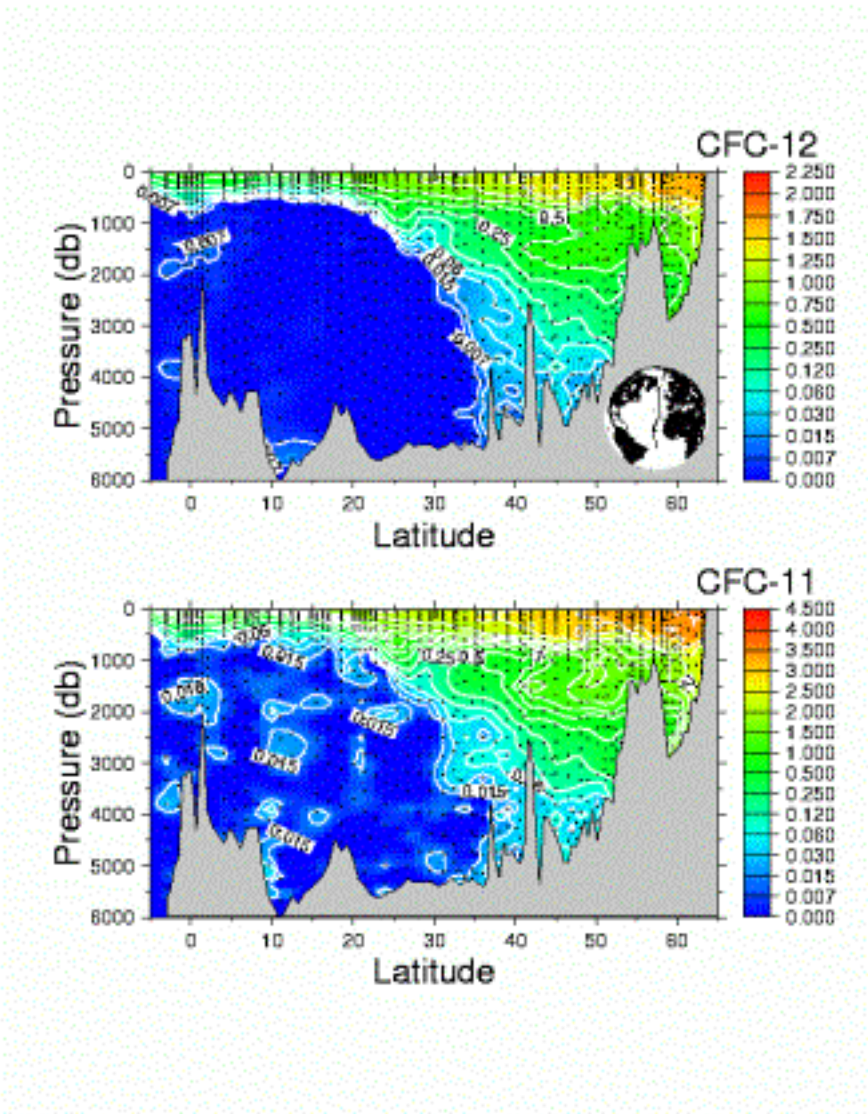
Transport Times in Subpolar North Atlantic Ocean

