# Executive summary

This is the final report of the GISERA project "Characterisation of Regional Fluxes of Methane in the Surat Basin, Queensland" addressing the following project milestones:

Task 3: Broad scale application of methane detection, and

Task 4: Methane emissions enhanced modelling.

Fluxes (i.e. emissions in the present context) of methane to the atmosphere from the Surat Basin, a large region of coal seam gas (CSG) production and processing in Queensland, are the focus of GISERA research in Greenhouse Gas and Air Quality (https://gisera.csiro.au). Agricultural and coal mining activities are other significant sources of methane in the region. The main aim of the work done under the final Phase 3 of the project reported here was to demonstrate the utility of an inverse (or "top-down") modelling approach for regional scale (~ 100–1000 km) for inferring methane emissions across the Surat Basin, and to examine the inferred methane emissions vis-à-vis available "bottom-up" emissions for the region. The inverse approach uses continuous measurements of atmospheric methane concentrations, atmospheric transport and dispersion modelling, and prior information about emissions, all within a Bayesian probabilistic framework.

A model domain of approximately 350 km x 350 km centred near the town of Miles was considered and is taken to represent the Surat Basin in this report. The CSG emission activities of interest in the Surat Basin and the Ironbark and Burncluith monitoring stations lie within this domain.

Analysis and modelling of continuous, hourly mean methane concentration data from the Ironbark and Burncluith monitoring stations was undertaken for the measurement period July 2015 to December 2016. The two stations, approximately 80 km apart, were established on either side of existing and future-projected CSG activity, and measured concentrations of methane and carbon dioxide (and carbon monoxide at Burncluith), as well as meteorological data. Methane concentration roses for each monitoring site showed higher concentrations when the winds were from the CSG area.

Methane data were filtered to remove transient spikes in concentration caused by occasional cattle passing nearby the monitor inlets and to remove nighttime low-wind stable atmospheric conditions which atmospheric models have difficulty representing. Hours with high observed carbon monoxide concentrations at Burncluith were also excluded as these periods represent local and transient biomass burning events that are not accounted for in the emission inventory and modelling.

A gridded "bottom-up" methane emission inventory for the region for the year 2015 was compiled. It contained the source intensities and their spatial distribution for all major methane sources, and yielded a domain-wide methane emission of 173 x $10^6$ kg $yr^{-1}$ of which cattle grazing (54%) is the largest contributor followed by feedlots (24%) and CSG processing (8.4%).

This bottom-up inventory emissions were further processed and used in CSIRO's state-of-the-art regional scale meteorological and air pollution model, TAPM, to simulate methane concentrations to compare with measurements from the two monitoring stations. This comparison required a methodology to estimate the time-varying regional background concentration of methane.

The above forward TAPM modelling using the bottom-up methane emission inventory provided a credible simulation of the observed methane concentration distributions at both Ironbark and Burncluith, except that the model underestimated approximately the top 15% of the concentration values. The likely reasons for this underestimation include underestimation of emissions from sources close to the monitoring sites; possible presence of time-varying, intermittent or additional sources that are not accounted for in the bottom-up emission inventory; and errors in the modelled meteorology and plume transport.

The forward modelling also showed that the top three contributors (in order) to the overall averaged modelled methane at both Ironbark and Burncluith are Grazing cattle; the combined emission due to Feedlot, Poultry and Piggeries; and CSG Processing. In contrast, the top three contributors to the highest 5% of the modelled concentrations at Ironbark are CSG Processing, Feedlot + Poultry + Piggeries, and Grazing cattle, whereas these at Burncluith are Grazing cattle, Feedlot + Poultry + Piggeries, and CSG Processing.

The regional Bayesian inverse model formulated to infer methane emissions across the region used the hourly mean methane measurements from the two stations, coupled with TAPM running in backward-in-time meteorological and dispersion mode to calculate the required source-receptor relationship. Emissions were inferred for grid points with a resolution of 31 km x 31 km across the domain. As a test, the inverse model was first applied to a 'synthetic' case in which modelled concentrations were treated as ambient concentration measurements. It yielded a stable and sensible solution, giving confidence in the computational technique.

The inverse model was applied with several choices of prior emission information. The results showed that even when no prior information (except for loose bounds on the emission rate) is specified, the information contained in the measured concentration time series from the two monitoring stations is able to constrain the total emissions realistically, but compared to the bottom-up inventory emissions the estimated emissions are more concentrated in a few areas in the middle of the domain and less in the areas further away.

The use of the bottom-up emission inventory as a prior (with an uncertainty of 3%) in the inverse model yielded optimal source emission estimates, as judged from their ability to describe the methane measurements when used in forward modelling compared to the bottom-up inventory emissions. The domain-wide inverse estimate of methane emission is 166 x $10^6$ kg $yr^{-1}$ which is slightly lower than the total bottom-up inventory emission. However, in a subdomain of approximately 155 km x 155 km covering areas between and immediately around the two stations, dominated by agricultural and CSG emissions and where there are potentially other sources not accounted for in the inventory, the estimated emissions were 30% higher than the bottom-up inventory emissions.

The development and application of inverse modelling for regional scale conducted in this report demonstrate that, when appropriately formulated with a realistic prior, it can provide a source distribution estimate that is stable and updates the "bottom-up" source distribution for its consistency with atmospheric concentration measurements. An aim of the study was to focus on the emissions between the stations. However, it was also apparent that having only two monitoring stations across the large domain that contains many methane sources is a limitation.

The modelling showed that the two stations do not sample some distant areas adequately, particularly those located in the north-west and south-east of the domain, due to the large distances between those areas and the monitors coupled with the infrequency of winds from those areas towards the monitors. Thus, potential sources in these areas would not have been estimated as well. The limited number of stations across the large area also necessitated the attribution of sources to points within a grid that is relatively coarse.

There are other uncertainties in the inverse modelling that could lead to inaccuracies in the inferred source emissions. The modelling makes assumptions about the sources that contribute to the measured concentrations, including that they are constant in time and are all contained within the model domain. It relies on the source-receptor relationship (derived using the modelled meteorology which carries its own inherent uncertainty) being accurate across the region. These are typical difficulties of inverse modelling.

The present study (both measurements and the emissions inferred from them) does not distinguish between different source sectors. To do source attribution, measurements of tracers specific to source sectors (such as isotopes of methane) would be required, when instrumentation suitable for field deployment becomes available. The inverse modelling will need to be further developed to account for these types of data streams and extended to sources other than point (e.g. area and line sources).