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THE NAME-INVERSION METHOD IN THE NITRO-EUROPE PROJECT

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Abstract: The Met Office NAME-Inversion Method was one of five inversion methods employed in the Nitro-Europe Project (http://www.nitroeurope.eu/), to provide top-down estimates of methane and nitrous oxide for 2006 and 2007 and independently assess European inventories of these gases that have been obtained using bottom-up methods. Measurements from a network of 11 continuous monitoring and 10 flask European stations containing were used. The paper gives an overview of the NAME-Inversion method and its performance, in particularly the sensitivity to various input parameters.

Key words: *Inversion Methods, source attribution, top-down modelling of greenhouse gases.*

INTRODUCTION

The Nitro-Europe project was a five year EU FP6 programme (2005-2011), with the aim to derive European estimates of greenhouse gas budgets of methane (CH_4) and nitrous oxide (N_2O). The main objective of the modelling component was to verify European emissions and evaluate independently the estimates obtained using bottom-up methods (measuring and modelling of factors such as land use, number of animals, crops etc.). This is important, in particular for CH_4 and N_2O, for which considerable uncertainties in the bottom-up inventories exist (uncertainty in the estimates reported to UNFCCC: CH_4: ~ 25%; N_2O > 100% for annual country totals).

In the Nitro Europe project, European CH_4 and N_2O emissions were estimated for 2006 and 2007 using 5 independent inverse modelling systems, based on different global and regional Eulerian and Lagrangian transport models. Each one of the participating models used different inversion methods and meteorological parameters but the same observations. A principal objective was to understand the uncertainty and provide better estimates of European emissions.

In this paper, we discuss the Met Office NAME-Inversion Method and its performance in the Nitro Europe project. The inversion method developed in the Met Office (Manning et al., 2011a) and has been used to provide UK estimates of a large basket of green house and ozone-depleting gases (Manning et al., 2011b). Basic elements of the method are given below along with an example from Nitro Europe.

THE NAME-INVERSION METHOD AND DATA

The inversion method is described by equation (1) below

$$M \otimes e = o' = o - b \tag{1}$$

where,

- M is a transport matrix with dimensions [t×m]; where t is the number of times observations are available and m is the total geographical dimension of the domain; units = s/m
- e is the desired emission map solution to (1) with dimension [m]; units = g/sm^2
- o is the array containing all observations with dimension [t]; units = g/m^3
- o' is the array of deviations of observations from b; units= g/m^3
- b is a suitable baseline with dimension [t]; units = g/m^3. The baseline is representative of well mixed, mid-latitude Northern Hemisphere background concentrations.

To obtain the transport matrix M the Met Office Lagrangian atmospheric dispersion model NAME (Jones et al., 2007), is run in backward mode for 13 days, starting from a unit release from each observation station. From these runs, integrated air concentrations (dosage) from 0-100m above ground are obtained in 2 hour intervals that show the recent history of air en route to the station. By dividing the dosage by the total mass emitted and multiplying by the geographical area of each grid box, the transport matrix M is obtained.

A European domain of dimension [-14.63 to 39.13 longitude, 33.8 to 72.69 latitude], with 128×144 grid points and a resolution of 0.42°×0.27° in the EW and NS directions respectively was used in the inversion. This domain contains 11 continuous monitoring (CM) and 10 Flask measuring (FM) stations, listed in Table 1. The CM sites have hourly observations, whereas the FM ones vary but typically are once a week. The total number of all available observations make up the array o in equation (1).

Fundamental to the emission solution in equation (1) is the choice of the baseline b. Mace Head (MH) in Ireland is the obvious choice of station to use for the calculation of baselines and the method for this is described in Manning et al, (2011a). Using stations across Europe presented a new challenge to the basic methodology, since the MH baseline might not have been appropriate for all stations. Obvious examples are high altitude mountain stations like Jungfraujoch. Another possible way is to use a 3D model, like TM5 (Bergamaschi et al., 2010, Corazza et al., 2011, Meirink et al., 2008) and calculate

station specific baselines. The influence of baseline was explored thoroughly, by performing two types of inversions; one using the MH baseline and a second using station specific baselines from the TM5 model, in a manner described in Rodenbeck et al., 2009.

Table 2. List of high frequency monitoring stations CM & flask type monitoring stations FM, that are used in the inversion.