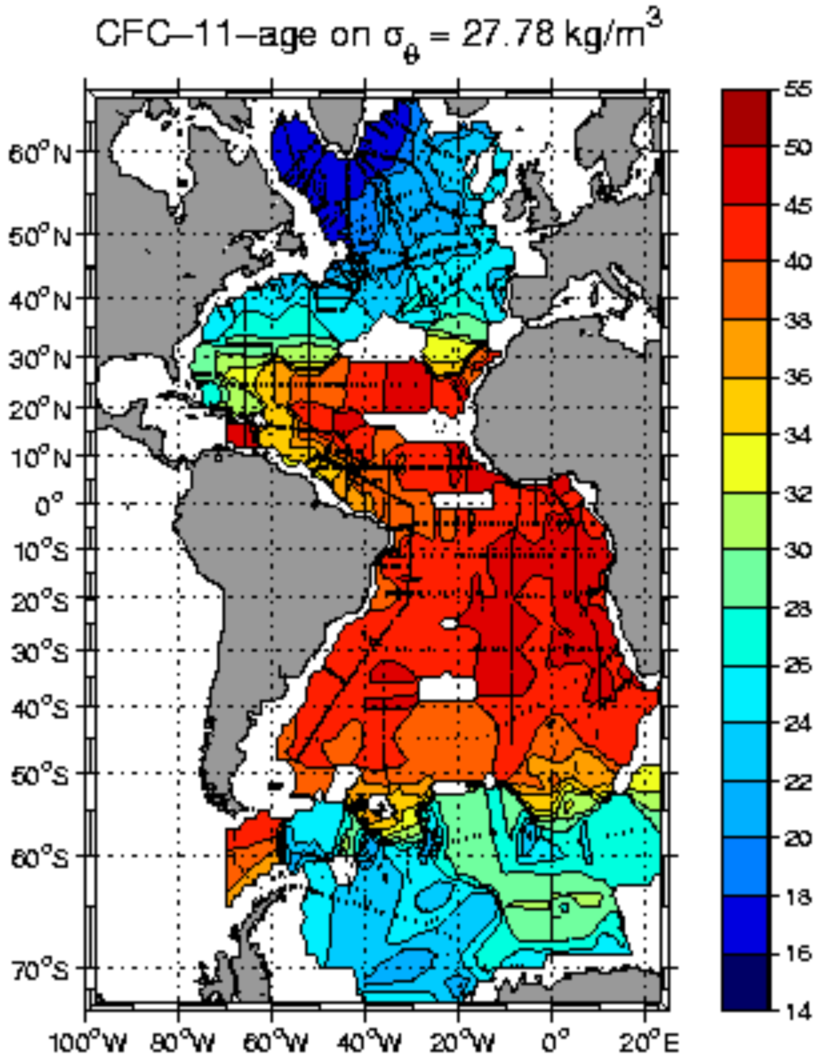
[See Waugh et al., DSR, 2003 for details.]

Measurements of several transient tracers (e.g., CFC11, CFC12, tritium and helium) have been made in the North Atlantic, and other, oceans. These measurements have been used to quantify the ventilation pathways and timescales. The plots below show that in 1988 there were measurable CFC concentrations are observed at the ocean bottom at 20W as far south as 35 deg. N. A clear signal of Labrador Sea mid-depth ventilation can also be seen.



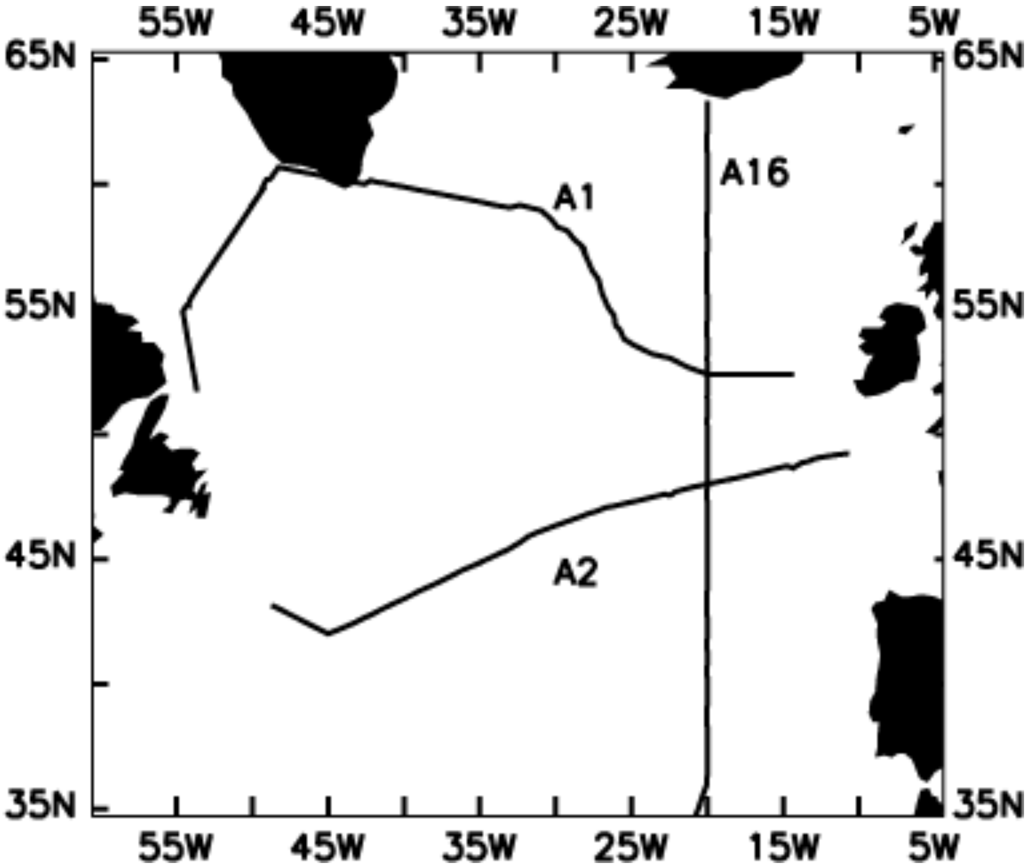
CFC11 and CFC12 along 20W (A16) from measurements in 1988. (Figure courtesy Scott Doney).

