4th International Workshop
on Uncertainty in Atmospheric Emissions
7-9 October 2015, Krakow, Poland

PROCEEDINGS

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Warszawa 2015

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Printed from the material submitted by the authors.

ISBN 83-894-7557-X
EAN 9788389475572

About the Workshop

The assessment of greenhouse gases and air pollutants (indirect GHGs) emitted to and removed from the atmosphere is high on the political and scientific agendas. Building on the UN climate process, the international community strives to address the long-term challenge of climate change collectively and comprehensively, and to take concrete and timely action that proves sustainable and robust in the future. Under the umbrella of the UN Framework Convention on Climate Change, mainly developed country parties to the Convention have, since the mid-1990s, published annual or periodic inventories of emissions and removals, and continued to do so after the Kyoto Protocol to the Convention ceased in 2012. Policymakers use these inventories to develop strategies and policies for emission reductions and to track the progress of those strategies and policies. Where formal commitments to limit emissions exist, regulatory agencies and corporations rely on emission inventories to establish compliance records.

However, as increasing international concern and cooperation aim at policy-oriented solutions to the climate change problem, a number of issues circulating around uncertainty have come to the fore, which were undervalued or left unmentioned at the time of the Kyoto Protocol but require adequate recognition under a workable and legislated successor agreement. Accounting and verification of emissions in space and time, compliance with emission reduction commitments, risk of exceeding future temperature targets, evaluating effects of mitigation versus adaptation versus intensity of induced impacts at home and elsewhere, and accounting of traded emission permits are to name but a few.

The *4th International Workshop on Uncertainty in Atmospheric Emissions* is jointly organized by the *Systems Research Institute of the Polish Academy of Sciences*, the Austrian-based *International Institute for Applied Systems Analysis*, and the *Lviv Polytechnic National University*. The 4th Uncertainty Workshop follows up and expands on the scope of the earlier Uncertainty Workshops – the *1st Workshop* in 2004 in Warsaw, Poland; the *2nd Workshop* in 2007 in Laxenburg, Austria; and the *3rd Workshop* in 2010 in Lviv, Ukraine.

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Uncertainty associated with fossil fuel carbon dioxide (CO_2) gridded emission datasets

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Abstract

CO_2 emissions from fossil fuel combustion (FFCO2) serves as a reference in carbon budget analysis and thus needs to be accurately quantified. FFCO2 estimates from different emission inventories often agree well at global and national level, however their subnational emission spatial distributions are unique and subject to uncertainty in the proxy data used for disaggregation of country emissions. In this study, we attempt to assess the uncertainty associated with emission spatial distributions in gridded FFCO2 emission inventories. We compared emission distributions from four gridded inventories at a 1 × 1 degree resolution and used the differences as a proxy for uncertainty. The calculated uncertainties typically range from 30% to 200% and inversely correlated with the emission magnitude. We also discuss limitations of our approach and possible difficulties when implemented at a higher spatial resolution.

Keywords: Emission inventory, carbon dioxide, fossil fuel emissions, uncertainty, atmospheric inversion

1. Introduction

CO_2 emission from fossil fuel combustion (FFCO2) serves as a reference in carbon budget analysis where carbon uptake by natural processes is typically the biggest unknown. The uncertainty associated with global total FFCO2 was estimated as 8% (2 sigma) by the work by Andres and co-authors [1] and FFCO2 estimates from difference emission inventories often agree well at global and country level [2].

Disaggregation of country emissions is a common method to develop a gridded emission inventory. Emission spatial distributions are estimated using spatial proxy data such as population density/counts [e.g. 3, 4] and satellite-observed nightlights [e.g. 5, 6] for diffused sources, geographical locations of point sources (e.g. power plant, cement production facilities and steel furnaces) [e.g. 6, 7, 8] and line sources such as road and railroad networks, aircraft and ship tracks [e.g. 7], and combinations of those.

While the uncertainties for country total emissions are thought to be small (e.g. 5% for US), the emission disaggregation step can introduce significant errors in emissions estimates at higher spatial resolutions. The errors introduced will be propagated through atmospheric transport model simulations and subsequent budget analyses. Thus, it is critical to quantify and characterize the uncertainties (errors) associated with the spatial distributions of fossil fuel emissions. In this study, we present a new approach to assess an uncertainty associated with spatial distributions in gridded FFCO2 emission inventories.

