UNCONSTRAINED OCEAN CARBON CYCLE MODELS

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Global ocean carbon cycle models have emerged over the last decade as powerful tools for studying marine biogeochemistry and remain one of the few viable approaches for projecting the response and feedbacks to future climate change. With respect to ocean carbon transport, prognostic or unconstrained models can be useful in linking the observed distributions and flux estimates (air-sea and horizontal) with the underlying physical and biogeochemical dynamics. Conversely, these models should be continuously confronted with the observational data as part of the ongoing cycle of model evaluation and development. Finally, data assimilation schemes are built around prognostic models and the skill of the assimilation is dependent on a good forward simulation particular, as is presently the case for carbon, for relatively data poor situations. Here we will discuss the current state of global, coarse resolution ocean carbon cycle models drawing on examples from the NCAR ocean model using the OCMIP-2 biotic routines (Doney et al., 2001).

The oceanic uptake of anthropogenic carbon, currently estimated to be about 2PgCyr^{-1} occurs on top of a large natural background inventory (~40,000 PgC) and carbon cycle. For comparison, the estimated export flux of particulate and dissolved organic carbon from the surface layer is about 10 PgC yr^{-1}. This export flux together with physical solubility effects on dissolved inorganic carbon (DIC) drives the vertical partitioning and large-scale patterns of nutrients, oxygen, DIC and alkalinity in the ocean. A number of models of varying complexity and sophistication have been developed to estimate export flux. A simple example is the OCMIP-2 biotic model which neglects the ecological details of the upper ocean and predicts the production of organic matter based on restoring of the surface nutrient concentrations to an observed climatology. The production is partitioned into sinking particles, which are remineralized over the water column with a simple empirical vertical profile, and a dissolved organic matter (DOM) pool, which is advected and mixed with the water decaying as a first order process with a 6 month half-life. Most of the dissolved organic pool is remaineralized over the upper 250m of the water column and the particles by 1000m. Observational estimates of export production range widely, but the model tends to capture the broad patterns-high in regions of upwelling and convection (Equatorial band, mid- to high latitudes) and low in the subtropical gyres (Figure 1). The subtropical gyres are regions of net horizontal convergence of DOM. Some caution should be taken with the predicted export fluxes from this class of coarse-resolution models because the production is sensitive to explicit and implicit vertical mixing and may depend upon issues such as numerical advection schemes.

