A new method to investigate regional scale carbon budgets from satellite measured carbon dioxide

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What can the atmospheric concentration of CO₂ tell us about surface fluxes?

The earlier work carried out by the University of Leicester group, in the retrieval of atmospheric CO₂ columns from SCIAMACHY using the Full Spectral Initialisation – Weighting Function Modified (FSI-WFM-DOAS) technique, has shown both seasonality and large scale spatial patterns (figure 1) which are at least in part due to the spatial variation of carbon flux magnitudes between the terrestrial biosphere and the atmosphere.

The potential of the next generation of satellite instruments to improve upon the current understanding of carbon cycle dynamics is great. Using knowledge of carbon cycle dynamics and the geometry of satellite instrument sounding of the atmosphere, we have manipulated the UK Met Office Lagrangian model NAME (the Numerical Atmospheric-dispersion Modelling Environment) to represent the real atmosphere, and the potential to be coupled with any space instrument and any other carbon cycle model.

This new tool is designed to operate in two ways:

• A forward modelling approach, where NAME is coupled to a pre-existing carbon flux model. This approach as been used to test the new tool and the initialisation of the background concentration. It can potentially be used with GOSAT retrievals to validate the CO₂ fluxes of the coupled model.

• An inverse modelling approach, to obtain surface fluxes. This approach makes use of the assumption of homogeneous carbon flux ecoregions.

Developing the NAME carbon cycle tool!

The method used to investigate the surface exchange of carbon involves relating the mass change of carbon between an ensemble of satellite retrieved CO₂ columns (figure 4) and the background to the amount of time air in that ensemble column spends in contact with the surface (where the exchange of carbon happens). The mass change is a direct result of the surface fluxes to the release column.

The NAME model has particles followed backwards in time from the release column to obtain both the surface residence time and to identify where and when particles leave the domain which is used in conjunction with either another set of measurements or an atmospheric CO₂ model to initialise the background concentration (obtaining the mass change).

In the forward modelling approach, the mass change at the release column is obtained in two separate ways, leading to a variety of validation experiments.

In the inverse modelling approach, the various grids square in the domain are grouped together as homogeneous carbon flux ecoregions, possibly by vegetation type (figure 2). Flux magnitudes and precisions are obtained for each ecoregion using a linear regression approach.

Validation of method

Using the forward approach with products from CarbonTracker, an experiment was set up to validate the initialisation of the background CO₂. Each CT weather product (Fig. 6) is produced by adding the wind field to the (three hour) previous CO₂ weather plus the CT flux product (Fig. 5).

Particles were released from a column, and a mass difference for each 3-hour interval was calculated in two ways: flux × residence time and weather mass change. A one to one ratio would indicate that the initialisation of background CO₂ is reliable. Results show a high correlation coefficient (figures 7-9) and are close to a linear one to one relationship, indicating that this methodology can reliably obtain background CO₂.

An experiment was set up to investigate the inversion method. Seven ecoregions were included in the domain with a constant background of 370ppm. Particles were released from many locations and the ecoregion flux magnitudes × the surface residence time was used to create the simulated measurements.

After adding different measurement errors, the linear regression inversion was used to return the seven fluxes. With a small measurement error (±0.1 ppm), the inversion was able to return the initial fluxes. As this grew, the inversion was less reliable for surface types that were rarely sampled by the NAME particles (see table 1).

As a test run of the forward approach, FSI measurements were used with CarbonTracker background producing a carbon mass change in the domain to compare with the mass change produced by multiplying the residence time with CarbonTracker fluxes. This was noisy (Fig. 10), although some structure is visible when these are clustered together based on where they were released (Fig. 11).

The inversion of SCIAMACHY FSI CO₂, using MODIS land classification to define the ecoregions, has not been successful, partly as a result of differences between FSI and CarbonTracker (used to initialise the background CO₂).