Supporting Methane Mitigation Efforts in Melbourne, Australia. Part 1: Modelling

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Introduction

Methane (CH_4) is a long-lived greenhouse gas and the second most significant contributor to radiative forcing from greenhouse gases after carbon dioxide. Improved understanding of methane emissions from different sectors in Australia is necessary to focus and prioritise mitigation efforts; however, methane emissions are uncertain, especially at fine resolutions needed for mitigation. This study establishes a regional inverse framework to improve methane emission inventories for Melbourne, Australia.

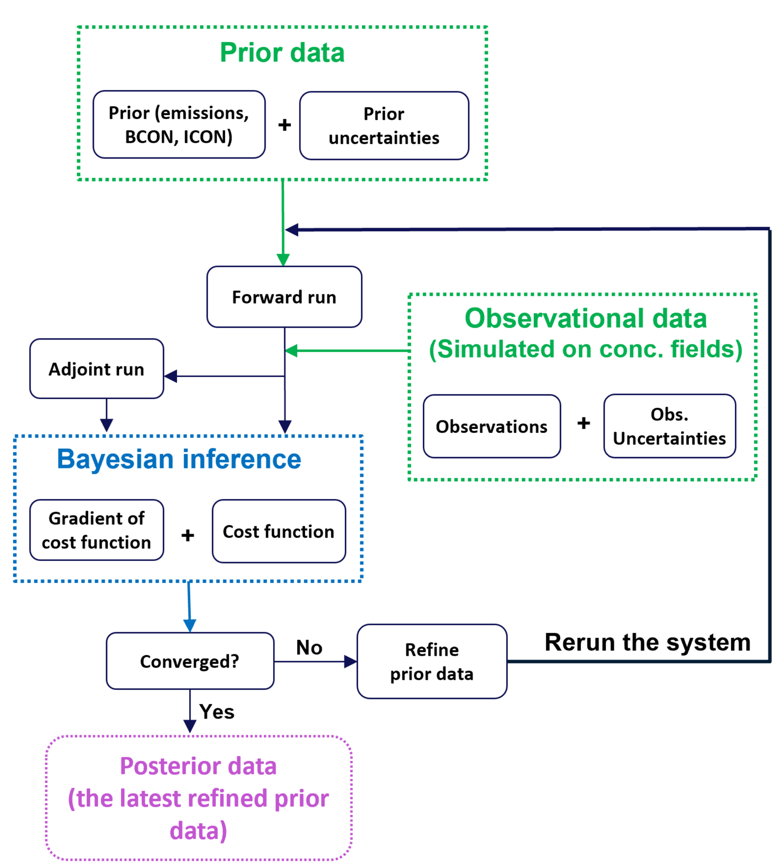

Figure 1: Flowchart of the Py4dVar system.

Inverse system: We utilise a combination of surface-level atmospheric methane measurements and a variational inversion technique (Py4dVar[1]) based on Bayes' theorem to refine estimates of methane emissions at an urban scale.

The inversion process is iterative and will continue until the cost function is minimised, resulting in the optimal combination of prior and observational data, yielding the posterior.

The temporal variation of emissions in this system is presented in a classified scheme that includes four time categories (Morning, Day time, Evening and Night time). Each category represents the average of a specified six-hours window of the diurnal cycle for the entire simulation period for each grid-point.

Simulation design: The inversion process is run on a regional domain (left panel of Figure 2) with a resolution of 3 x 3 km^2. The current surface observation sites in the Melbourne urban area are shown in the right panel, and data collected from these stations are applied in the inversion system. We run the inversion for a 6-week period from Dec 2022 to Jan 2023 using data from four surface observation sites: Aspendale, Clayton, Cornish college and Kennaook/Cape Grim.

