

On The Distribution of Bomb Carbon-14 in the Southern Ocean

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Introduction

In an earlier WOCE newsletter (Ribbe & Tomczak, 1995) we reported on the development of an off-line radiocarbon validated tracer model for the Southern Ocean based on the Fine Resolution Antarctic Model (FRAM). During the initial stages of the project computational experiment were carried out with the model for an idealised oceanic tracer. We intended to verify the physical mechanisms that operate in the model and are responsible for removing atmospheric tracer and surface water. The results of these experiments have recently been reported in a series of papers (Ribbe & Tomczak, 1996a, 1996b, 1996c) and some very early results were published in this newsletter previously.

In this note we report on the first experiments to investigate the uptake of bomb carbon-14 within the model. The effect of convection has been quantified in one of our experiments shown here. The integrated bomb carbon-14 flux due to convection alone results in an oceanic uptake of approximately 15 per cent. We are presently investigating the sensitivity of the total uptake to effects such as changes in fluxes at the northern model boundary, the distribution of convection, and sea-ice coverage.

Although the model covers the ocean area south of 24° S, the discussion in this note is limited to bomb carbon-14 in the Indian Ocean. This ocean has been the focus of our earlier communications, which dealt with the formation of Subantarctic Mode Water (SAMW) in the southeast Indian Ocean. Our intention with the model is to quantify the role of this process for bomb carbon-14 uptake. During the last few months we were able to analyse samples collected from the Great Australian Bight (GAB) for carbon-14 using, for the first time in Australia, the Accelerator Mass Spectrometry (AMS) technique (Ribbe et al., 1996). The model will eventually be applied to interpret the distribution of carbon-14 within the Australian sector of the Southern Ocean where a radiocarbon sampling program is being carried out along WOCE Sections SR3 and SR4.

Method

The methodology in setting up the tracer model was described in Ribbe & Tomczak (1995). The same approach is taken here in our bomb carbon-14 experiments. The bomb carbon-14 is added to the model following the approach of Duffy et al. (1995). We are using a wind dependent exchange coefficient calculated from the FRAM wind field. The atmospheric carbon-14 history for the southern hemisphere is taken from Vogel & Marais (1971). At the northern boundary bomb carbon-14 values are prescribed for inflowing water using the time history of carbon-14 values in surface water given by Broecker et al. (1985).

Carbon-14 values are reported as $\Delta^{14}\text{C}$ in [ppt] which is the deviation of the $^{14}\text{C}/^{12}\text{C}$ ratio from a standard value of that ratio. The guidelines for ocean water samples were laid out by Stuiver & Polach (1977). We followed the same procedure but will refer to $\Delta^{14}\text{C}$ as a carbon-14 concentration. Various properties are calculated for the modelled bomb $\Delta^{14}\text{C}$ distribution; our values for the bomb carbon-14 inventory, the mean penetration depth, mean surface value and mean column inventory should be compared to the data presented in Duffy et al. (1995) and Broecker et al. (1995).

Results

The evaluation of both the modelled and observed data is in a very early stage and we would like our results to be considered as preliminary.

In Figure 1 we show the bomb carbon-14 distribution calculated by the model in a comparison with the bomb carbon-14 data calculated by Broecker et al. (1995) from GEOSECS Indian Ocean observations. The agreement between both data sets is generally quite reasonable with observations (Figure 1a) and modelled data (Figure 1b) closest north of 30°S . The modelled data clearly show the observed north-south gradient with the lower values in the south. The gradient is a result of the surface Ekman transport which removes surface water and introduces tracer quantities to the north.

The area of SAMW formation in the southeast Indian Ocean, located in the model between 100° to 130°E and 45° to 55°S , is characterised by minima in the bomb carbon-14 distribution with values below 100 ppt. Mid-latitude convection removes the bomb carbon-14 signal from the surface and homogenises the water column down to a depth of 300 - 400 m.

The mismatch between the observed and modelled data might be related to the presentation of physical mechanisms in the model, the procedure used by Broecker et al.

(1995) to calculate the bomb-carbon-14 signal or a combination of both. It is worthwhile to notice that Duffy et al (1995) used various approaches to model the distribution of bomb carbon-14 in global ocean models and obtained surface maximum carbon-14 values within the centre of the south Pacific Ocean gyre ranging from 180 ppt to 330 ppt. The exact causes for the mismatch between observations and our model require further analysis.