ID	Station	Type	lon	lat	Alt (m)	CH_4	N_2O
AN	Angus Tower, UK	CM	-3.0	56.6	313+222	✓	✓
BK	Bialystok, Poland	CM	22.8	52.3	160+300	✓	✓
C3	Cabauw, NL	CM	4.93	52.0	-2+120	✓	✓
EG	Royal Holloway, UK	CM	-0.6	51.4	45	✓	×
HY	Hegyhatsal, HU	CM	16.7	47.0	248+96	✓	✓
MH	Mace Head, UK	CM	-9.9	53.3	25	✓	✓
OK	Ochsenkopf, D	CM	11.8	50.1	1185	✓	✓
JJ	Jungfraujoch, Sw	CM	7.98	46.6	3580	✓	✓
PA	Pallas, Finland	CM	24.1	68.0	560	✓	✓
SL	Schauinsland	CM	7.91	47.9	1205	✓	✓
SY	Saclay, France	CM	2.15	48.71	160+7	✓	×
BS	Baltic Sea, Poland	FM	17.2	55.4	28	✓	✓
BR	Begur, Spain	FM	3.23	41.97	13+2	✓	×
CO	Black Sea, Romania	FM	28.7	44.2	3	✓	✓
HB	Hohenpeissenberg, D	FM	11.0	47.8	985	✓	✓
LM	Lampedusa, IT	FM	12.6	35.5	45	✓	✓
IG	Ile Grande, France	FM	-3.58	48.80	20+10	✓	×
PM	Pic du Midi, France	FM	0.14	42.94	2877+10	✓	×
PU	Puy de Dome, France	FM	2.97	45.77	1465+10	✓	×
SI	Shetland, UK	FM	-1.27	59.85	46	✓	✓
OS	Ocean station, Norway	FM	2.0	66.0	5	✓	✓

Equation (1) is solved in the NAME-Inversion Method iteratively, using simulated annealing (Press et al., 1992). The iterative process can start from a set of randomly generated maps and use an appropriate cost function to minimise the error between the observations and emissions. An *a priori* emission map can also be used to guide and constraint the solution along with an appropriate cost function. To obtain a mean solution and a measure of the solution uncertainty, the process is repeated 52 times, each independent of the previous one and all starting from a different randomly specified emission distribution.

The number of observations and geographical distribution of the stations affects the inversion grid. In order for the best fit algorithm to provide robust solutions for every area within the domain, each region needs to have a significant contribution on a reasonable number of times. Otherwise, potentially for some grids, the impact on the cost function will be minimal and the inversion will have little skill at determining the true emission from that region (usually at a distance from the observation station). To account for that, grid boxes are grouped together into increasingly larger blocks, if insufficient signal from a region is observed. An example of a grid using only 3 stations compared to 21 stations is shown in figure 1.

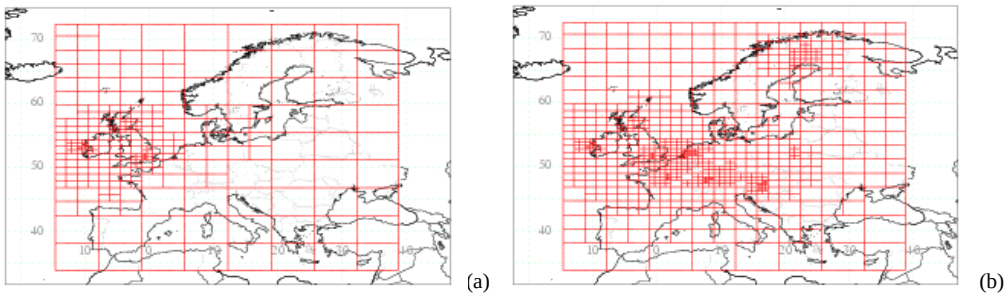


Figure 7: Typical grids using: (a) 2 stations over UK and 1 over Ireland and (b) 21 stations across Europe.

Different selection criteria for the observations or the number of stations used in the inversion were tested during the Nitro Europe project and their effect on the inversion solution evaluated. Here, we concentrate on one of the most important influences, namely the choice of baseline.

RESULTS

Shown in figure 2 are emission maps for CH_4 and N_2O, both for 2007, obtained from two different inversion set-ups. On the left of figure 2, MH baselines were used for all stations, whereas on the right, the results are using station-specific baselines from the TM5 model. All cases were initialised from a random emission map and not constrained by *a priori* information. For CH_4, the obtained solutions using different baselines present a similar overall picture with rather similar European emission totals. For N_2O there are more pronounced differences. Moreover, the inversion using station specific baselines give higher emissions overall.