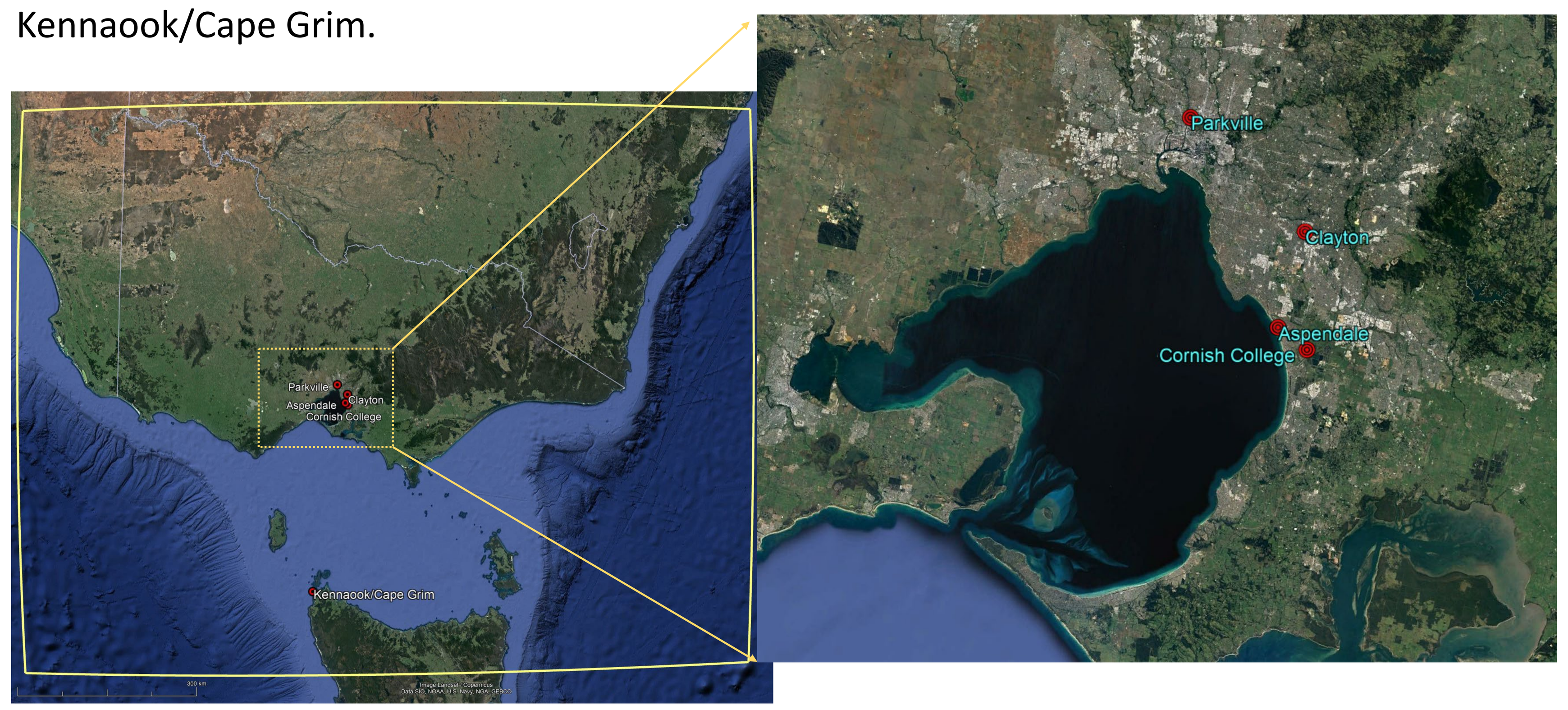

Figure 2: Applied domain in the inverse modelling system for Melbourne, prepared using ©Google Earth Pro Software.