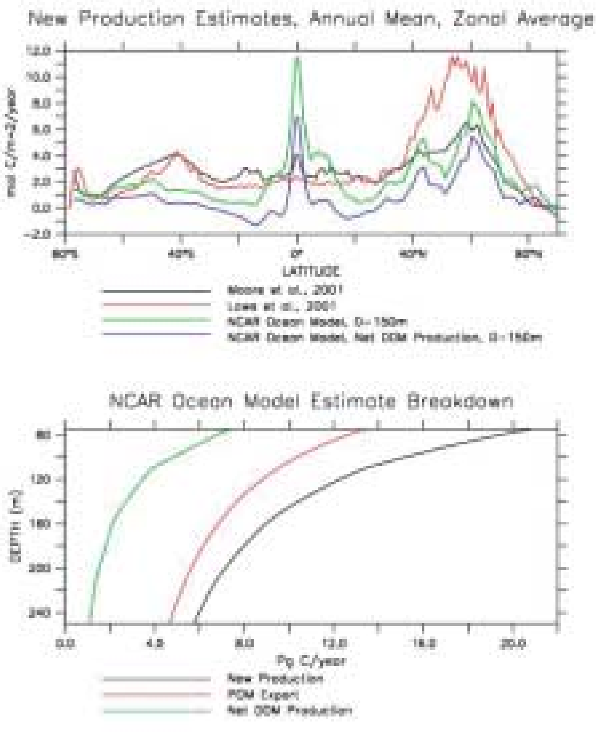
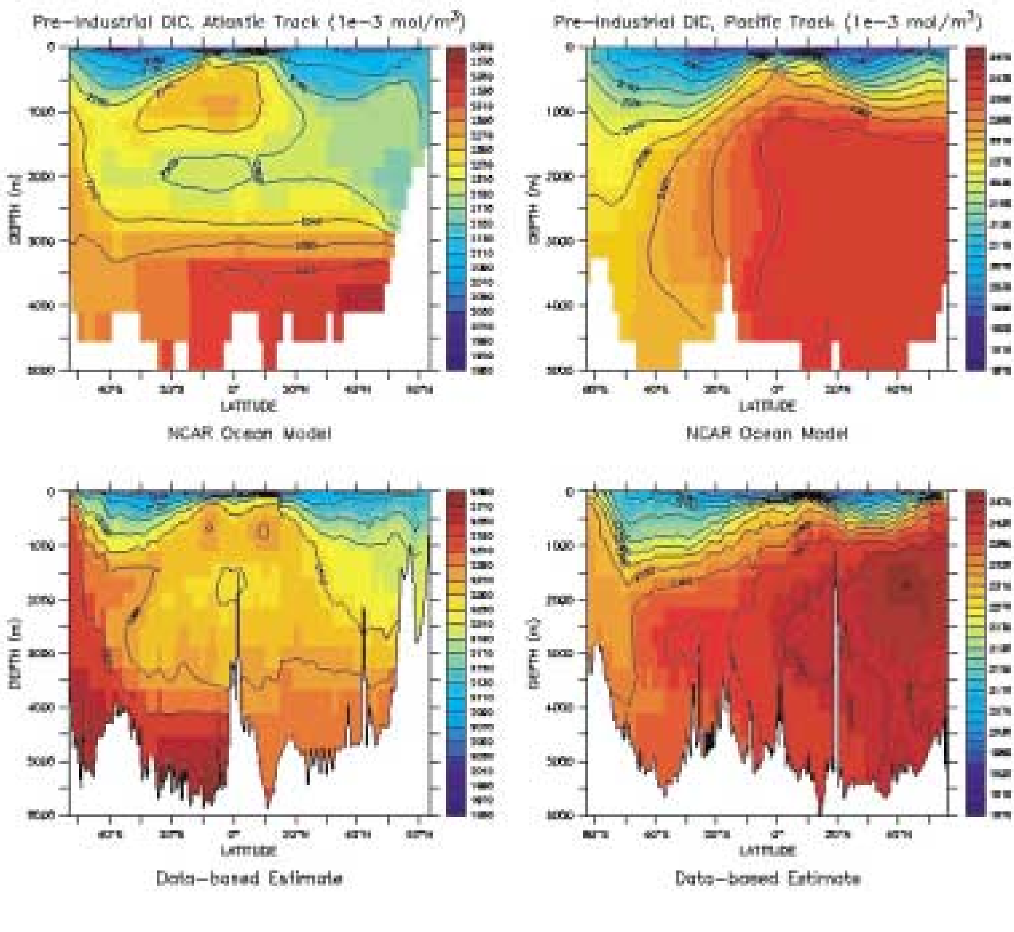


Figure 1

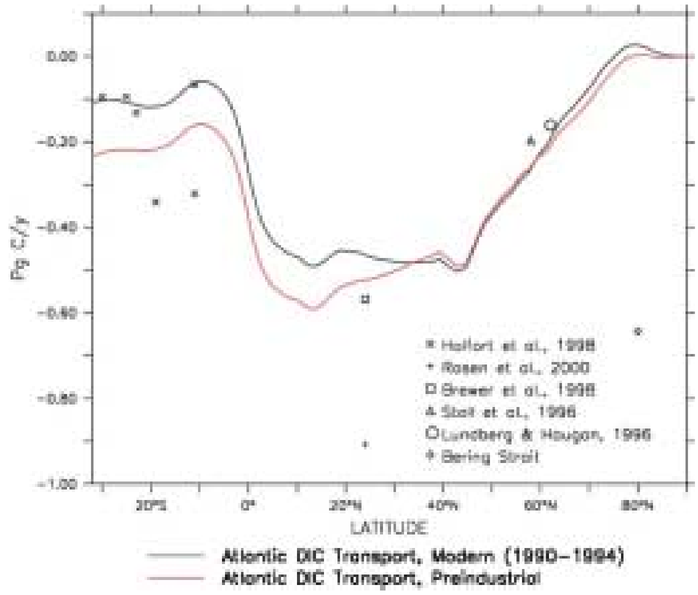
The WOCE/JGOFS global CO_2 survey data set provides an excellent and unique metric for assessing the model predicted large-scale DIC and alkalinity fields. Additional measures of model skill include the more extensive nutrient and oxygen data bases, the Takahashi et al. surface air-sea CO_2 climatology, and transient tracers (CFCs, ^{14}C) and empirical estimates of anthropogenic carbon. The NCAR model preforms reasonably well in capturing the large-scale patterns in these different field as shown for example in Figure 2 for an Atlantic and Pacific meridional section of the pre-industrial, subsurface DIC concentration. But clear regional deficiencies can be noted, and many of these problems can be traced back to a poor physical circulation field. In particular, as is common with z-coordinate models the simulated North Atlantic Deep Water outflows at too shallow a depth leading to a dipole error pattern in the Atlantic meridional section. As a rule the skill of the biogeochemical solution depends critically upon the physical circulation.