In the 1990s, the CFC ages for Labrador Sea Water varies from around 15 yrs in the Labrador Sea, around 30 yrs in the Northeastern Atlantic, to over 50 yrs in the tropical Atlantic, e.g.,



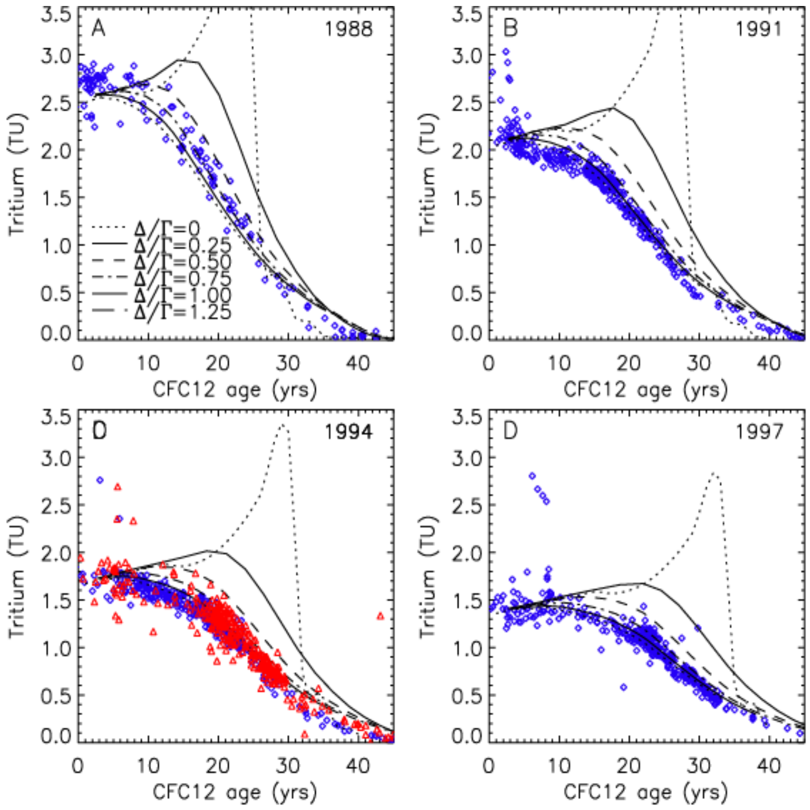
CFC-11 age on the 27.78 σ_θ surface (Figure courtesy of University of Bremen CLIVAR/AIMS web site).