2. Method

In disaggregation of country emissions, emission magnitude at grid cells can be achieved by multiplying the mass of the total emission to normalized spatial proxy data. In this example, a single emission sector is assumed along with the use of single proxy data for simplification

$$E_{i,j} = M_{Total} \times W_{i,j} \quad (1)$$

$$W_{i,j} = P_{i,j} / \sum_{i=1}^{m} \sum_{j=1}^{n} P_{i,j} \quad (2)$$

where $E_{i,j}$ is the emission magnitude of grid (i,j), M_{Total} is the total mass of emissions for the domain of interest, $W_{i,j}$ is the weight given as a normalized proxy value of $P_{i,j.}$ With a rule of combined uncertainty, the percent uncertainty of $E_{i,j}$ can be calculated as a combination of percentage uncertainties for (a) total emission mass and (b) weight at grid cell

$$\delta E_{i,j}/E_{i,j} = \sqrt{(\delta M_{Total}/M_{Total})^2 + (\delta W_{i,j}/W_{i,j})^2} \quad (3)$$

The uncertainty for the total mass is often available, however the challenge is to estimate the uncertainty for the second term based on spatial disaggregation. One could use the uncertainty estimates for the proxy data to estimate the second term in the root in the equation (3). A limitation of such approach is the inability of accounting for emissions that are not represented by proxy data used. The spatial distributions are unique and subject to the proxy data used for disaggregation of national emissions. Thus, the uncertainty assessment is specific to a particular disaggregation method and do not reflect the fact that some of the emission features might not be addressed by the underlying methodology.

In this study, we compared emission distributions from four emission inventories that are based on different disaggregation methods and used the differences to estimate the second term. We normalized the emission datasets to the same global total and calculated the mean and standard deviation at grid cells as follows:

$$\delta W_{i,j}/W_{i,j} \sim SD_{i,j}/Mean_{i,j} \quad (4)$$

We used four emission datasets used in a recent atmospheric inversion intercomparison work by Peylin and co-authors [9]: Emission dataset developed by Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory (ORLN) [3] (hereafter CDIAC), the Open source Data Inventory for Anthropogenic CO_2 (ODIAC) [6] and two versions of Emission Database for Atmospheric Research (EDGAR) (v4.2 and Fast Track) [7]. Those emission datasets share some of underlying country level data and/or spatial proxy data, but the authors believe that their methods have produced distinct emission spatial distributions and can be considered to be reasonably different from each other. In common atmospheric CO_2 inversion, FFCO2 is assumed to be the flux quantity with the least uncertainty and, unlike natural fluxes, is not optimized [e.g. 10]. The differences we would see in different gridded FFCO2 emission inventories are possible sources of uncertainty associated that could propagate into flux inverse estimates.

3. Results and discusssions

Figures 1 shows spatial distributions of four different gridded emission datasets (CDIAC, ODIAC, EDGAR/v4.2, EDGAR/FastTrack). Here only emissions over land (normalized to the same total) were presented. We aggregated four different gridded inventories to a common 1 x 1 degree domain. The major patterns we can see in the global distributions are driven by country emissions estimates that have very good agreement in general, especially for top emitting countries. The differences seen in subnational emission distributions are largely attributable to the differences among disaggregation methods. In CDIAC and ODIAC for instance, areas with no emission are spreading over northern high latitudes and some desert areas such as Africa and the center part of Australia. This can be explained by the fact that CDIAC and ODIAC do not have an explicit representation of emissions from road network and its spatial distributions, while the two versions of EDGAR do. If uncertainty associated with spatial distributions is assessed just using a single gridded emission inventory, the emission distribution discrepancy like we found between CDIAC/ODIAC and EDGAR would not be addressed.