System preparation and validation

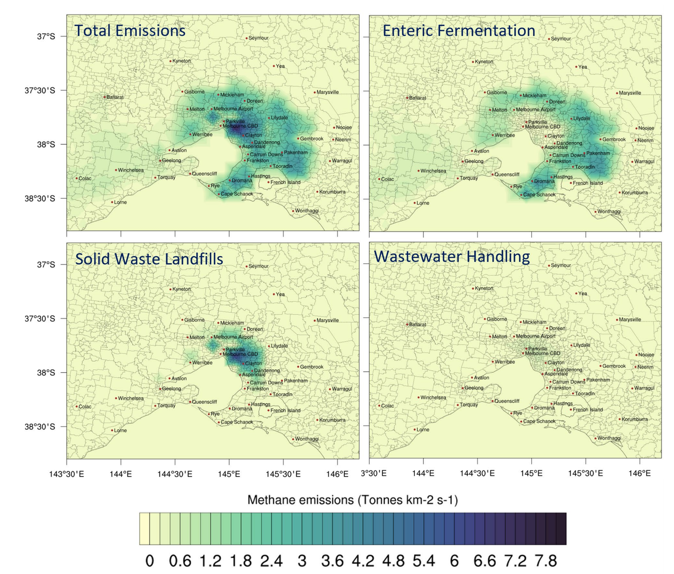

Figure 3: EDGAR emissions around Melbourne.

Prior emissions: (1) anthropogenic emissions estimated from the Emissions Database for Global Atmospheric Research (EDGAR), (2) fire emissions derived from the Global Fire Assimilation System (GFAS) dataset and (3) biogenic emissions estimated using the Model of Emissions of Gases and Aerosols from Nature (MEGAN).

Figure 3 shows the spatial distribution of EDGAR around Melbourne, revealing an incorrect distribution pattern of emissions. For example, emissions from enteric fermentation are expected to be located in rural areas rather than the city and surrounding suburbs.

Updating livestock emissions:

We updated enteric fermentation emission estimations using a national livestock distribution dataset[2] and relevant emission factors.

Figure 4 presents a more realistic distribution of emissions than EDGAR, better capturing the actual spatial pattern of emissions.

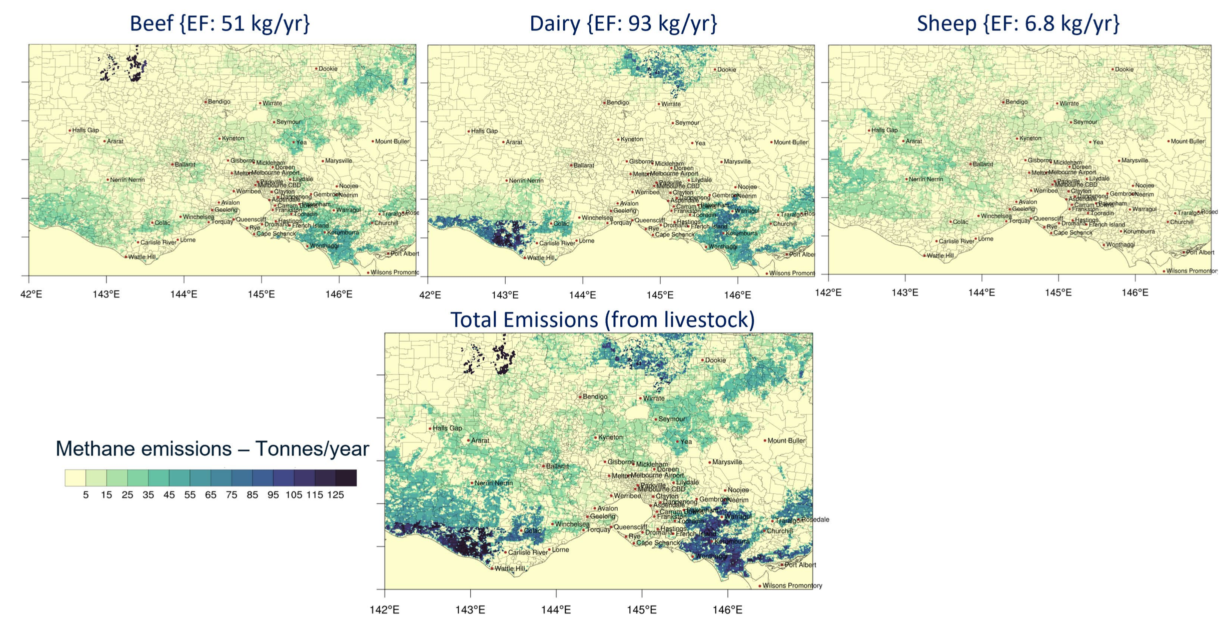

Figure 4: Estimated emissions from livestock in Victoria.