Here we focus on measurements of CFC11, CFC12, tritium and helium were made on several World Ocean Circulation Experiment (WOCE) cruises in the North Atlantic subpolar ocean. In particular on A1 (in 1991 and 1994), A2 (1994 and 1997), and A16 (1988), see map below. CFC113 and CCl4 were also measured on the A2 cruises These measurements of multiple transient tracers can be used to infer the distribution of surface-to-interior transit times.



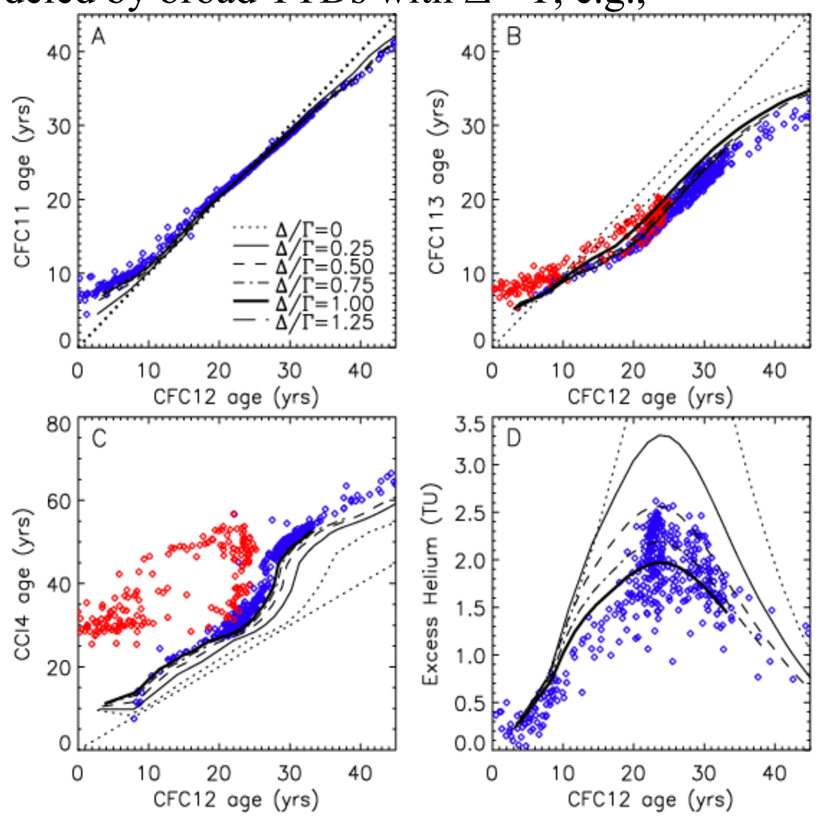
Map of WOCE cruise lines A1, A2, and A16.

Examination of the tritium - CFC12 age relationships from all 5 cruises shows that the tracer-tracer relationships are very similar between cruises, with compact relationships, with little dependence on basin and smooth transition with depth, for each cruise (see plots below). Calculations assuming advection only ($\Delta = 0$; dotted curves) do not match the observations. However, the observations are well modeled by TTDs with $\Delta \sim \Gamma$.



