2.10. INVERSE MODELING

Efforts to quantify the possible responses of the climate system to anthropogenic emissions of radiatively active trace species such as CO_2 and CH_4 are complicated by the significant contributions of terrestrial biospheric and oceanic sources to the budgets of these gases. Future attempts to manage carbon reservoirs depend critically on the ability to understand and quantify the distributions of carbon sources in the atmosphere and oceans. Inverse modeling techniques, which have long been applied to geophysical problems such as seismology, satellite data retrieval, and acoustic tomography, have over the past decade been applied to the problem of determining the source and sink distributions of atmospheric trace species, especially CO_2. Early attempts were aimed at obtaining the interhemispheric gradient of the CO_2 sources and sinks [*Tans et al*., 1990; *Enting and Mansbridge*, 1991; *Ciais et al*., 1995a,b; *Bousquet et al*., 1996; *Law and Simmonds*, 1996]. However, with the expansion of the CO_2 observational network, attempts have been made over recent years to obtain source and sink distributions over continental scales.

Currently it seems that the observational network is too sparse to allow accurate estimates of trace gas budgets on continental scales, though it is likely that reasonable estimates over large latitude zones may be made. A further complication is that the current network is designed to sample mostly marine boundary layer air so that information from the terrestrial biosphere at regional scales is lost by mixing over large distances. In addition it is clear that even if more observations over continental regions were obtained, the current generation of models would likely not represent atmospheric boundary processes adequately, leading to significant uncertainty [e.g., *Denning et al.,* 1995]. Despite these daunting difficulties, efforts to estimate the carbon budget at continental scales with reduced uncertainty are underway. It is hoped that the observational network will be expanded and that models will improve significantly in the near future.

Ongoing work by the CCGG group is focused on development of an operational inverse calculation at continental scales. The mass balance and assimilation technique employed has been described in detail by *Bruhwiler et al.* [2000]. The global transport model to be used for operational source calculations is the NCAR MATCH model with the National Center for Environmental Predictions (NCEP) winds. Since this model requires large amounts of computational resources, development and evaluation of the inverse technique has taken place using a much simpler and faster low resolution version of TM2/TM3 [*Heimann*, 1995] with 1 year of European Center for Medium-Range Weather Forecasts (ECMWF) winds that are repeated for multi-year calculations (although multiple year wind fields and 1 year of TM2 vertical diffusion may be used with TM3 for a rough idea of the effects of interannual variability). The inversion uses the Globalview-CO_2 data set and 14 basis functions for continental and oceanic regions.

The sensitivity of source regions to a variety of conditions has been tested. Examples of these conditions include use of radon (Rn) to filter out simulated CO_2 values of recent continental origin and applying a smoothing procedure to calculated time series rather than using instantaneous values. Estimates of the long-term average (1979-1998) CO_2 sources range from about -1 to +1 Gt C yr^{-1} for the terrestrial biosphere and from 0.0 to -2.75 Gt C yr^{-1} for the oceans. In each case, the estimate is for nonrepeating meteorology. Although the estimates seem to be rather insensitive to smoothing and Rn filtering, use of nonrepeating meteorology appears to have a large impact, at least in the present configuration of TM3.

Current estimates of the North American carbon sink are -1 to -1.75 Gt C yr^{-1}, while Eurasia appears to be a carbon source on the average (about 1 Gt C yr^{-1}). The high-latitude northern hemispheric oceans are estimated to take up carbon at the rate of about 1.5 Gt C yr^{-1}(larger than suggested by ΔpCO_2 data), while the equatorial oceans, especially the equatorial Pacific, release carbon at approximately the same rate. Time series of monthly estimates of carbon sources are rather noisy, and time series of annual averages exhibit significant variability, which is due to both uncertainty in the inversion and real variability in sources and sinks. During El Niño years, for example, the emissions from the equatorial Pacific are estimated to decrease, and the total terrestrial sink appears to decrease, possibly to the point at which the terrestrial biosphere becomes a net source of CO_2.

Recent developments were aimed at reducing noise and uncertainty in the inverse calculation. The ability to retain basis function (the CO_2 pattern resulting from a well-defined source) transport information for an arbitrary length of time previous to the time of the inverse calculation was added. Tests suggest that basis functions may need to be carried for periods of half year or longer. In addition the inverse technique was modified to allow simultaneous inversion of multiple trace species. This allows the possibility that constraints relating the budgets of two or more trace species may be used to reduce noise and uncertainty. Test calculations suggest that uncertainty could be significantly reduced if the uncertainty in the constraints employed is not too large.