Figure 2



Global numerical models capture the key processes relevant for transport calculations namely the horizontal transport (and divergence) itself, air-sea fluxes, and internal storage (e.g. anthropogenic carbon build-up). Depending on their formulation they may or may not include aspects such as river runoff and an open Bering strait (the NCAR model has neither), important for computing absolute mass and carbon transport (which in many ways behaves more like freshwater than heat transport). Figure 3 shows the model predicted pre-industrial and modern meridional carbon transport for the Atlantic compared with observations corrected for the Bering Straits carbon inflow of roughly 0.6 PgC yr^{-1}. The model and data predict comporable net southward preindustrial DIC transport (maximum of 0.6 PgC yr^{-1}) associated with the thermohaline overturning and net northward anthropogenic DIC transport (0.1-0.12 PgC yr^{-1}) in the surface layer. One issue to be aware of is that many models do not include a full natural boundary condition for freshwater and thus resort to "virtual" surface fluxes for salt and carbon. The resulting "virtual" carbon transports are similar in size to actual fluxes and can be corrected for to first order.

Figure 3



One advantage of models is that they allow us to look in detail at the processes generating integrated properties such as the zonally average flux. As one example, the model suggests that the net transport of DOM varies regionally and could be as large as ±0.15 PgC yr^{-1}. Dynamically, most of the carbon transport is occuring via the mean Eulerian flow but a significant diffusive flux is found in the model tropics and eddy-induced advection (based on the Gent-McWilliams meoscale mixing parameterization is found along the Gulf Stream-North Atlantic Current. The model circulation/transport patterns can also be explored at the level of an individual section, though some care is warrented as coarse-resolution model exhibit known deficencies in currents (e.g. too broad Gulf Stream with limited recirculation; slow core velocities; poor representation of vertical structure in the Deep Western Boundary Current).

Several atmospheric and oceanic studies have suggested that the pre-industrial ocean had a net southward interhemispheric transport of carbon of up to 1.0 PgC yr^{-1}. This would have important ramifications for the hemispheric atmospheric gradient, which has been used extensively to infer that the main location for ocean/land anthropogenic carbon sinks must be in the northern hemisphere. More recent 3-D ocean simulations suggest the number is more like a few tenths of a PgC yr^{-1} at most. The addition of riverine carbon input, which occurs primarily in the Northern Hemisphere but which is outgassed in both hemispheres, could add about another 0.25 PgC yr^{-1} to those values. While smaller than orginally thought, this transport has a non-negligible impact on atmospheric CO_2 fields.

Future work is required in a number of areas to improve on exisiting ocean carbon cycle models. Key areas for advancement focusing on ocean carbon transport include (Doney, 1999):

- mechanistic ecosystem biogeochemical components (e.g. plankton functional groups, particle flux & remineralization)
- physical model developments (e.g. diapycnal mixing, deep-water formation & overflows, isopycnal coordinates)
- interannual variability & eddy resolving biogeochemical simulations - net mass transport (e.g.~Bering Straits, natural boundary conditions, rivers)
- reconciliation of atmosphere & ocean flux estimates

References

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