

The article “Implementation and application of an improved phase spectrum determination scheme for Fourier Transform Spectrometry” by Hase et. al. describes a more robust method for determining the phase spectrum of a Fourier transform spectrometer and applies the described method to a selection of instruments used for ground-based measurements of atmospheric trace gases.

This work has been carried out in the context of the European Space Agency’s Fiducial Reference Measurements for Greenhouse Gases (FRM4GHG) programme and so there is an expected focus on retrieval of greenhouse gases from absorption spectra. The presented results show that the changes in retrieved CO<sub>2</sub> column using the new and traditional phase determination are very modest. However, the new and more rigorous method presented can provide insight into the instrumental features of the various spectrometers presented.

We sincerely thank the anonymous reviewer for the careful evaluation of our draft and the very useful resulting suggestions repeated below. In between, we insert our replies in red and sections of the revised draft in green colour.

The manuscript is generally well written, especially the introduction section, and the content will form a beneficial addition to the field. I would recommend that it is published subject to the changes and clarifications outlined below.

Specific comments:

Given that this work was carried out as part of FRM4GHG, the discussion of the impact of the phase determination on retrieved gas column is very limited, with quantified results only presented for one instrument and one species. It would be good to include these results for all of the instruments investigated and multiple species or spectral windows. Even if all the differences are at or below the magnitude reported for the IRCube CO<sub>2</sub> window, this is still a useful finding which should be noted.

We agree and have significantly extended section 5. In the updated version, we investigate results covering a wider range of airmasses using IRCube spectra. The 8730 – 8850 cm<sup>-1</sup> region and the retrieved XH<sub>2</sub>O data appears to be an ideal-typical example of a near-opaque band, which shows considerable deviations in the Mertz phase. In our feeling, a systematic investigation for all relevant bands and species is well beyond the scope of this paper, which mainly intends to introduce the algorithms now included in the COCCON preprocessing. (Unfortunately, a systematic investigation of the effects of phase calculation is not covered by the FRM4GHG project. We agree it would be desirable to include a systematic study of phase effects in a follow-up project.)

In section 2 the instruments should be introduced in a more consistent way. For example, there is very little discussion of the location of any of the instruments until the Izaña IFS125HR is introduced, and a paragraph is used to describe the observatory before a second, shorter paragraph describes the instrument.

We have significantly shortened the instrument descriptions and we have added an overview table. We now clarify in the beginning of the section that all portable spectrometers were operated at the Sodankyla site in the framework of the FRM4GHG project.

Furthermore, when describing the IRcube, it is noted that single or double-sided interferograms can be measured, but it is never made explicit which are used in this study.

In order to reach a  $0.5 \text{ cm}^{-1}$  resolution, the interferometer of the IRcube needs to be configured for single-sided interferograms. If the interferometer is configured for recording double-sided interferogram, then a maximum resolution of only  $1.0 \text{ cm}^{-1}$  is achievable. However, exclusively the configuration for recording  $0.5 \text{ cm}^{-1}$  single-sided interferograms is studied in the framework of FRM4GHG (it would be an interesting exercise to test which instrument configuration actually is superior, but this is not covered by the current FRM4GHG project).

A table in this section that summarises the important instrument characteristics would be very helpful to the reader.

We added such a table.

When describing the algorithm for the new phase determination a discussion on the choice of the threshold value  $T$  would be useful. What constitutes significantly above the noise and artefact level, and what are the implications of setting this value too low?

The phase unwrapping algorithm requires a locally smooth phase spectrum without sudden changes of phase orientation between adjacent spectral positions reaching or exceeding the value of  $\pi$ . In order to safely eliminate all points from the process, which might induce ambiguities in the phase unwrapping, a threshold of several standard deviations of the noise level (e.g., 5 or 6) should be chosen. This is not an overly demanding requirement, as it refers to the noise level of the low-resolution complex spectrum used for the phase calculation, which has a much lower noise level than the spectrum used for the trace gas analysis derived from the complete interferogram.