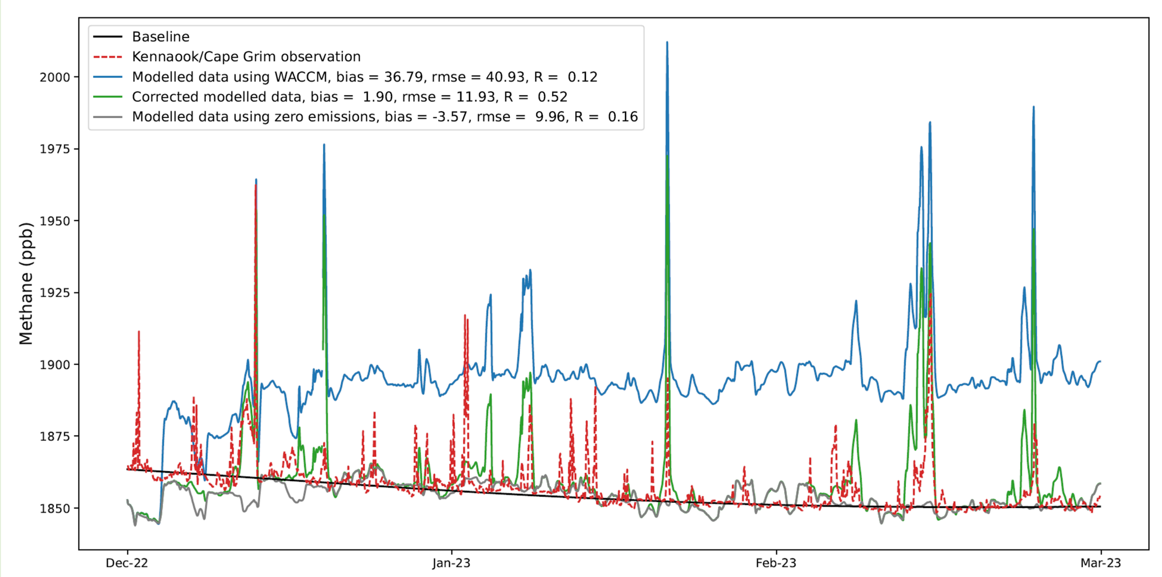

Figure 5: Boundary condition adjustment. The diurnal peaks come from emission data as they are not captured in the run with zero emissions (gray line).

Boundary condition adjustment:

Boundary conditions (applied at the outer domain) were first based on the Whole Atmosphere Community Climate Model (WACCM) dataset. We have found that this dataset is biased compared to baseline data derived from continuous in situ measurements at Kennaook/Cape Grim station. We applied the baseline data to adjust the boundary conditions.

Meteorological data validation:

Modelled meteorological data shows reasonable consistency with observations. We concluded that modelled meteorological data are accurate enough to be applied in the system.

