?
There exists four MIPAS Level 2 Processors, each one has now its own methane product. A homogenized description of the four processors and extensive comparison of their ozone products is given in (Laeng et al, 2015). In (Raspollini et al, 2014), among other species, methane from ESA Processor is compared with the three other products. All four products suffer from positive bias at heights below 25 km. We added corresponding references and discussion in the text.

is there a full resolution CH4 product?
Yes, there is a full resolution methane product from MIPAS IMK/IAA Processor. The MIPAS products from two MIPAS measurement periods should be seen as different datasets. The scope of the present paper is the validation of the Reduced Resolution product. We added corresponding explanation in the text.

Secondly, there is no discussion after each section is presented as to what is the physical meaning of the comparisons shown. How are these to be used by other scientists? How do the comparisons shown render this product good to be used by other groups, such as the climate community mentioned in the end of the conclusions section.

The text in sections was changed accordingly.

No mention is made as to whether this is a publicly available product even.
The product is publicly available from
https://www.imk-asf.kit.edu/english/308.php
we added corresponding text.

Lastly, I suggest that the prime authors read carefully through the annotated text I am attaching to this review and attempt to view their paper through the eyes of a third party interested in the latest in methane science.

Please find our replies below.

Page 2:
I assume this -1 is a typo error?
Yes, it is corrected.

I guess you need to explain the acronyms here.
Done.

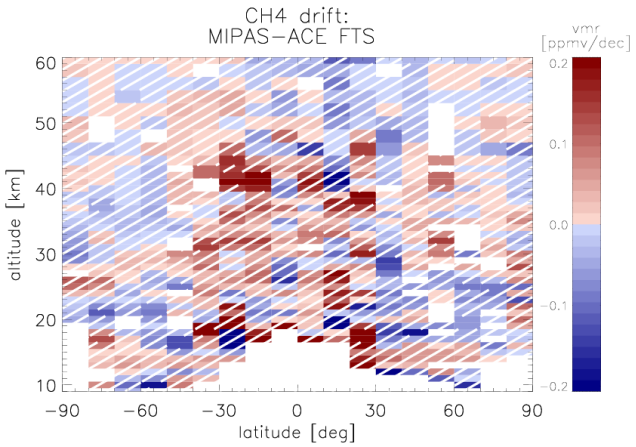
Ditto for this acronym.
Done.

What is this resolution?
From July 2002 until March 2004, MIPAS took measurements with a maximum optical path difference of 20 cm corresponding to a 'high' spectral resolution (HR) of 0.025 cm^{-1}. Due to problems with the interferometer mirror slide system, MIPAS performed very few operations in April–December 2004. In January 2005 regular observations resumed, but with reduced spectral resolution (RR) of 0.0625 cm^{-1}, which corresponds to an optical path difference of 8 cm, comparatively to 20 cm for HR period.
The description is now included in the introduction, also a Table 1 summarizes now the spectral resolutions of MIPAS measurements, theoretical, anodized, and real.

Are these in situ measurements ?
The definition of 'in situ measurements' is ambiguous among the communities. In some communities air sampling measurements are called in situ, while other communities reserve the term 'in situ' for measurements which are analyzed immediately when the sample is taken. A third type of terminology does not use the term 'in situ' at all if a sample is taken. To avoid confusion we thus avoid the term `in situ' and use the more specific term `air sampling'.
The cryogenic whole air sampler, operated by the University of Frankfurt, is deployed on stratospheric balloons. The instrument collects high volume whole air samples in stainless containers, that are internally electropolished and freezing out the air by means of liquid neon. After the flight the air is left to evaporate which provides high pressure whole air samples from different altitudes (Engel et al. [1997]). We added this description in the text as well.

I.e. 20% ?
Yes, 20% of uncertainty estimates values, provided with the data.
are these the *a priori* errors or the retrieval errors ?
Those are composed of the measurement noise and randomly varying parameter errors. We added this information in the section 5, which assess the quality of uncertainty estimates.