Several surface water samples collected within the Great Australian Bight were recently analysed using the AMS technique (Ribbe et al., 1996). The observed values are in the range of 84 to 101 ppt (Figure 2a) which compares to model values in the order of 100 to 125 ppt. The model integration was carried out for the bomb carbon-14 signal only, and in the absence of the natural carbon-14 component a discrepancy is expected. However, north of the Subantarctic Front which in the south east Indian Ocean is located at approximately 42° S, surface carbon-14 values are dominated by the bomb carbon-14 signal.

While the data shown in the previous figures concentrated upon the situation in the south east Indian Ocean, we will look in the following into the temporal evolution of the 'global' bomb carbon-14 integral. We calculated the total model bomb carbon-14 inventory (Figure 3a), the mean penetration depth (Figure 3b), the mean surface value (Figure 3c) and the mean column inventory (Figure 3d) for three experiments. In experiment 1 (solid line), no southward flow of bomb carbon-14 across the northern model boundary was specified. The inventory was solely determined by atmospheric input. In experiment 2 (long dashed line), a boundary flow was specified in addition to atmospheric input and in experiment 3 (short dashed line) we switched off oceanic convection but maintained both boundary and atmospheric input. Broecker et al. (1995) estimated a total inventory of approximately $5.4 \cdot 10^{27}$ atoms and a specific water column inventory of $8 \cdot 10^9$ atoms/cm² for the ocean area south of 20°S and observed during GEOSECS. This compares with our values of $6.5 - 7.5 \cdot 10^{27}$ atoms for the total inventory (Figure 1a) and a mean column inventory of $5.0 - 5.5 \cdot 10^9$ atoms/cm² in 1975. The mean surface value and the mean penetration depths of bomb carbon-14 observed during GEOSECS for the global ocean are given with 155 ppt and 391 m by Broecker et al. (1995) and with approximately 170-190 ppt and 250-320 m by Duffy et al. (1995). We obtained values of 110 - 125 ppt and 280-300 m, which is lower than the values obtained by Broecker as well as Duffy. This is expected, as the Southern Ocean is dominated by upwelling and northward Ekman transport associated with flow out of the model domain.

In our model experiments, we are particularly interested in the effect of the convection parameterisation. This effect can be quantified by integrating the model without convection which results in a reduced oceanic uptake of bomb carbon-14 by

approximately 15 per cent. To describe in detail the parameterisation and distribution of convection in the model is beyond the intent of this note, but further details can be obtained from our manuscripts submitted for publications (Ribbe & Tomczak, 1996a, 1996b, 1996c) or by contacting us directly.

Conclusion

In an earlier note we described our plans with the development of the Southern Ocean tracer model. This progress report shows that our first results are in good agreement with work done previously, both by observationalists and modellers. The overall good agreement of modelled and observed data allows us to draw some preliminary conclusions on the effects of oceanic convection on bomb carbon-14 uptake. Some data mismatches still remain to be explained and minimised in further model development.

Acknowledgment

Dr. D. Stevens at the University of East-Anglia in England was an invaluable source of information; he supplied many FRAM data and assisted throughout the project. We thank him for his genuine support.

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Figure Captions

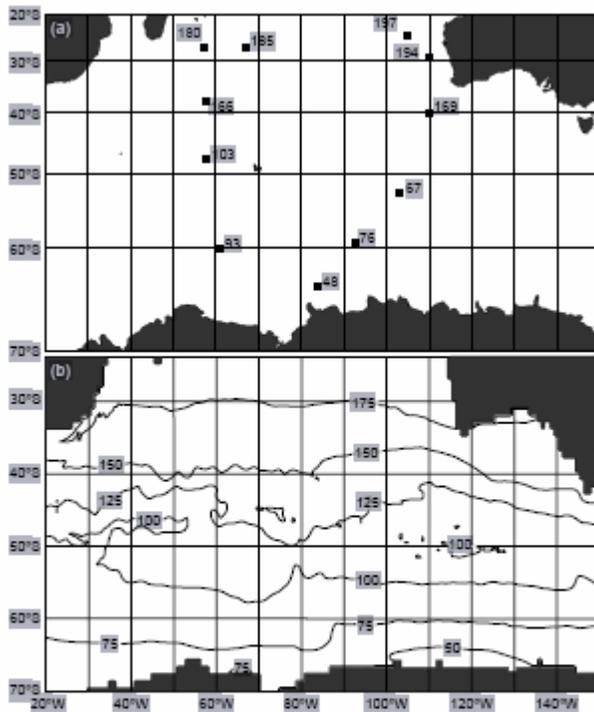


Figure 1. Distribution of bomb carbon-14 [ppt]: (a) as derived from observations (Broecker et al., 1995), and (b) as calculated by the tracer model for the Indian Ocean and the year 1978.

