

Quantifying global emissions of methane using a 4D-Var inverse model and satellite observations

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Inverse modelling of methane

- **Methane (CH₄)**: an important greenhouse gas, emitted from a range of anthropogenic and natural sources. The largest individual source is wetlands.
- **INVICAT is a 4D-Var inverse model** based on TOMCAT, which optimises surface fluxes of atmospheric species through assimilation of observations (see Figure 2, or Wilson et al., 2014).
- CH₄ inversions carried out for period 2010 – 2015 using GOSAT data from University of Leicester (proxy method – version 7) and surface flask observations from NOAA GMD.

Assimilation using surface observations only

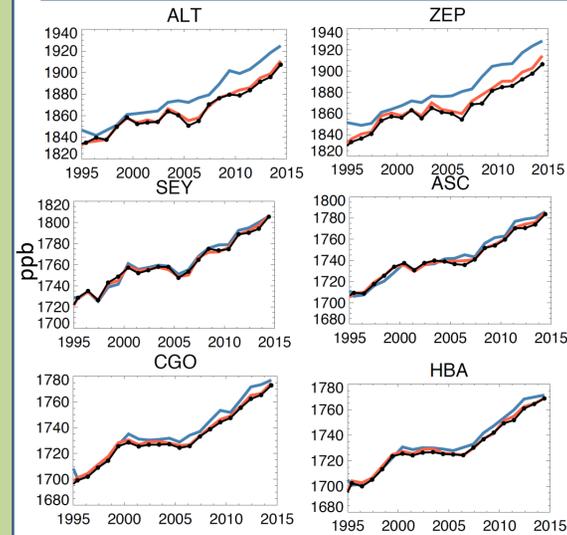


Figure 1. Annual mean observed CH₄ concentrations at six measurement sites for the period 1995 – 2015 (black lines). Also included are simulated CH₄ concentrations using bottom-up (prior) emission estimates (blue lines) and posterior emissions after assimilating surface data (red lines).

— Observations
— Model prior
— Model posterior

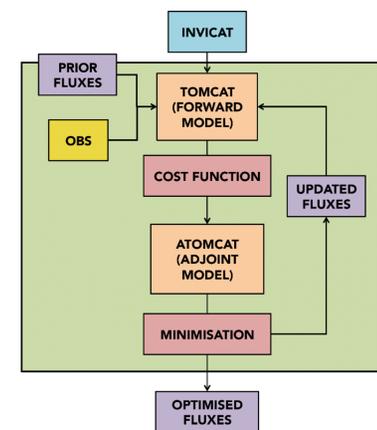


Figure 2. Flow chart describing the iterative 4D-Variational process used by INVICAT in order to optimise surface fluxes.

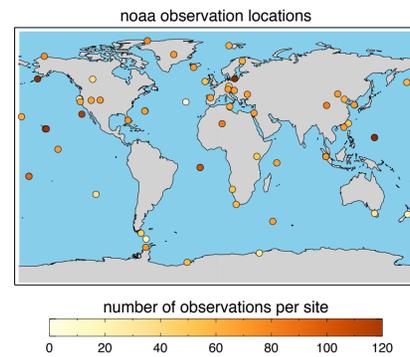


Figure 3. Location of NOAA surface sites from which in-situ flask observations of CH₄ were assimilated into INVICAT in order to optimise surface emissions of CH₄. Colour bar indicates number of independent observations assimilated from each location.

How best to assimilate satellite data?