Page 3:
***Significant drifts with respect to ACE-FTS tend to have higher absolute values in the Northern Hemisphere, have no pronounced tendency in the sign, and do not exceed 0.2 ppmv per decade in absolute value*.**
And what does this indicate?
We have rewritten this section completely.
Due to the limitations of coincidences available, drifts MIPAS wrt ACE are mostly insignificant, see the plot below.



Drifts of MIPAS with respect to ACE-FTS methane measurements as function of height and latitude. The bins where the significance is less than 2 sigma are hatched.

Since most of drifts are non-significant, we decided to show rather the overall behavior of the drift. We have replaced the example of a significant drift by the plot above. Our conclusion is that although a drift is to be expected due to theoretical considerations (Kiefer et al, 2013) and analysis of other species (Eckert et al, 2014), we have not found any empirical evidence of a drift in MIPAS methane, using the available comparison data.

The Institut fur....
Corrected

Please mention here what these two resolutions are.
We included the values of high and reduced spectral resolution in the text.

Might be also interesting to note the range of heights as well.
Range of heights is added.

As above, Might be also interesting to note the range of heights as well.
Range of heights is added.

IAA - What is this acronym?
Instituto de Astrofísica de Andalucía; we added the abbreviation explanation.

Page 4:
MIPAS IMK methane retrieval - is this the same as the IMK/IAA retrieval?
IAA operates the version of MIPAS IMK processor adapted for special modes of MIPAS instruments. The dataset under validation was measured in the nominal mode. For consistency, we use throughout the paper the abbreviation *IMK/IAA processor*.

Replace with ", as seen in Figure 1."
Done.

I wouldn't say "only", it is quite remarkable that there are six instruments measuring the atmospheric state simultaneously.
Removed.

Provide the acronym.
BIRA = Belgian Institute for Space Aeronomy, the acronym is provided in the text.

Make a reference here to Table 1 where very important information is given of high interest to the reader.
Done.

What is this sample?
Size of the sample is given in the Table 1, column "number of matchs".
who/what decides what is sufficiently big?
It must be sufficiently big to provide meaningful statistics, at least a few hundreds collocations, taking however into account limitations on the initial number of measurements from the reference instrument. We changed the text to:
"*The choice of the collocation criteria was a result of the trade off between the collocations being as close as possible and the resulting sample being sufficiently big, at least a few hundreds measurements, distributed homogeniously over the measured part of the globe. For ACE-FTS, half ot the measurements lies at the latitudes over 60°, this gave the collocation criteria of 9 hours and 800 km. For SCIAMACHY and SOFIE, which have a denser sampling pattern, these were tightened to 5 hours and 500 km. For HALOE, whose time overlap with MIPAS reduced resolution period is less than eight months, the criteria were relaxed to 24 hours and 1000 km, which stays acceptable in terms of the physics of CH_4 in the stratosphere*."

This sampling pattern should also be included in the Table for all instruments/datasets.
This information is given in the references provided in the last column of the Table 1, and would overload the Table. The meaningful information is the size of the resulting sample of matchs which is given in the Table.

Page 5:
In terms of the physics of CH4 in the stratosphere, is that acceptable? normal? used in other studies? presented before?
Indeed, the collocation criteria are always limited by the sampling pattern of the reference instrument. In view of long chemical lifetime of methane, only atmospheric variability is taken into account when choosing these criteria, and the assumption that the same air samples are measured within the distance 1000 km and 24 h is pretty standard for instruments with low sampling pattern such as ground-based or balloon measurements. For instance, at Fig.13 in Park et al (1996) HALOE methane measurement are compared with 3 MkIV profiles, with coincidences 12 h – 600 km, 26 h-2400 km, and 24 h-60 km respectively. The same criteria as ours, 24h-100km, were used by de De Mazière et al. (2008) in validation of ACE-FTS methane v2.2 when comparing with mid-latitude stations.
We added a corresponding phrase in the text.

... with each satellite reference....
Done

Replace with .... "assessment of the precision of the pairs between MIPAS and each reference instrument...."
Done

"Indeed, it is usually done by comparing the standard deviation of the differences with the combined estimated random error (von Clarmann, 2006)
What does combined mean in this context?
As explained in (von Clarmann, 2006), the error of the diffrences can be estimated as

$$combined\ error = \sqrt{(mean\ MIPAS\ error)^2 + (mean\ ref.instr.error)^2}$$

And hence the co-location criteria play an important role?
Yes, this is why the Figure 2 is included in the paper: to illustrate the distribution of the matched pairs with respect to the variability of the air masses measured.

