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Short communication

Estimating the uncertainty of methane emissions from New Zealand's ruminant animals

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Abstract

In New Zealand, the principal source of methane emissions to the atmosphere (E_{CH_4}) is ruminant animals, up to ca. 85 million sheep and cattle fed by year-round outdoor grazing on pasture. Uncertainty analysis is developed for a change in E_{CH_4} from 1 year to another (ΔE_{CH_4}). For 1990 and 2003, annual E_{CH_4} averaged 1036 Gg and ΔE_{CH_4} was 88 ± 52 Gg with 95% certainty that $\Delta E_{CH_4} > 0$ was due to a true increase of emissions. The standard error was largely attributed to uncertainty in estimating pasture herbage consumption from the animal's energy requirements for maintenance and production.

Keywords: Sheep; Cattle; Trace gas

1. Introduction

Stabilisation of greenhouse gas emissions to the atmosphere at 1990 levels, assuming these can be precisely determined, is a goal of the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC is a climate treaty based on changes in the annual emissions of member countries, not the absolute values as suggested by popular misconception. Awkwardly, a change in the annual emissions will probably be smaller than the corresponding absolute values. It is inherently challenging to precisely estimate a relatively small change. A priori, given the epistemic limits, estimating the corresponding uncertainty is also daunting at the national and annual scales required by the UNFCCC. Nevertheless, atmospheric scientists in this policy domain must answer questions about uncertainty (Shackley and Wynne, 1996).

Since 1992, in accordance with its commitment to the UNFCCC, New Zealand has produced annual (3-year-running averages) inventories of greenhouse gas emissions commencing with 1990. This includes methane (CH_4), mostly from ruminant animals. At the beginning, on 30 June 1990 during winter, New Zealand had 57.9 million (M) sheep, 4.6 M beef cattle and 3.4 M dairy cattle grazing year round on most farms (Ministry of Agriculture and Forestry). In the spring, about 35 M lambs were born, of which 26 M were slaughtered before the following autumn. There were also about 2 M replacement calves born in the spring.

New Zealand's annual CH_4 emissions inventory is based on measurements made at smaller time and space scales; that is, on observation and generalisation.

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Extrapolating the uncertainty of these measurements to annual and national scales involves expert judgement. The uncertainty of some inventory components cannot be measured at any scale, such as seasonal changes in NZ's sheep and cattle populations, so their uncertainty is based solely on expert judgement. For tractability, the same objective probability theorems used for measurements may be applied to the uncertainty of expert judgements. Analysis will be developed here, using these theorems, for UNFCCC reporting related to changes in New Zealand's CH_4 emissions from the 1990 baseline year to that of another year thereafter. Principles of the analysis are independent of this case study, so there may be wider application to the uncertainty issue.

2. Uncertainty analysis

New Zealand's ruminant CH_4 emissions are reported annually by the Ministry for the Environment (2005). To summarise, we write an equation to represent the CH_4 emissions inventory for sheep and cattle as:

$$E_{CH_4} = a_n d \left(\frac{1}{c}\right) m \qquad (1)$$

where E_{CH_4} is annual CH_4 emissions (Gg CH_4), a_n the number of animals, d the average animal's annual energy requirement (intake, MJ animal^{-1}), c the average feed energy content (MJ kg^{-1} dry matter) and m is the average CH_4 emissions factor (kg CH_4 kg^{-1} dry matter intake). For sheep and cattle, including those for beef and dairy production, in 1990 and 2003, respectively, quantity ($a_n d$) was 496×10^9 and 540×10^9 MJ as 3-year-running averages based on Clark et al. (2003) as briefly described below. Values for c vary monthly ranging from 9.6 to 12.6 MJ kg^{-1}, however, the average value over each year is assumed constant. Values for m are 21.6, 20.9 and 16.8×10^{-3} kg CH_4 kg^{-1} (pasture herbage dry matter intake) by cattle, sheep >1 years old and sheep <1 year old, respectively. Inserting average values into Eq. (1), including c = 11 MJ kg^{-1} and $m = 22 \times 10^{-3}$ kg kg CH_4 kg^{-1}, E_{CH_4} is 992 and 1080 Gg in 1990 and 2003, respectively. The change in E_{CH_4}, analogous to that reported to the UNFCCC, is thus 88 Gg.

For 1990 and 2003, calculated by New Zealand's CH_4 emissions inventory method for all ruminant animals, E_{CH_4} was 1025 and 1123 Gg, respectively, and the change actually reported to the UNFCCC was 98 Gg. The reported inventory accounts for CH_4 sources in addition to sheep and cattle, such as deer. The reported inventory also differs from Eq. (1) because (i) variable c varies monthly, (ii) variable c is the same for sheep and beef cattle but higher for dairy cattle and (iii) variable m varies according to species, and in the case of sheep, age.

The variables in Eq. (1) are average values based on sets of imperfect measurements or judgements. We can assess the uncertainty of each variable and express its standard error (S.E.) as a proportion of the average, a fraction known as the coefficient of variation (CV). Uncertainty in the change of CH_4 emissions from 1 year to another depends strongly on whether the same parameter value is used twice, or whether the parameter must be estimated independently for each year. In the former case, the fractional uncertainty in the value causes the same fractional uncertainty to the change. However, in the latter case each year's uncertainty adds to the uncertainty in the value. Often both sources of uncertainty will exist, leading to an (appropriately weighted) average effect on fractional uncertainty of the change.

The primary data for a_n comes from a survey sent by the Ministry of Agriculture and Forestry to around 40,000 farms annually that yields close to a 90% response. However, sampling uncertainty associated with these data analysed by Statistics NZ means the value of a_n at 30 June each year has a CV of around 0.02. Moreover, during the year, a_n depends on a monthly population model developed by H. Clark to account for births, deaths and slaughter. Consequently, a_n may have additional uncertainty, due to simplifying assumptions such as all lambs having the same birth date as do the calves. Nevertheless, on an annual basis, it must be emphasised that the correct total number of animals are born and slaughtered. Although the uncertainty in a_n is thought to be modest, in principle, at least a portion of it is likely to differ each year and so contribute more to uncertainty of the change than its small CV might otherwise suggest. Nevertheless, anticipating the results, the uncertainty of a_n does not need to be quantified exactly for our analysis.

Variable d is determined by the Australian feeding standards for grazing ruminants (CSIRO, 1990), including industry-supplied animal weight and production data (e.g. milk production, fecundity rates, weights of animals at slaughter, etc.), according to Clark et al. (2003). Weight data are used to account for the maintenance component of variable d. They used expert judgement to estimate that the CV of variable d was 0.05. As stated, the uncertainty represented by this CV has two components. Firstly, there is that due to uncertainty in the parameters used to convert weight and production to energy requirement. These are