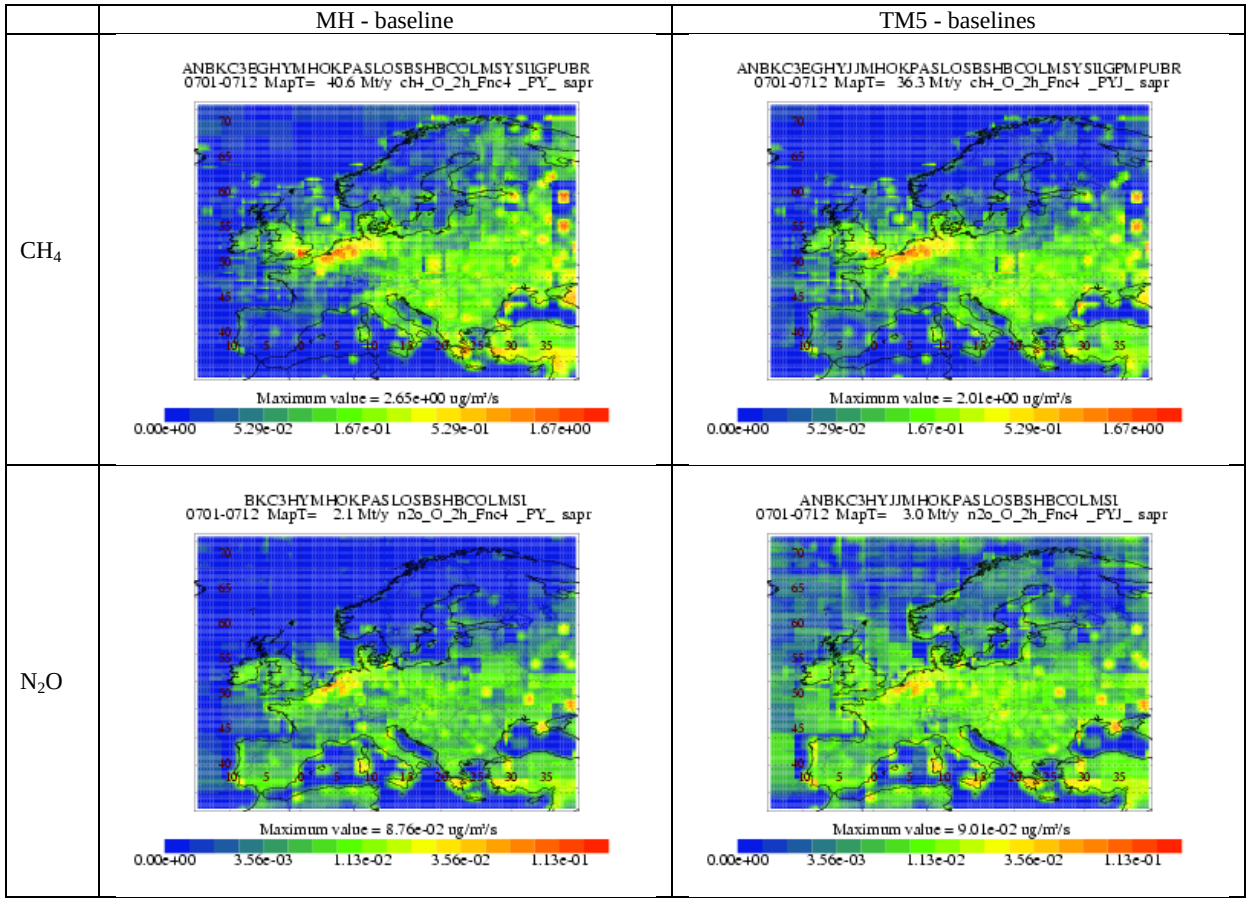


Figure 2: Emission maps for 2007, obtained using MH baseline (left column) and baselines from TM5 (right column) for CH_4 (top) and N_2O (bottom).

Figure 3 shows aggregate totals from the two inversions, along with estimates from two different bottom-up inventories, over EU15 (Ireland, UK, Greece, France, Benelux, Germany, Spain, Portugal, Italy, Denmark, Austria, Sweden, Finland), EU27 (EU15 + Poland, Czech R., Hungary, Slovakia, Slovenia, Bulgaria, Romania, Baltic States) and NWEU (Ireland, UK, France, Benelux, Germany, Denmark). The blue columns are from the solution using TM5 station-specific baselines and the green ones from the inversion using MH baselines. The red and yellow columns represent emissions from the UNFCCC and EDGAR inventories. The error bars represent the uncertainty of the solution or the given uncertainty for the bottom up inventories (25% for UNFCCC, unknown for EDGAR). On a regional scale, there is no discernable difference between the two solutions for CH_4. Moreover, there is good agreement with both solution and UNFCCC estimates. For N_2O, the difference between the two solutions on a regional scale is significant. No error bars are shown for the N2O since the uncertainty is considerable (>100%) and it would obscure the results on the graph.