... from the...
Done.

... were changed by less....
Done

Page 6:
To the uninitiated eye the most striking feature of this Figure is the matching fluctuations/oscillations in height shown in the red and blue curves/comparisons. Maybe a small comment on that? and why is the green curve, the SCIA comparisons, following the same pattern?
The patterns are similar at heights under 25 km, where MIPAS has a known high bias. SCIA, in turn, at the same heights has a known low bias. We added this comment in the text.
Over 35 km, relative bias is more variable due to the low concentration of methane and the changing vertical gradient of the methane field.

Reading all these reasons for variability of methane between MIPAS and ACE-FTS it is a wonder that a 12 to 15% bias is achieved!
For most of the gases measured by these two instruments, the agreement is usually quite good.
The agreement is even more surprising if one remembers that half of the ACE measurements are taken at high (over 60°) latitudes, where the polar vortex, especially in the Northern hemisphere, starts to play a role. For instance, it can separate a matched pair into inside/outside of the vortex. Such a good agreement could mean that the collocation criteria are however reasonable enough to minimize the situations where one measurement is inside and another outside of polar vortex.

Page 7:
"Extensively used" and then providing only one reference from 18 years ago do not coincide. Please provide reference to more HALOE CH4 works.
Done

Where were the balloons launched from? by which organisation?
Corresponding information is added in the section 2.

The agreement with which MIPAS profile: the Sept one or the SON one?
There is no SON profiles on Figure 4 (new Figure 5), and the panel comparing the profile from the flight 20 Sept 2005 contains only one MIPAS profile : mean in Septembers 2005-2011.

Page 8:
I think that a sentence as to the scientific merit of these comparisons is missing: are they good? bad? mediocre?
They are reasonable. The key message of the comparison with MkIV profiles is less pronounced high MIPAS bias at heights under 25 km, and this message is stated at the end of the section.

what are the errors associated with the in situ measurements? within the MIPAS errors?
All this information is contained in the reference papers listed in the Table 2. We added in the Section 2 a short resume.

have any of the other satellite products been compared in papers to these in situ measurements?
ACE-FTS – no, HALOE – yes (Park et al, 1996), SOFIE – no, SCIAMACHY – no.

What are cryosampler measurements? who makes them? have they been used in other works? what is their error estimate? Important information is missing from this introduction.
A short description of the cryosampler technique was added in the Section 2.

This figure is incredibly busy and the information you are trying to convey cannot be seen at all. Not all these lines are paramount, either separate the plots or choose what to show.
We changed the plot accordingly.

How much is this in percentage?
We added the percentage value (less than 10%)
is it big? small? normal? expected?
The sentence that immediately follows the comment answers this question: "Unlike in the satellite-satellite comparisons, at 20-25 km the MIPAS measurements agree very well with the cryosampler measurements."

Page 9:
***This suggests that the cryosampler, which performs point measurements, samples a very localized phenomenon which is not resolved by MIPAS whose measurements represent for each profile point an air parcel of about 400 km in length times 30 km in width times 3 km in height. At the other altitudes, the cryosampler profile agrees reasonably well with both the collocated and the zonal mean MIPAS profiles*.**
What does this mean in physical terms? that there are no localised phenomena in other altitudes?
Yes, this suggests that atmospheric variability on small spatial and temporal scales is much smaller there. Thus the different sampling characteristics have less impact on the comparison.
a discussion on the scientific merit of this comparison is also important here.
While the small number of coincident measurements is a limitation of the comparison of MIPAS with the cryosamplers, the scientific merit is the high precision of the cryosampler data.
We added a corresponding sentence in the text.

Is this so? do the ACE-FTS co-authors agree with this statement?
Yes, this information is provided by Kaley Walker in person. We added a phrase
"… even though it is expected that the instrument would provide better long-term stability,because the occultation technique relies on ratiois of atmospheric spectra to exo-atmospheric spectra."