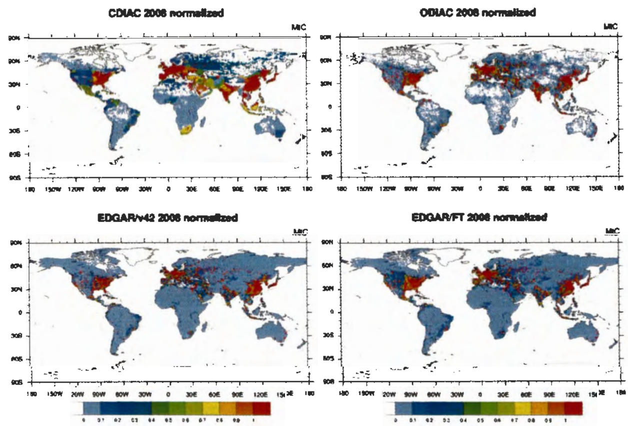

Figure 1. Spatial distributions of fossil fuel emissions from four different emission inventories (CDIAC, ODIAC, EDGAR v4.2 and EDGAR Fast track). Emission fields for the year 2008 were aggregated to a common 1 × 1 degree resolution and then global total are scaled to the same total as CDIAC. Values are given in the unit of mega tonne Carbon per year.

Our uncertainty estimate associated with emission spatial distributions is shown in Figure 2. The values in the map were calculated as standard deviation of emission values at grid cell from four different gridded inventories (normalized) divided by mean of the four, as briefly described in the section 2. The calculation was implemented at a common 1 x 1 degree resolution. The calculated uncertainties typically range from 30% to 200%. The uncertainty tends to be lower over areas with intense emissions and higher over the areas with relatively low emissions. This seems to be qualitatively reasonable if we take emissions from road network as an example. The final uncertainty (uncertainty for emission estimates and spatial distribution) can be achieved by combining the uncertainty with the uncertainty for the global total emissions using a root-square fashion.

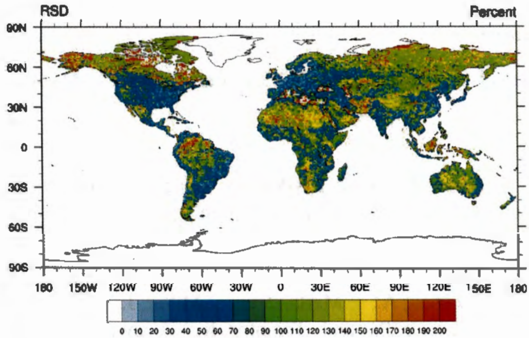

Figure 2. Estimates of uncertainty associated with the spatial disaggregation of country emissions. Values are given in the unit of percentage (%).

The uncertainty estimates from this approach are directly applicable to the studies such as atmospheric inversions where FFCO2 is not optimized and, as a result, is assumed to be perfect. Our approach might be limited by the fact that the variety of disaggregation methods (hence, emission spatial distributions) is not rich enough to implement this type of analysis, although we attempted selected four emission datasets that contain substantial differences. We also acknowledge that the use of multiple emission dataset for estimating the spatial uncertainty does not assure it addresses all the possible error sources. This approach might not work if implemented a much higher spatial resolution where distinct spatial patterns of sector emissions become more visible. The proxy data is as it says "proxy" and in fact is not explicitly representing unique dynamics of human activities. At a high spatial resolution, geolocation information of sources would become a key to achieve accurate emission spatial distributions [e.g. 6]. Currently, it seems less common to collect geolocation information of sources as we regularly do for activity data. Collecting activity data with geolocation information for example would allow us to precisely map emissions and greatly improve emission spatial distributions even at a high spatial resolution.

4. Summary

We present a method to estimate the uncertainty associated with disaggregation of national emissions. We compared four different gridded inventories and used the differences as a proxy for the spatial uncertainty. The calculated uncertainty typically range from 30~200% and are inversely correlated with emission magnitudes. This seems to be qualitatively reasonable considering the fact intense emissions are relatively easy to identify and weak emissions are often difficult to place. We also discussed some of the methodological limitations we have identified.

Demands for an emission inventory gridded at a high spatial resolution has been increased as observational data have become rich and modelling capabilities have been improved to facilitate higher resolution transport and inversion modeling. The emission inventories face a difficulty in achieving accurate spatial distributions at increasingly high resolutions. Collection of additional information associated with emission sources (e.g. geolocation) could greatly help us to accurately map emissions and assess uncertainties associated the resulting emission spatial distributions.

Acknowledgement

Tomohiro Oda is a recipient of the NASA Grant #NNX14AM76G.

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