Figure 4, shows the same information and using the same colour scheme as figure 3, but for individual country totals rather than regional aggregates. For both CH_4 and N_2O, there are big differences between UNFCCC and EDGAR inventories, especially in certain countries e.g., UK, France, Germany. For CH_4, the solutions from the two sets of inversions give rather similar values for most countries. Moreover, the emissions from each country are within the uncertainty of solution. For N_2O, country total emissions are consistently higher from the inversion using station-specific baselines than the case using MH baselines to all stations. In a few cases, the difference between the two inversions for N_2O, is outside the uncertainty of the solution i.e., France.

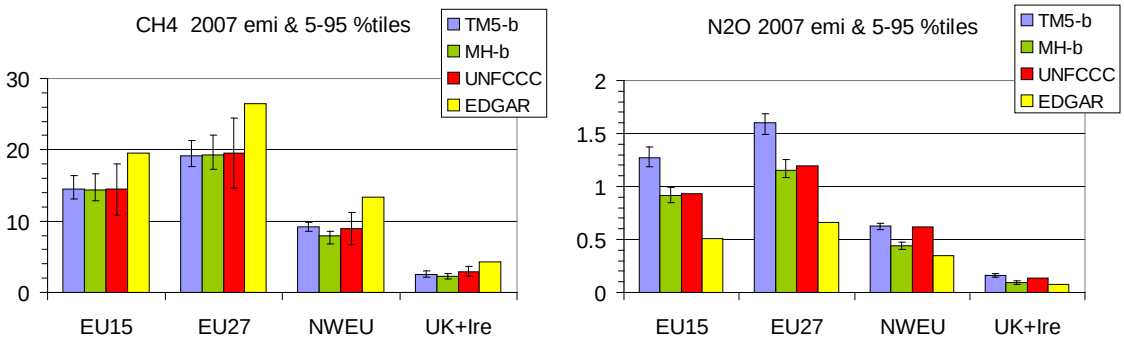
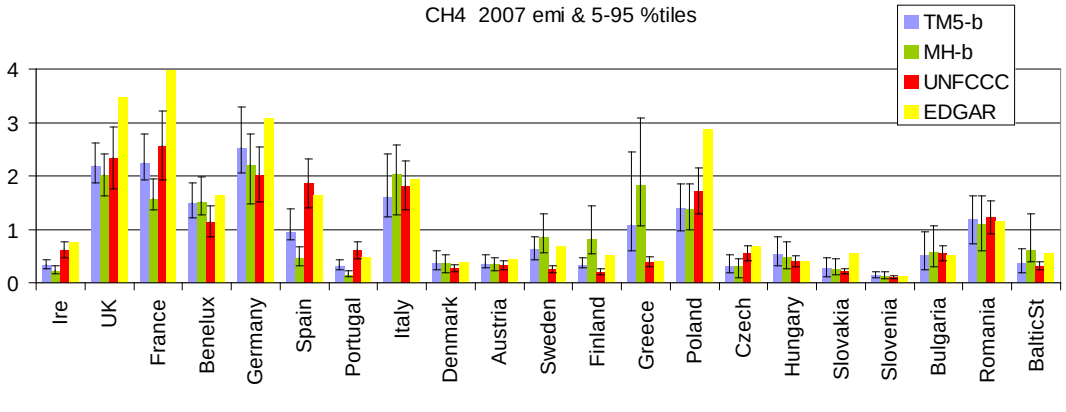
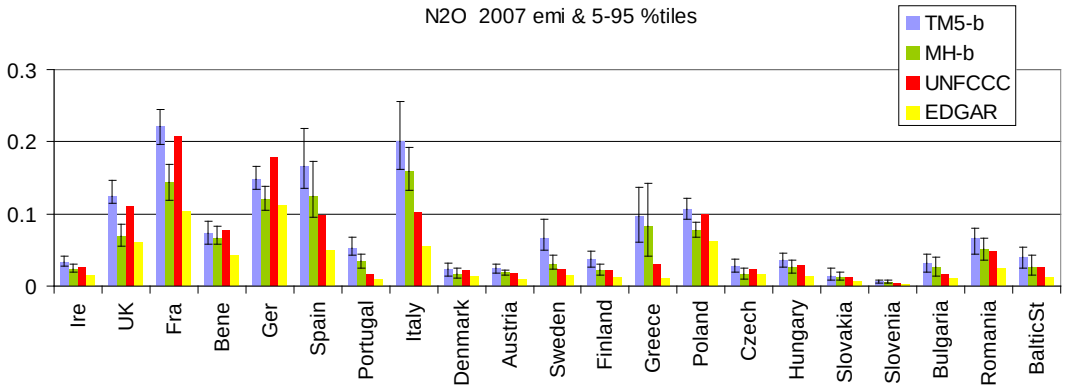