...., a recent study by....
Done

... at the 2sigma level....
Done

Significant to what level? 90%? 95%? why are you expecting a drift?
As stated in the previous sentence : at the 2-sigma level.
or are you not expecting a drift?
As stated in the previous paragraph : yes, we do expect the drift.

Section "Temporal evolution of the bias"

I find this paragraph somewhat disappointing. There is absolutely no discussion on the physicality of the findings, only one example at high NH latitudes for 20km is given where already the authors have claimed the MIPAS has a tendency to higher CH4 values. This section should be expanded, maybe a table of results, both significant and non-significant should be included, and a full discussion as well.

See the answer to the first comment on the Page 3 (same topic in the abstract)

Page 10:

What does "closed profiles" mean?

We replaced "closed" by "collocated".

And what did those two studies show? the fact that an approach was used does not give it merit.

We changed the phrase into :

"This approach was used in Sofieva et al. (2014) and Laeng et al. (2015) for evaluation of the quality of the uncertainties estimates provided with respectively GOMOS and MIPAS ozone measurements".

Both studies concluded that the uncertainty estimates were realistic, moreover, a cross-verification was performed by comparing the estimates of the natural variability obtained from the two instruments were concordant up to 1.5 %.

What does this term mean? is it the Sdiff?

As explained 2 sentences before, it is a sequence of $S_{diff}/\sqrt{2}$'s for different samples with tightening collocation criteria.

I do not think that the common reader should be expected to know what ex-post and ex-ante mean...

This terminology was introduced in (von Clarmann, 2006) and used in (Laeng et al, 2014).

We added reference to (von Clarmann, 2006), and define the rem in the text.

And? will you suggest to the PIs of this data to re-evaluate their error estimates? how will the knowledge gained with this analysis you made improve the IMK/IAA CH4 product? again, a scientific discussion of the findings of this paragraph is missing.

The uncertainty estimates are a major part of the characterization of the data. The aim of the geophysical validation of the error estimates is to see how realistic are the uncertainty estimates provided with the dataset. The user of the data should keep in mind that when he takes the values 1.7 ppmv for methane mixing ratio at certain heights, with uncertainty 0.1 ppmv, in reality it means "1.7 ppmv +/- 0.12 ppmv".

We added a discussion of the importance of the realistic uncertainty estimates in the beginning of the section.

It is the purpose of a validation paper to characterize the bias, precision and stability of a data set. While we agree that our main findings must be stated in a clearer manner, the question "and?" seems to challenge the usefulness of validation papers as such. With our final conclusion that MIPAS has a high bias at altitudes below 25 km, a reasonable random error estimate (estimated underestimation of about 20%) and no significant evidence of drift, don't we provide exactly the information a validation paper is supposed to provide?

SCIAMACHY

Done

Page 11:

This is the first time in the paper that the function of CH4 in the atmosphere is mentioned!
As suggested, we added the physics and chemistry of the methane in the introduction of the paper

"In the springs of the years 2005 and 2007, MIPAS methane distribution present secondary peaks at 25–27 km."
What is the physics behind this?
It turned out to be non-representative. When comparing MIPAS with SCIAMACHY measuring in [50N,70N] band with collocation criteria 5h – 500 km, part of the MIPAS measurements are located outside of the [50N,70N] band. It happens that for some months, including July 2005 and July 2007 where the two peaks mentioned in the text have occurred, this outside-[50N,70N] part is dominating in the collocation sample, leaving inside just a few measurements; that gives non-representative statistics. In order to avoid such situations, we enlarged the comparison band to [45N,75N].

... polar vortex....
Done

Hence, for the co-locaton criteria you have chosen, you should not compare the winter-times.
We prefer to make the comparison on the whole sample and carefully interpret the results obtained in these climatology plots, by taking the seasons into consideration.

Why these coincidences and not the MIPAS-SCIA coincidences?
In order to have a more global sample of measurements: SCIA measurements are concentrated at [50N,70N]. We added in the beginning of the paragraph the sentence "Our histogram analysis is illustrated on SOFIE dataset".

... present....
Done

I.e. in the SOFIE retrievals?
Yes, we added the precision in the text.