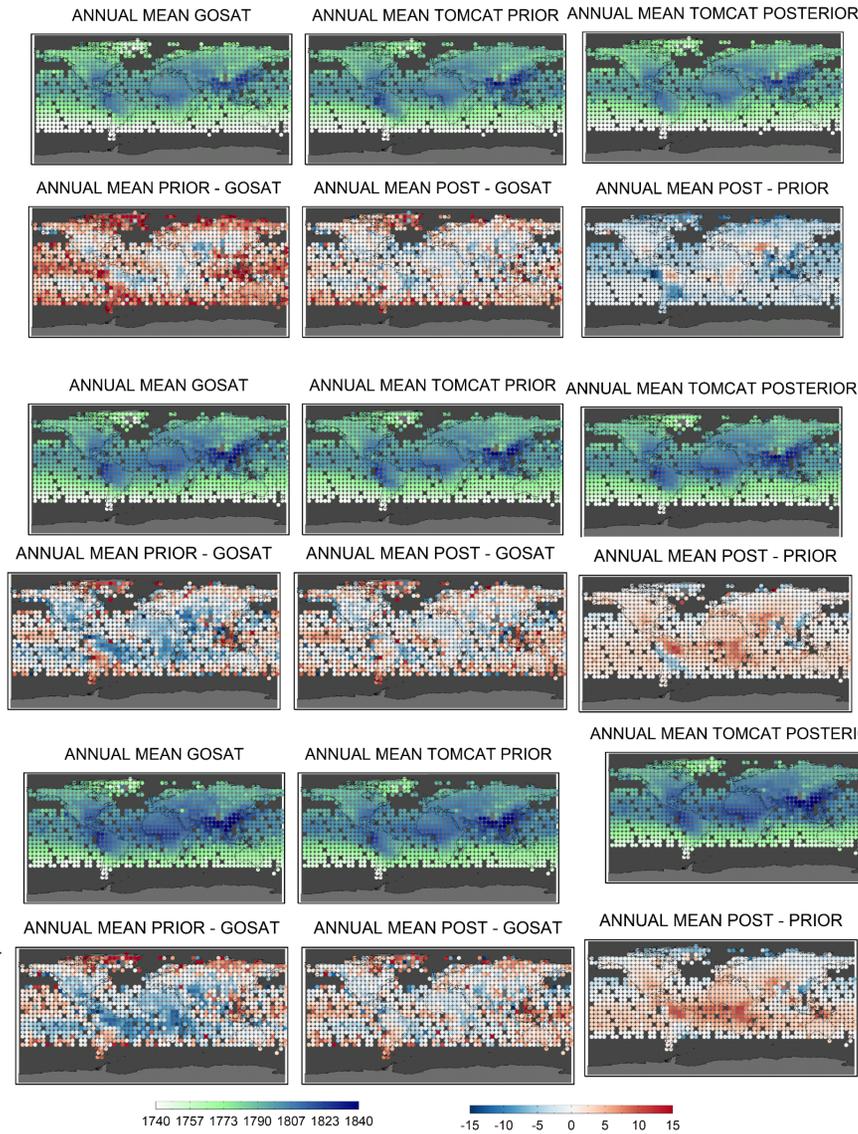


Figure 5. Mapping the IASI v1 XCH₄ 4 retrievals (ppb, top left in each block), the TOMCAT XCH₄ with IASI averaging kernels applied (top right in each block), the model/satellite bias (bottom left) and the satellite error (bottom right) onto the 5.6 x 5.6 degree TOMCAT grid. IASI has very high density retrievals, which should not be assimilated as independent data points if they are in the same model grid box at similar times. We convert into ‘superobservations’ as shown in the right-hand block of panels. Whilst this does reduce information content compared to direct assimilation it significantly reduces the problem of correlated observations being assimilated.

Figure 6. Example of multiple IASI averaging kernels within a model grid cell (red lines) being combined to give a ‘super’ averaging kernel (black solid line).

