Review of “Instrumental characteristics and Greenhouse gases measurement capabilities of the Compact High-spectral Resolution Infrared Spectrometer: CHRIS“ by El Kattar et al.

The publication under consideration introduces a new portable spectrometer commercially available from Bruker, which offers moderate spectral resolution (max optical path difference 4.42 cm) and wide spectral coverage (680 – 5200 cm^{-1}). The authors present the instrumental setup, the methods applied for achieving radiometric calibration, and finally present a theoretical study on the presumed instrumental capabilities.

The topics addressed by the paper match well with the scope of AMT. However, in my impression, the actual elaboration falls short with respect to the premises stated in the title, so major extensions (and a readjustment of the title?) are required before the work can be considered for publication in AMTD.

The title phrase “Instrumental characteristics” would suggest that real world instrumental characteristics are elaborated and reported, what currently is reported hardly reaches beyond the specifications provided by the manufacturer. The following questions need to be addressed:

(1) Which SNR is achieved in the measured spectrum as function of wave number (this also requires the specification of scan speed and total scan time applied, which is not reported in the current version of the draft)?
(2) How stable are the radiometric characteristics of the device (use e.g. Allan deviation plots of spectral or derived quantities, see e.g. the investigation performed on a portable spectrometer by Chen et al., 2016)? Characterize the instrumental line shape (ILS) by using lasers, gas cells or open path measurements (see, e.g. Frey et al., 2015). Is the ILS near the nominal expectation? Does the spectrometer achieve the nominal resolution at all?
(3) On which levels other well-known important kinds of spectral artefacts are controlled which might critically detoriate retrieval quality? For a broadband spectrometer covering more than one octave along the frequency axis non-linearity, double passing and sampling ghosts need to be investigated.
(4) The spectrometer offers higher spectral resolution than other portable units described earlier by other investigators. Nevertheless, it still uses a similar non-stabilized He-Ne laser (which might drift during recording interferograms). Which recommendations concerning applied scan speed result from this? How many interferograms can be coadded before spectral recalibration is needed in order to avoid degradation of spectral resolution?

The title phrase “Greenhouse gases measurement capabilities” would suggest that some kind of empirical validation and verification with respect to other independent observation systems is performed. A high level of precision and accuracy needs to be achieved (in the sub percent range), otherwise remotely-sensed measurements of column-averaged abundances of carbon dioxide or methane are essentially useless due to the low variability of these long-lived gases in the atmosphere. The TCCON was the first network to solve this task for ground based solar absorption spectroscopic observations. The successful strategy was to extend spectral observations into the near infrared including the 1.26 um band of molecular oxygen, so transferring the absolute measurement of a column amount into a relative measurement of the ratio of the target gas column to the column of molecular oxygen. Target gas and oxygen column amounts are derived from the same spectrum and the fact that the dry molar fraction of molecular oxygen is well known can be exploited. This strategy reduces the impact of many instrumental and other detrimental effects. It is difficult to see how a spectrometer not using the oxygen reference can match the abovementioned requirements. For demonstrating that the quality of data collected with CHRIS nevertheless is sufficient for validation and other purposes, a long-term side-by-side empirical test next to a TCCON spectrometer would be required. The period of investigation should cover at least one year for demonstrating the measurements can reproduce the annual cycle of the column-averaged abundances and for investigating possible biases related to atmospheric humidity, solar elevation, and other possible impact factors. Stability characteristics of the portable EM27/SUN spectrometer have been investigated by Frey et al., 2018 (measuring three years side-by-side to a TCCON spectrometer). First results of a long-term study performed at the TCCON site Sodankyla encompassing different kinds of portable spectrometers have recently been presented by Sha et al. (currently handled in AMTD: AMT-2019-371).

Judging from these studies and the experiences gained by TCCON, main obstacles in achieving the desired quality level are all kinds of practical instrumental issues and various details of the data processing, which all need to be addressed. The argumentative connection between the schematic theoretical information content analysis presented by the authors and the actual “greenhouse gases measurement capabilities” of CHRIS therefore seems weak. The theoretical study can only provide a rather optimistic theoretical extrapolation of the instrument’s capabilities, and would suggest a modified title as “…and potential Greenhouse gases measurement capabilities …” or alike.

I would recommend adding substantial empirical evidence concerning the capabilities of measuring greenhouse gases, especially as the spectrometer was already operated side-by-side to a TCCON spectrometer on Tenerife island and I assume together with other instruments and aircore soundings during MAGIC. I understand that the data analysis scheme for CHRIS is still under development, but well-characterized codes for the processing as GFIT are available and could be used meanwhile.

A couple of more detailed comments on the information content analysis:

Under Equation 5 it is stated that the forward model F takes into account surface emissivity – not a good example in case of an upward looking solar absorption spectrometer as considered here.

Under Equation 7: the a-priori covariance matrix describes our assumptions concerning the *variability* of the a-priori profile.

Line 235: the model atmosphere extends only up to 20 km altitude? This neglects a non-negligible fraction of the total column for e.g. carbon dioxide.

Line 240: The assumption of zero off-diagonal elements in the a-priori covariance for long-lived greenhouse gases is highly unrealistic. Climatological data describing the variability of greenhouse gases profiles are available and should be used.

Line 255: Handling water vapor as a non-retrieved parameter does not match with retrieval strategies as applied in practice. Water vapor will be part of the retrieved state vector if in the spectral range under consideration it is not negligible as interfering species.

Table 2 is inconsistent. Either “IFS125HR” refers to a TCCON spectrometer, then 45 cm MOPD is correct or it refers to an IFS125HR spectrometer operated by NDACC, in this case the 0.005 cm^{-1} resolution is reasonable. The specified spectral range is incorrect for either network. From the viewpoint of an information content analysis it might be preferable to separate the two kinds of spectrometers, the FTIR spectrometers operated in the framework of NDACC and those operated by TCCON.

Line 325 ff: Both TCCON and EM27/SUN (dual-channel version) spectrometers offer a lower wavenumber limit of about 4000 cm^{-1}.

References:

Chen, J., Viatte, C., Hedelius, J. K., Jones, T., Franklin, J. E., Parker, H., Gottlieb, E. W., Wennberg, P. O., Dubey, M. K., and Wofsy, S. C.: Differential Column Measurements Using Compact Solar-Tracking Spectrometers, Atmos. Chem. Phys., 16, 8479–8498, https://doi.org/10.5194/acp-16-8479-2016, 2016

Frey, M., F. Hase, T. Blumenstock, J. Groß, M. Kiel, G. Mengistu Tsidu, K. Schäfer, M. Kumar Sha, and J. Orphal: Calibration and instrumental line shape characterization of a set of portable FTIR spectrometers for detecting greenhouse gas emissions, Atmos. Meas. Tech., 8, 3047-3057, doi:10.5194/amt-8-3047-2015, 2015

Frey, M., Sha, M. K., Hase, F., Kiel, M., Blumenstock, T., Harig, R., Surawicz, G., Deutscher, N. M., Shiomi, K., Franklin, J. E., Bösch, H., Chen, J., Grutter, M., Ohyama, H., Sun, Y., Butz, A., Mengistu Tsidu, G., Ene, D., Wunch, D., Cao, Z., Garcia, O., Ramonet, M., Vogel, F., and Orphal, J.: Building the COllaborative Carbon Column Observing Network (COCCON): long-term stability and ensemble performance of the EM27/SUN Fourier transform spectrometer, Atmos. Meas. Tech., 12, 1513-1530, https://doi.org/10.5194/amt-12-1513-2019, 2019