The question raised by the reviewer about potential artefacts is of special relevance. Imperfections of the measurement process, as detector nonlinearity, double-passing, or periodic sampling errors, can all superimpose spurious spectral flux to the real signal. This spurious flux is derived from spectral signal located elsewhere and therefore has a differing phase orientation. Contrary to noise superimposed on the phase, the phase orientation of spurious flux is continuous, so it does not vanish when a smooth phase model is fitted through the unwrapped phase spectrum.

Spectrometers used for the remote sensing of GHGs (aiming at accuracies well below the percent level) need to control such artefacts very well. The proposed construction of an analytical phase provides a sensitive tool for detecting residual artefacts in the spectra: when moving along the spectral abscissa into a more opaque region, the spurious flux becomes larger in proportion to the real signal. This introduces a rotation of the unwrapped phase, while the smoother analytical phase largely removes such phase excursions. Therefore, visualization of the difference between unwrapped and the analytical phase allows to recognize spurious flux. However, the proposed method only is a partial cure: while the reconstructed phase in the opaque region will be a much better approximation to the actual phase than the local Mertz phase, the spurious signals are still there and instrumental improvements are required to remove these spurious fluxes.

In Section 3, we have added the following sentences: For generating a phase point of the raw unwrapped phase, the spectral amplitude is required to exceed the adjustable threshold value  $T$ . It should be chosen well above the noise level of the complex spectrum used for the phase determination. Otherwise, the phase difference between adjacent points could occasionally exceed the requirement of phase differences to reside within the  $\pm\pi$  range. Moreover, the phase in nearly opaque spectral sections can be dominated by spurious signals (originating from, e.g., nonlinearity, double-passing, or sampling ghosts), so it is desirable to exclude these spectral sections from the calculation of the analytical phase anyway.

Technical corrections:

L75. ILS should be more fully introduced

We have included some extensions in this paragraph and added a reference. It now reads (new inserts in boldface):

In equation (1), we have extended the integration over all optical path differences. In practice, only a limited section up to a maximum optical path difference (MPD) is accessible. The truncation of the interferogram is equivalent to a multiplication with a boxcar function. **In spectral domain, this becomes a convolution with a sinc function. The spectral response inherent to an FTIR spectrometer is called instrumental line shape (ILS).** It can be adjusted by applying a numerical weighting function along the interferogram (the process of apodization). **Especially, numerical apodization allows to dampen the sidelobes of the sinc function, which allows – at the cost of widening the ILS width – to suppress the ringing surrounding unresolved spectral lines.** A proper description of the instrumental line shape (ILS) is further complicated due to the presence of practical imperfections of the interferometer [Hase et al., 1999]. Finally, we do not further follow the problem of spectral ordinate calibration here, because it, too, is not closely related to our aim of an improved phase reconstruction.

L176. The reference IFS125HR has not been discussed prior to here. Is this the Izaña instrument?

Thanks for rising this point. For clarification, we have added the following statement in the first paragraph of section 2:

For this purpose, extended measurement campaigns with the portable spectrometers under test are performed at the TCCON site Sodankyla operated by the Finnish Meteorological Institute. At this site, also regular aircore measurements are executed, which provide in-situ measurements of Greenhouse Gas profiles. Further details of the campaign setup are provided by Sha et al., 2020.

The reason for using the Izaña spectrometer for demonstrating the phase of an IFS125HR is due to the fact that the required interferograms were at hand (the TCCON data analysis for Izaña is operated by KIT) and that the Izaña spectrometer presents the basic TCCON configuration without optional instrumental extensions or any deviations from the standard setup.

L328. Include units after  $2 \cdot 10^{-5}$

Thanks, in the discussion of CO column change, we have added the notion “relative change” instead of “change” in order to clarify that the reported change is a unitless quantity.

Figure5. It isn't clear that there are two spectra plotted. Consider including a legend. The curve labelled residual isn't really a residual in the normal sense but a difference, consider relabelling. Include a description of the curve colours in the caption.

In order to clarify what is shown, we changed the ordinate label to “spectral signal” (we hesitate to name it “transmission”, as solar absorption measurements lack proper ordinate calibration). We have changed “residuals” to “spectra difference”.