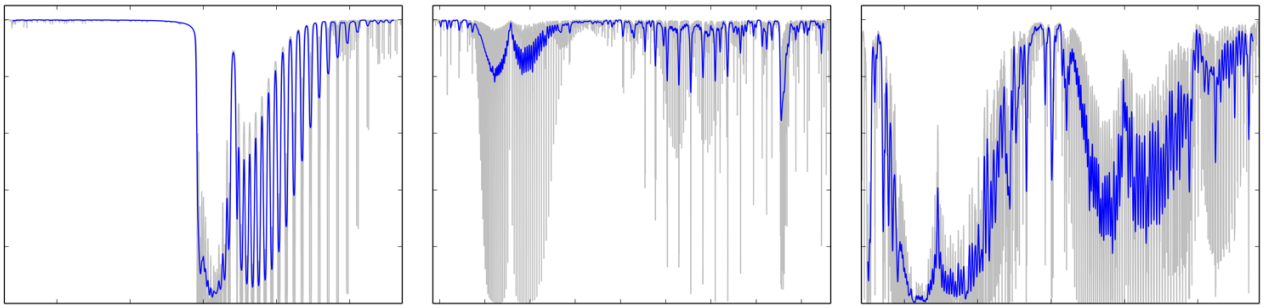

Study on Spectral Sizing for CO_2 Observations: Executive Summary

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To expand the current European Copernicus Programme, ESA initiated studies on six high-priority candidate missions including a dedicated mission to monitor anthropogenic CO_2 emission sources. To this end, atmospheric CO_2 column concentrations will be measured by a three-band spectrometer based on GOSAT and OCO-2 heritage, both are two missions in space measuring CO_2 on a global scale. To address all objectives of the envisaged CO_2 candidate mission asks for a well-balanced design of a satellite payload accounting the following key performance aspects:

- Global data coverage within 2-3 days
- Observation capability of individual CO_2 emission plumes
- High XCO_2 accuracy $\leq$ 0.5 ppm
- High XCO_2 precision $\leq$ 0.7 ppm

In this study we elaborated on the spectral band specification of the CO_2 spectrometer covering the 0.76, 1.61 and 2.0 μm (NIR, SWIR-1 and SWIR-2) band to meet the mission accuracy and precision requirements. The study included extended trade-off analyses for a wide range of geophysical scenarios with global coverage considering driving instrumental errors such as spectrometer straylight, instrument polarization sensitivity, radiometric offset and knowledge errors of the instrument spectral response. To this end, we considered a challenging but feasible signal-to-noise performance of the spectrometer. Our evaluation is based on three algorithms to infer XCO_2, which are developed and maintained at three key research institutes in Europe. Our analysis led to the specification of the spectral sizing of the CO_2 spectrometer as indicated in Table 1. As the envisaged CO2M payload includes also a cloud imager with a dedicated spectral band for cirrus detection at 1.38 μm, optionally the SWIR-2 band can be narrowed to 1993-2095 nm allowing for an improved spectral resolution of 0.3 nm. The confidence in the proposed spectral sizing of the spectrometer is supported by XCO_2 retrievals from GOSAT and OCO-2 measurements, which are reduced in spectral resolution applying a spectral smoothing to the observations.

Our study is complemented by a detailed analysis of scattering induced XCO_2 errors including the development of mitigation strategies. For all investigated spectral sizing of the spectrometer, the XCO_2 biases due to erroneous light path through the atmosphere are non-compliant with the stringent mission requirements. Therefore, we propose a multi-angle polarimeter (MAP) as an additional CO2M payload instrument. Here, the observations of spectral radiances and the degree of linear polarization are particular sensitive to aerosol information. Using both the spectrometer and the polarimeter in a synergistic manner will enable us to characterize the atmospheric light path with sufficient accuracy to meet the XCO_2 mission objective. We specified two equivalent polarimeter concepts: (1) a polarimeter measuring radiances and polarization in discrete spectral bands (MAP-band) and a spectro-polarimeter, which measures a continuous radiance spectrum with the state of linear polarization as a sinusoidal modulation of the spectrum. Key instrument characteristics of the polarimeter are summarized in Tab. 2. The complementary payload of a three-band spectrometer, a multi-angle polarimeter and a cloud imager provides a unique and compliant instrument suite for anthropogenic CO_2 monitoring on spatial scales of single point sources, cities and countries.

Table 1: Instrument spectral sizing of the proposed CO2M spectrometer. For the SWIR-2, the number in parentheses specify an alternative specification based on the fact that the cloud imager observes a saturated water vapor absorption band around 1.38 µm for cirrus detection.

	NIR	SWIR-1	SWIR-2
Band width	747-773	1590-1675	1925-2095 (1993-2095)
resolution	0.1	0.3	0.55 (0.32)
Sampling ratio	3.1	3.1	3.3 (3.0)

Table 2: Key performance aspects of the Multi-Angle Polarimeter for CO2M. The 753 nm spectral channel of MAP-band should measure only radiances in the nadir direction for radiometric cross-calibration between the payload instruments.

	MAP-band[1]	MAP-mod[2]
spectral coverage [nm]	410, 443, 490, 555, 670, 753, 865	385-770 nm
Radiance resolution [nm]	20, 20, 20, 20, 20, 9, 40	5 nm
DoLP resolution [nm]	20, 20, 20, 20, 20, -, 40	15@385nm - 40@770nm
Number of observation angles	40	5
Radiometric uncertainty	3%	3%
DoLP uncertainty	0.0035	0.0035

[1] discrete spectral bands (band polarimeter)
[2] contiguous spectral samples (spectro-polarimeter)