Abstract. Methane is the second most important anthropogenic greenhouse gas in the terrestrial atmosphere. Thus any attempt to understand its impact on climate change requires knowledge of its sources and sinks, which may be derived from high precision satellite measurements. A possible OCO-like [Miller et al., 2007] spaceborne measurement of methane by using reflected sunlight from the ground in the near infrared bands of methane at 4100–4300 cm⁻¹ and 5900–6100 cm⁻¹ is discussed. It is shown that by making use of the reflected sunlight, the sensitivity peaks at the surface, thus allowing better observations of the sites of methane’s sources and sinks.

Choice of CH₄ bands

There are two choices of spectral regions for methane observations in the solar absorption region. The many absorption bands between 4100 and 4300 cm⁻¹ is one choice and the one band near 6000 cm⁻¹ is the other (Figure 2). Other spectral regions in the solar absorption region contain methane absorptions that are too weak to be useful.

The 4100–4300 cm⁻¹ region contains a dense number of methane lines belonging to the ν₂ + ν₃ and ν₂ + ν₃ + ν₄ bands; at 6000 cm⁻¹, the 2ν₂ band is the major component. On the basis of band strength alone the absorptions at 4200 cm⁻¹ are a clear choice. However, the absorptions at 6000 cm⁻¹ are less dense and the band strength is distributed among many fewer absorption lines. Therefore, there are some isolated lines in that band that have stronger peak absorptions that are comparable to the absorptions in the stronger bands at 4200 cm⁻¹. The absorptions in both spectral regions have absorptions that are about the right strength for accurate measurements of methane absorptions in a nadir observation. Another consideration is interference; the 2ν₂ band is possibly the better choice on that basis, but in neither spectral region is that a serious consideration if high resolution observations are made.

Information content

On one hand, the measurement accuracy of a channel is always limited by the signal-to-noise ratio of the instrument; on the other hand, according to the Bayesian theory [Rodgers, 2000], the covariances of the underlying atmospheric state and the instrumental accuracy. One way to characterize the usefulness of a channel is from its information content.

For a single channel, the total variance of a measurement at wavenumber ν is given by:

\[ \sigma^2 = \int a_{\nu}^2 \, dH \]

where \( a_{\nu} \) is the covariance matrix of the methane concentration [CH₄]. We assume that \( a_{\nu} \) can be described with a Markov process such that it takes the form:

\[ a_{\nu} = a_{\nu+1} \]

We can then define the degree of freedom \( d_F \) and Shannon information entropy \( H_F \) as:

\[ d_F = \frac{\sigma^2}{\int a_{\nu}^2 \, dH} \]

\[ H_F = \log \frac{1}{d_F} \]


Future work

Our next goal is to determine the precision of methane measurement from inverse modeling [Butler et al., 2004] such that the determination of sources and sinks become feasible. Based on the information content, we will determine which of the two bands we have discussed above is suitable for making the measurement.

References


Figure 1. SCIAMACHY column averaged mixing ratios of methane gridded on 1°x1° in 2004. Adapted from Frankenberg et al. (2008).

Figure 2. Transmittance of the methane bands in 4100-4300 cm⁻¹ (left) and 5900-6100 cm⁻¹ (right).

Figure 3. Jacobians of the strongest methane bands in the mid-latitude summer model atmosphere. Left: 4218.3 cm⁻¹; middle: 6003.0 cm⁻¹. The reference methane profile is shown on right.

Figure 4. Transmittance of the methane bands in 4100-4300 cm⁻¹ (left) and 5900-6100 cm⁻¹ (right).

Table 1. Degrees of freedom and Shannon information entropy of the proposed measurement of methane using the bands and resolutions shown in Figure 3.

Table 2. Emissions and concentrations of methane at different altitudes are calculated (Figure 3). The vertical profiles of pressure, temperature and methane are from the Mid-Latitude Summer Model Atmosphere [Anderson et al., 1986]. The surface is assumed to be Lambertian, with a constant albedo of 0.13 (corresponding to an ocean surface). The derivatives are estimated by the 3-point Lagrangian interpolation method, with the perturbations ±1%, 2% (a unperturbed reference) and ±10% applied at each wavenumber and altitude. Notice that the derivatives must be divided by the thicknesses of the atmospheric layer to cancel out the mass column effect in the radiative calculations. Only the Jacobian of the strongest bands at 4218.3 cm⁻¹ and 6003.0 cm⁻¹ are shown in Figure 4. They are averaged over several “instrumental resolutions”: 1, 5, 10 and 50 cm⁻¹. Since the 2ν₂ at 6003.0 cm⁻¹ is asymmetric, the center for the line window is shifted a bit to 6001.5 cm⁻¹ to capture other structures that are symmetric about the 2ν₂ band.

Regardless of the instrumental resolution, at Jacobians are peaked at the surface. These bands are therefore potential candidates for the measurement of methane concentrations near the surface level. Since there are a lot more methane lines in the 4100-4300 cm⁻¹ bands, the sensitivity has less variations with respect to the instrumental resolutions, even if the latter is very coarse. However, as far as high resolutions, e.g. <1 cm⁻¹, are concerned, the bands are very similar, and the retrieved quantities from these bands should be very close.

Jacobians

The assessment of global sources and sinks of methane requires a remote-sensing that is sensitive at the surface. This can be achieved if the reflected sunlight is employed [Kuang et al., 2002]. We use MODTRAN [Berk et al., 2004] to simulate the total outgoing radiance at the top of the atmosphere in the band regions 4100-4300 cm⁻¹ and 5900-6100 cm⁻¹, where the thermal components are negligible. Since only methane will be perturbed in the calculation, we use a model atmosphere with methane as the only trace gas. To zeroth order, the resultant spectra are the reflected sunlight multiplied by the transmittance functions described above.

The Jacobians of the total outgoing radiance with respect to methane concentrations at different altitudes are calculated (Figure 3). The vertical profiles of pressure, temperature and methane are from the Mid-Latitude Summer Model Atmosphere [Anderson et al., 1986]. The surface is assumed to be Lambertian, with a constant albedo of 0.13 (corresponding to an ocean surface). The derivatives are estimated by the 3-point Lagrangian interpolation method, with the perturbations ±10%, ±2% (a unperturbed reference) and ±10% applied at each wavenumber and altitude. Notice that the derivatives must be divided by the thicknesses of the atmospheric layer to cancel out the mass column effect in the radiative calculations. Only the Jacobian of the strongest bands at 4218.3 cm⁻¹ and 6003.0 cm⁻¹ are shown in Figure 4. They are averaged over several “instrumental resolutions”: 1, 5, 10 and 50 cm⁻¹. Since the 2ν₂ at 6003.0 cm⁻¹ is asymmetric, the center for the line window is shifted a bit to 6001.5 cm⁻¹ to capture other structures that are symmetric about the 2ν₂ band.

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Table 1 summarizes \( d_F \) and \( H_F \) for the channels and the respective resolutions in Figure 3. As discussed above, there are less bands around 6000 cm⁻¹, and thus it is more prone to the geographically sparse and prone to spatial bias. Both of these issues are shortcomings that a space-based observation program would be perfectly suited to remedy.

Recently, a global map of methane has been reported from the SCIAMACHY measurement (Figure 1), but which has led to great controversies whether there are aerobic sources of methane [Frankenberg et al., 2008]. Obviously, independent satellite measurement is tempted.