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Daily CO_2 flux estimates over Europe from continuous atmospheric measurements: 1, inverse methodology

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Abstract. This paper presents an inverse method for inferring trace gas fluxes at high temporal (daily) and spatial (model grid) resolution from continuous atmospheric concentration measurements. The method is designed for regional applications and for use in intensive campaigns. We apply the method to a one month inversion of fluxes over Europe. We show that the information added by the measurements depends critically on the smoothness constraint assumed among the source components. We show that the initial condition affects the inversion for 20 days, provided one has enough observing sites to constrain regional fluxes. We show that the impact of the far-field fluxes grows throughout the inversion and hence a reasonable global flux field is a prerequisite for a regional inversion.

1 Introduction

The task of determining the space-time structure of carbon fluxes to the atmosphere is one step in any attempt to monitor and possibly manage the carbon cycle. The task has generally been performed via two complementary approaches. In the so-called bottom-up methods, small-scale flux estimates are aggregated together to form regional totals. If the measurements are not spatially dense, the approach uses some kind of statistical or physical model to fill gaps. Spatially dense measurements are never of carbon fluxes directly (e.g. land cover) so a different kind of model (e.g. Potter et al., 2003) is used to relate these measurements to carbon fluxes on some time and space scale.

The other approach, the so-called top-down or inverse approach, infers the space-time flux distribution from concentration signatures in the atmosphere. The approach faces many of the usual difficulties of inverse problems, principally a lack of concentration observations and reliance on uncertain atmospheric transport. A detailed explanation of the underlying principles is given in Enting (2002) and especially of the "matrix approach" used in this study.

The two approaches have different characteristics in almost all respects. Most importantly they give rise to different kinds of uncertainty. For example, if the bottom-up approach must use some kind of extrapolation, then any error in a point measurement will be propagated by the extrapolator and bias large-scale estimates. This is even clearer if some kind of physical model is used to relate the measurements to the carbon fluxes we seek; errors in the model are not random and so will not disappear as we move to larger and larger regions.

The case for the inverse approach is quite different. Here the sparsity of concentration data limits the resolution of the inverse procedure, so that estimates are more certain at large scales. In fact the ability of the method to resolve small scales is limited and most studies employ some form of regularization method. Regularization imposes some extra constraint on the solution to limit its sensitivity to individual data points and hence limit error amplification. Bayesian methods, in which prior estimates of fluxes are inserted as extra data into the problem, have been the norm (e.g. Enting et al., 1995; Rayner et al., 1999; Bousquet et al., 2000; Gurney et al., 2002) but some studies have employed other forms

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