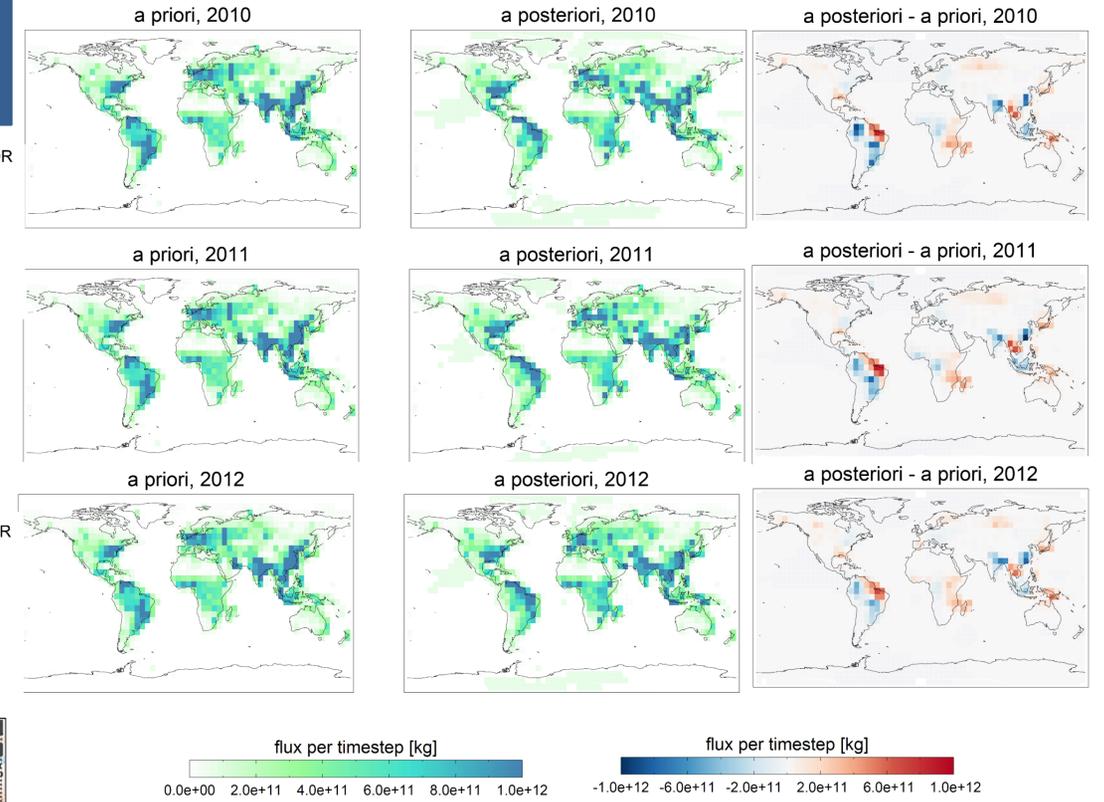


Figure 7. Regional and global monthly mean GOSAT XCH₄ (ppb) for the period 2010 – 2014 (black lines). Also included are simulated XCH₄ concentrations using bottom-up (prior) emission estimates (blue lines) and posterior emissions after assimilating surface and GOSAT data (red lines). Purple bars represent the number of GOSAT retrievals included in in each region during each month.

Figure 8. Regional and global bottom-up (prior) monthly total emissions (Tg(CH₄)/yr) for the period 2010 – 2014 (grey lines). Also included are posterior emissions from an inversion assimilating surface data only (red lines) and from an inversion assimilating surface data and GOSAT XCH₄. Differences between the red and purple lines are therefore information coming only from the GOSAT data. Note that the global total emissions from the two inversions are very similar but the regional distribution is often different.

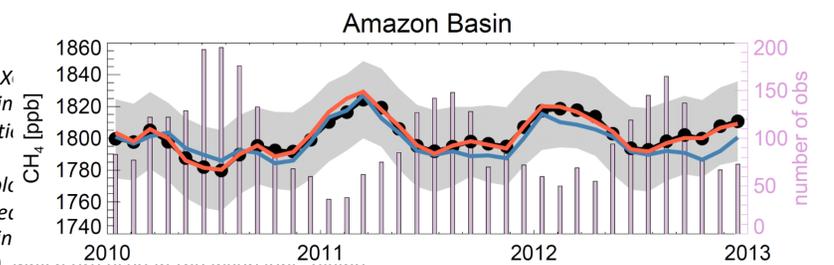
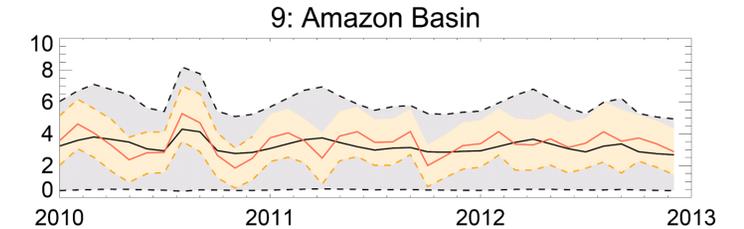


Figure 4. (Column 1) Monthly mean TOMCAT XCH₄ December 2009 (bottom) with GOSAT averaging kernels applied. (Column 2) Monthly mean GOSAT XCH₄ concentration [GOSAT minus TOMCAT w/ AKs applied]. (Column 3) Individual satellite/model biases per month December 2009 (bottom). Overlaid are the best fit: 2nd order with latitude (blue line) and 3rd order with sine(latitude) (yellow lines), which are used in the inversions, giving most weight to the tropics. Including these biases in the inversion allows us to simultaneously assimilate surface data and remote sensing data.