Figure 3: 2007 aggregate emissions over various regions, for methane (left) and N_2O (right).



(a)



(b)

Figure 4: 2007 individual country totals for (a) CH_4 and (b) N_2O

The influence of baselines can be better understood by a simple analysis summarised in figure 5. In figure 5, the thick blue line represents the MH baseline (MB) with the two thin blue lines around it the ±σ (variance). The red line represents the average pollution event (APE) (average of all points not calcified as baseline points) and the pink dots are the observations used in the calculation of MH baseline. The green line is the TM5-baseline for Mace Head (TM5B). We calculate the ratio

$$R = 100 \times (MHB - TM5B) / (APE - MHB) \quad (2)$$

i.e., the difference between the baselines at Mace Head compared to the difference between the MH baseline and average pollution signal. In the CH_4 case, this is only 8% i.e., the difference between the baselines is small compared to the difference between baseline and pollution. For N_2O though, R = 33% i.e., in this case the difference between the baselines is significant compared with the MH-baseline and the pollution signal. The baseline from TM5 being consistently lower in this case than the MH baseline (and thus the observed air flowing from the Atlantic) will naturally lead to elevated emission estimates.

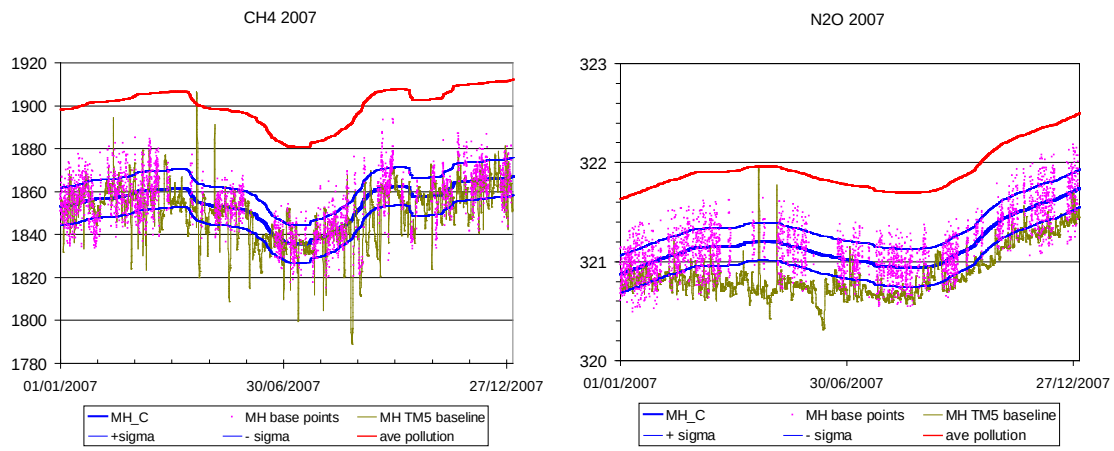


Figure 5: Baseline analysis for methane (left) and N_2O (right). See text for details.

SUMMARY

Using atmospheric measurements combined with inverse modelling can provide independent top-down emission estimates that may help to improve bottom-up estimates. The NAME-Inversion Method using a network of observation stations across Europe performed rather well in Nitro Europe project. Moreover, the ability of the method to converge to realistic solutions from random starting points, makes it truly independent from *a priori* emissions. It allows the solution to diverge strongly from the *a priori* emissions and is not influenced by any errors or bias in the *a priori*. The baseline is a key parameter in the inversion. It determines the magnitude of the regional pollution values (equation (1)), smaller baseline values result in higher observation perturbations and therefore larger estimated emissions.

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