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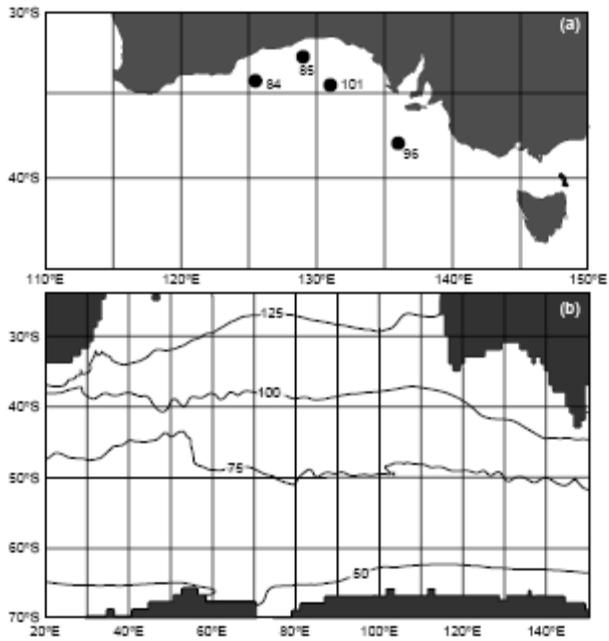


Figure 2. (a) Distribution of observed carbon-14 [ppt], and (b) of bomb carbon-14 calculated by the tracer model for the Indian Ocean and the year 1994.

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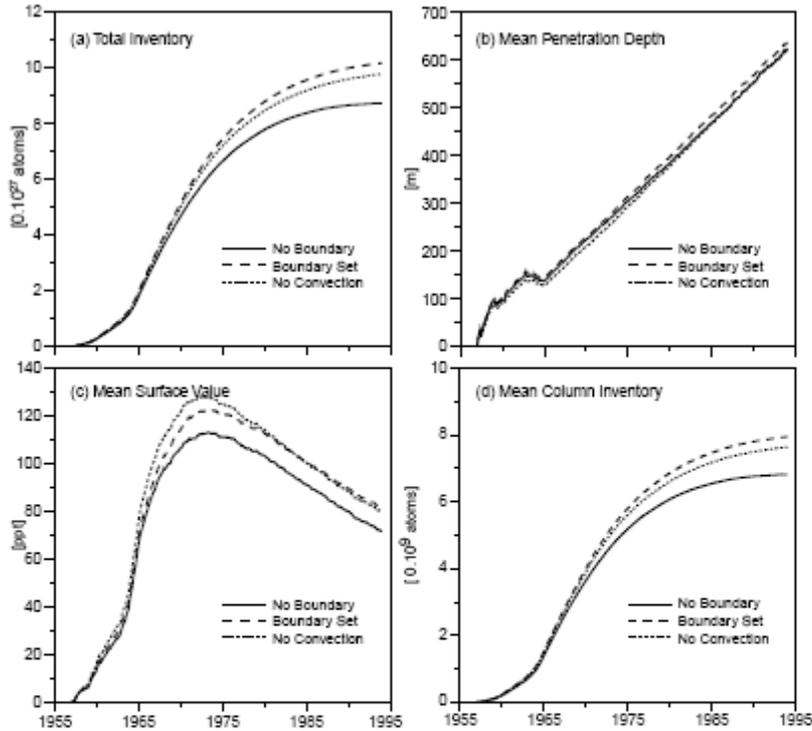


Figure 3. (a) Total bomb carbon-14 inventory [atoms] for the area of the Southern Ocean south of 24°S , (b) mean penetration depth [m], (c) mean surface value [ppt] and (d) mean column inventory [atom]. In each graphic the results of three model experiments are presented: integration for atmospheric input without specified northern boundary (NBD) inflow (solid line), integration for atmospheric input with NBD inflow specified (long dashed line), and integration for atmospheric input with NBD inflow but no convection (short dashed line).

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