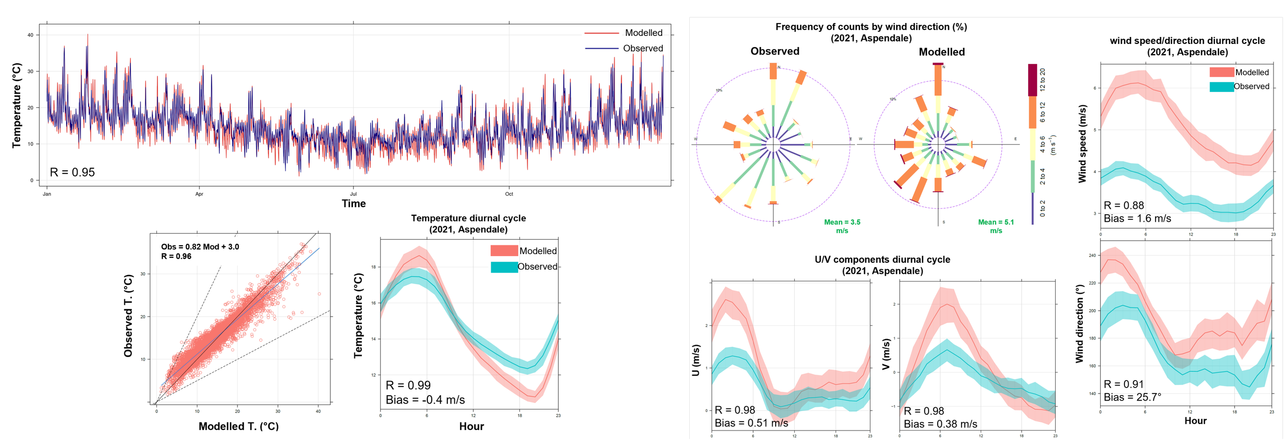

Figure 6: Comparison of modelled temperature and wind components with observations at Aspendale.

Results and discussion

Figure 7 compares observations with modelled concentrations forced with prior and posterior data. These are preliminary results and are still under investigation.

Cornish College and Aspendale have some very large peaks that are not captured in the model forced by either prior or posterior data (possibly due to emissions from very local sources and/or meteorological conditions).

All sites have many peaks that are overestimated by the prior but improved by the posterior.

Figure 8 shows changes in emissions. Posterior emissions are reduced significantly in some regions.

At Clayton, all modelled peaks in concentrations are higher than observations. The inversion has lowered the peaks by reducing nearby emissions, mostly landfill emissions from the EDGAR database.

The inversion made very little difference at Cape Grim.

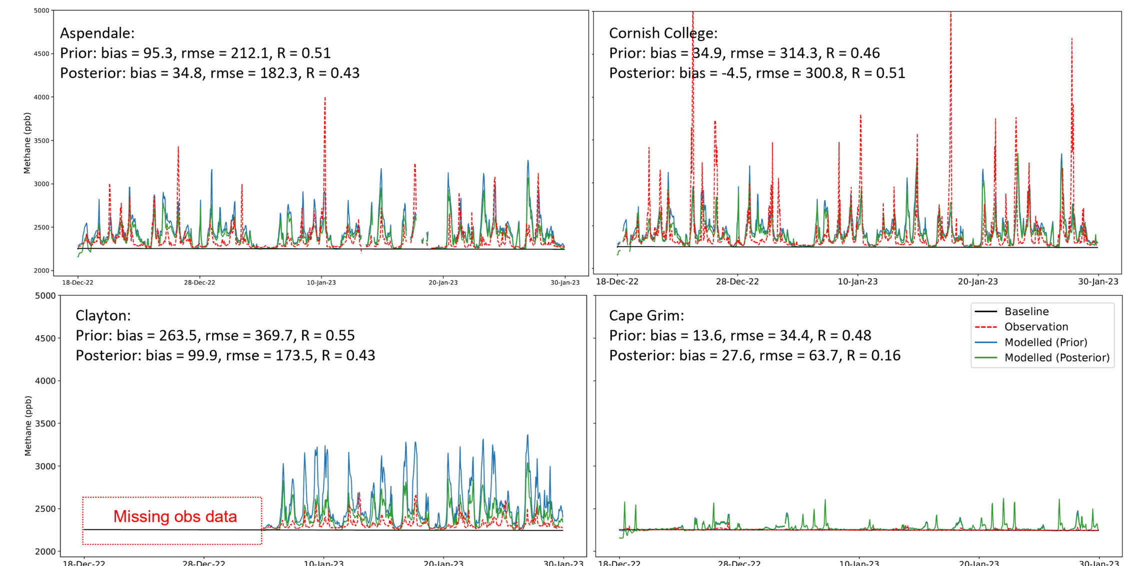

Figure 7: Comparison of prior and posterior with the assimilated data in each station. No data selection (e.g. low wind speeds) has been applied to the results.