… onion-peeling …
What does this term mean?
Onion peeling is a standard numerical scheme for analysis of limb measurements. We have added a reference.

"The SOFIE histograms, however, presents several chaotic secondary modes. Such a structure is not seen in any comparison of MIPAS with other instruments, which hints at some systematic or retrieval-related effect causing the numerous positive and negative outliers, e.g. turning-points of onion-peeling related profile oscillations."
Again, a discussion as to the physics/meaning of this paragraph is missing.
Our last sentence attributes these features to the onion peeling scheme. With this, it is already said that there is no physical explanation because these features are attributed to a numerical artefact in the SOFIE data. For clarity, we add "Thus these features provide no evidence of any spurious characteristics of the MIPAS data".

It might be more prudent to claim between 10 and 20%. 14% seems to be too "specific" as value when you claim in the paragraph above that you cannot unambiguously infer the magnitude.
Taking into considerations all the values appearing between 10 and 25 km height at the Figure 4 (old Figure 3), then 0-20% should be stated. But 0% and 20 % values appears at just one height each, in the comparison with the instrument with small number of collocations. We claim that 14% is *the*

most likely estimate of the bias. For completeness, we now report both the most likely value and the range of values.

Page 12:

Does the climate community agree with this assessment? is 10 to 20% bias a reasonable bias for climatological studies?

The usefulness of a data set depends on its particular application. We have rewritten the conclusions so that its main points now are the following:

* MIPAS has a fairly realistic characterization of its random retrieval errors (a slight underestimation by about 20%).
* There is no empirical evidence of a drift.
* The bias has been characterized and can now be considered in studies where absolute accuracy is an issue. Obvious future activities contain the investigation and tentative removal of this bias.

The sentence "… this dataset can be used for climatological studies .." was removed from the conclusions because this depends on the particular type of study.

have such studies been performed either with MIPAS or other CH4 datasets?

Yes, for example study by M. Juckes with (non-validated) MIPAS data from Oxford processor https://earth.esa.int/envisatsymposium/proceedings/posters/2P10/507165ju.pdf but this is outside of the scope of this paper. The sentence "… this dataset can be used for climatological studies .." was removed from the conclusions.

Page 17

I think you should also note where you got the data from, personal communication or are they publicly available?

All datasets except Cryosampler are publicly available. We added this in the text of the section 2.

Figures

Fig.2: Please, reduce the amount of colours in the colour bar to something more manageable, like 32. Then make the tick marks round numbers, what kind of percent is 13.9?! What does the dark blue colour in the ACE-FTS comparisons mean, one co-location per month?

We changed the picture according to your suggestions.

As to dark blue color in ACE-FTS comparisons, they correspond to <200 collocations. There were just two bins where there were 1 collocations, otherwise they are at least 6. The plot on the right shows the distribution of number of collocations for the cells where they are less than 50 (so the white bins are either no collocations at all, or > 50 collocations).

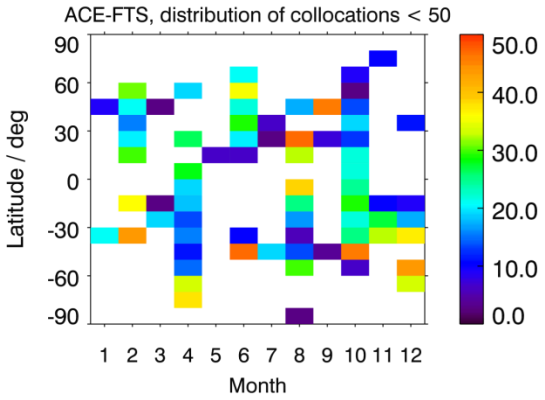


Fig. 5: This figure is incredibly busy and the information you are trying to convey cannot be seen at all. Not all these lines are paramount, either separate the plots or choose what to show.

We removed the "MIPAS mean collocated" curve.

Bibliography:

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Raspollini, P., Arnone, E., Barbara, F., Carli, B., Castelli, E., Ceccherini, S., et al. (2014). *Comparison of the MIPAS products obtained by four different level 2 processors*, Annals of Geophysics, 56.