Global and European scale N_2O emissions estimated using a variational inversion approach

R. L. Thompson[1], P. Bousquet[1], F. Chevallier[1], E. Dlugokencky[2], A. T. Vermeulen[3], T. Aalto[4], L. Haszpra[5], F. Meinhardt[6], S. O'Doherty[7], J. Moncrieff[8], M. E. Popa[9], M. Steinbacher[10], A. Jordan[11], T. Schuck[12], and C. A. M. Brenninkmeijer[12]

1) Laboratoire des Sciences du Climat et l'Environnement, Gif sur Yvette, France
2) NOAA Earth System Research Laboratory, Global Monitoring Division, Boulder, CO, USA
3) Energy research Center of the Netherlands (ECN), Petten, Netherlands
4) Finnish Meteorological Institute, Helsinki, Finland
5) Hungarian Meteorological Service, Budapest, Hungary
6) Umweltbundesamt, Messstelle Schauinsland, Kirchzarten, Germany
7) University of Bristol, Bristol, United Kingdom
8) Edinburgh University, Edinburgh, United Kingdom
9) University of Utrecht, Utrecht, Netherlands
10) Swiss Federal Laboratories for Materials Science and Technology (EMPA), Duebendorf, Switzerland
11) Max Planck Institute for Biogeochemistry, Jena, Germany
12) Max Planck Institute for chemistry, Mainz, Germany

rona.thompson@lsce.ipsl.fr

Overview

Atmospheric concentration gradients of N_2O provide a strong constraint on N_2O surface fluxes and can also be used for independent validation of flux estimates from statistical and process-based models. The use of atmospheric concentrations to optimize surface fluxes may be formalized in a Bayesian inversion scheme, which requires the inverse or adjoint of the atmospheric transport operator. We present estimates of N_2O emissions at the global and European scales using a variational formulation of the Bayesian inversion method and the atmospheric transport model, LMDZ. For our study, we have used a version of LMDZ with a 'zoom' over Europe, where the spatial resolution is 1x1 degrees. A global dataset of atmospheric concentrations was used, which includes data from 10 in-situ measurement sites in Europe. We focus on the results for 2006 and 2007, which show a considerable increase in global N_2O emissions, relative to the prior, and, in particular, higher emissions in Europe, tropical Africa, South and Southeast Asia and the Amazon.

Methods

Atmospheric N_2O concentrations $\mathbf{y}$ contain information about the surface fluxes $\mathbf{x}$, which can be used, by applying Bayes' Theorem, to transform the prior probability density about the fluxes, $p(\mathbf{x})$ into an optimized (or posterior probability density) $p(\mathbf{x}|\mathbf{y})$. In this case the probability densities are sufficiently close to Gaussian, so that posterior probability is:

$$p(\mathbf{x} \mid \mathbf{y}) = \frac{p(\mathbf{x})p(\mathbf{y} \mid \mathbf{x})}{p(\mathbf{y})} = const.\exp\left(-J(\mathbf{x})\right) \tag{1}$$

where $J(\mathbf{x})$ is the cost function:

$$2J(\mathbf{x}) = (\mathbf{x} - \mathbf{x_b})^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x_b}) + (\mathcal{H}(\mathbf{x}) - \mathbf{y})^{\mathrm{T}}\mathbf{R}^{-1}(\mathcal{H}(\mathbf{x}) - \mathbf{y}) \tag{2}$$

and $\mathbf{x_b}$ is the prior surface flux, $\mathcal{H}$ is the atmospheric transport operator, described by the transport model, LMDZ, and **B** and **R** are the prior flux and observation error covariance matrices, respectively (for details about Bayes' theorem applied to linear inversions see Tarantola [2005]). In the variational approach, the optimal solution **x**, for which $J(\mathbf{x})$ is minimized, is calculated using a descent algorithm; here we use the Lanczos version of conjugate gradient algorithm (for details see [Chevallier et al., 2005]). For this study, we have used atmospheric observations from two global networks, NOAA and AGAGE, and 10 in-situ measurement sites in Europe. To overcome the problem of scale offsets between the different networks and sites, we have included variables for the offsets relative to the NOAA scale in the optimization problem and thereby avoid spurious results in the retrieved fluxes. Prior fluxes $\mathbf{x_b}$ were compiled from monthly estimates of anthropogenic (EDGAR-4.0), terrestrial biosphere (L. Bouwman, personal communication), and ocean fluxes (GEIA). Anthropogenic emissions included those from agriculture, livestock, biomass burning, deforestation, agricultural waste burning, industry, and fossil and bio-fuel combustion. Surface fluxes were resolved at 4-weekly intervals for the period January 2005 to December 2007, with 2005 being treated as a 'spin-up' year to ensure independence from the initial conditions.

Results

We find a consistent spatial pattern in the posterior N_2O emissions for 2006 and 2007. The regions with the strongest N_2O emissions were found to be the Amazon, tropical Africa, South and Southeast Asia, and Europe, where the emissions were also significantly higher than in the prior estimates. Most notable are the high emissions found in Borneo, Indonesia, where the emissions reached 0.7 $gNm^{-2}y^{-1}$, the highest per area emissions seen anywhere in the tropics and sub-tropics. Globally, the inversion found a mean total annual emission of 19 $TgNy^{-1}$ while assuming a mean total annual loss of 13 $TgNy^{-1}$, consistent with an atmospheric lifetime of 111 years. For Europe, the strongest emissions were found for the regions of Benelux, Baden-Württemberg in Germany, and northwest Italy. The total EU27 emission was 0.9 $TgNy^{-1}$, thus contributing about 5% to the global total emissions.

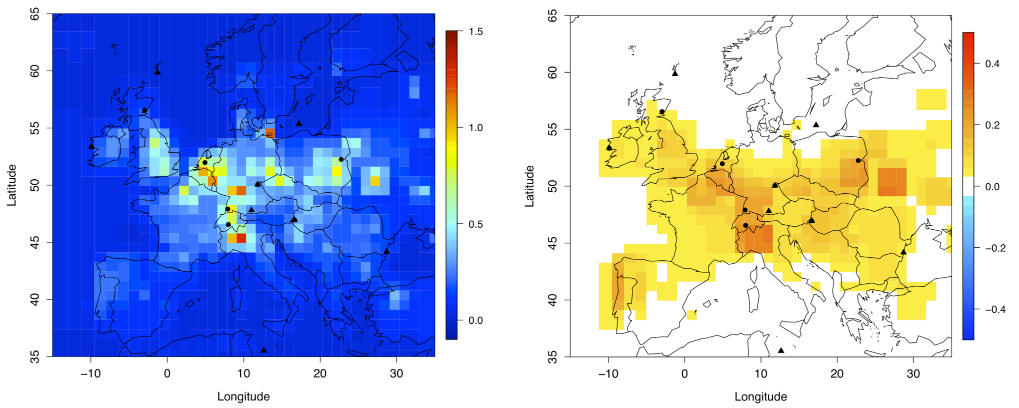

Fig. 1. Annual mean posterior N_2O fluxes (left) and posterior-prior differences (right) [$gN/m^2/y$] for 2007

References

Chevallier, F., M. Fisher, P. Peylin, S. Serrar, P. Bousquet, F.-M. Bréon, A. Chédin, and P. Ciais (2005) Inferring CO2 sources and sinks from satellite observations: Method and application to TOVS data, *J. Geophys. Res., 110*, D24309, doi: 10.1029/2005JD006390.

Tarantola A. (2005) Inverse Problem Theory and Methods for Model Parameter Estimation, Society of Industrial and Applied Mathematics, Philadelphia, USA, 342pp.