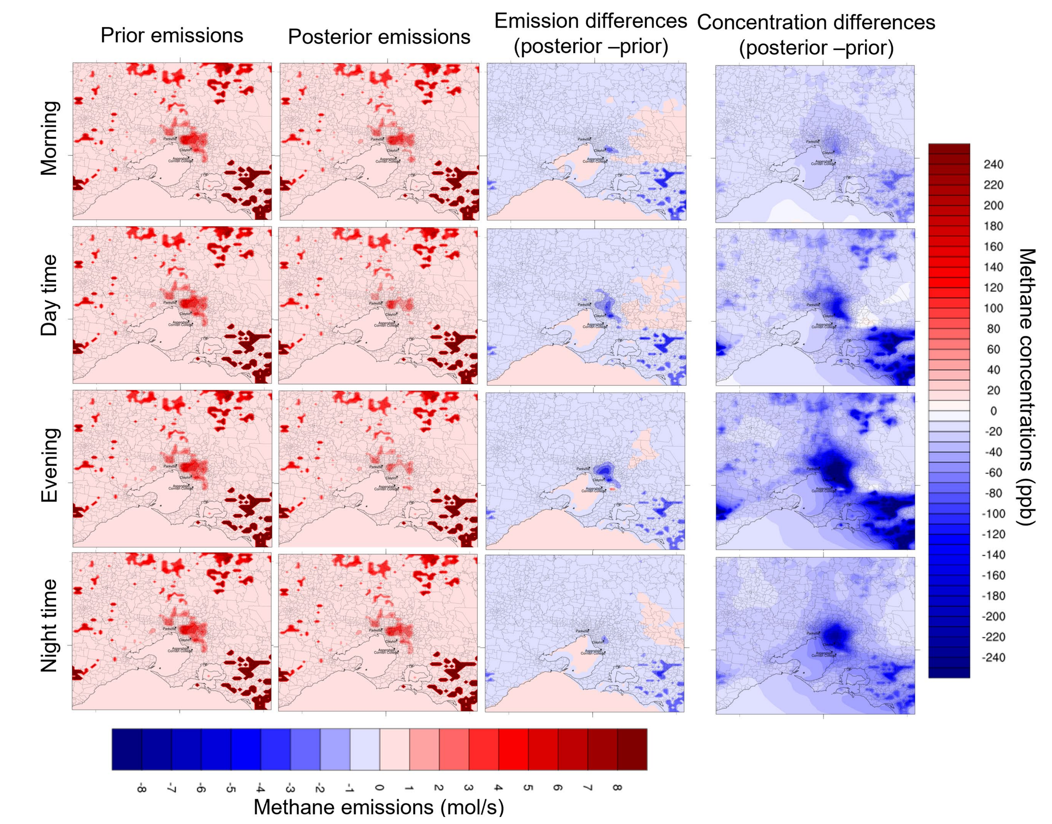

Figure 8: Spatial pattern of emissions and concentrations in each time category.

Summary:

Regional methane emissions are generated using globally-accessible datasets. These data are updated using national livestock distribution data for enteric fermentation.

The global boundary conditions are adjusted using baseline data.

More observational data are necessary to constrain Melbourne's emissions. We will use this inversion system to assess potential observation locations.

Independent measurements (including satellite data) are required to validate the system capability in improving emission data.

References:

1. Thomas, S.: Py4dvar, 2017, https://github.com/steven-thomas/py4dvar.
2. Navarro, J. Marcos Martinez, R. (2021) Estimating long-term profits, fertiliser and pesticide use baselines in Australian agricultural regions. User Guide. CSIRO, Australia.

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