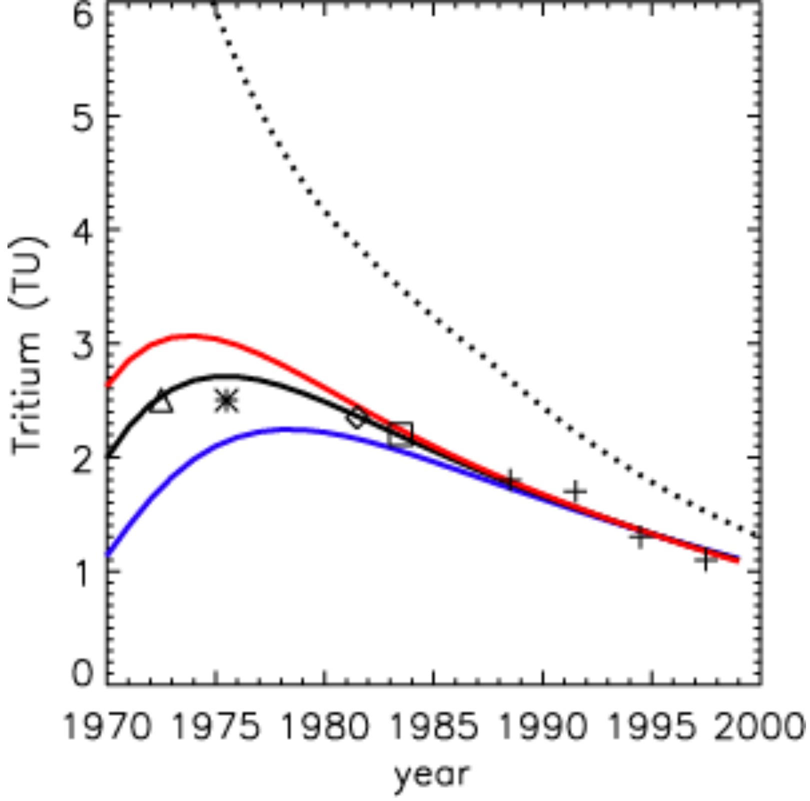
Tritium concentration (TU) plotted against CFC12 AGE for data from WOCE cruises in (a) 1988 (A16), (b) 1991 (A1), (c) 1994 (red symbols for A1 and blue for A2), and (b) 1997. Curves are predictions from model TTDs with different Δ/Γ ratios.

Comparisons of the observed relationships of other tracers with CFC12 age are also inconsistent with advective flow but are well modeled by broad TTDs with $\Delta \sim \Gamma$, e.g.,



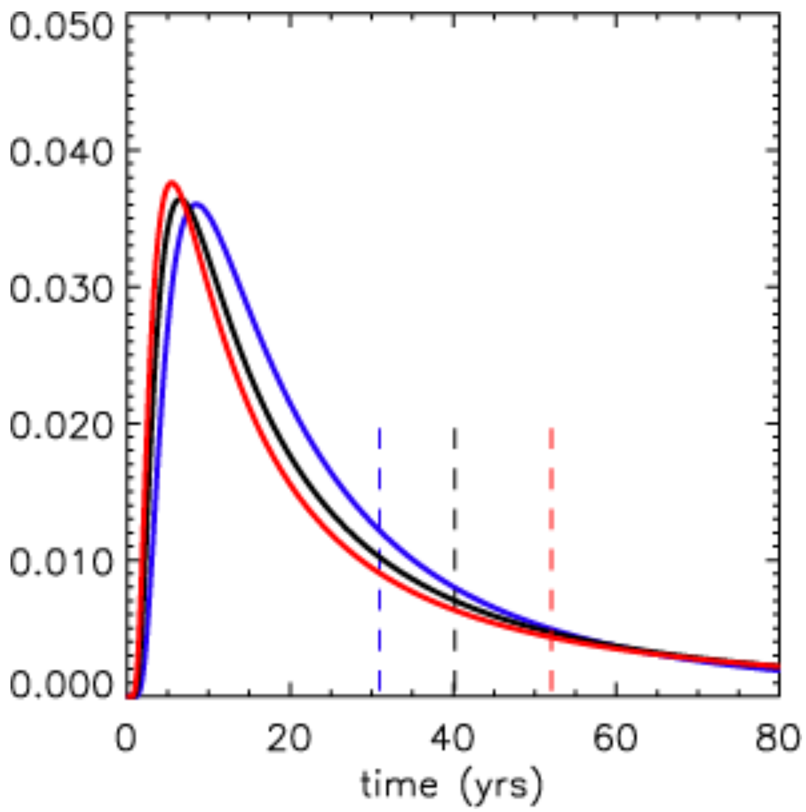
Relationships between (a) CFC11 age, (b) CFC113 age, (c) CCl4 age, and (d) Excess Helium, with CFC12 age for measurements along A2 in 1997 (symbols) and for model TTDs (curves). Red symbols in panels (b) and (c) correspond to observations in water with temperatures warmer than 5C.

The temporal variation of tritium also provides information on the TTDs. Measurements of tritium in LSW water in Newfoundland or West European Basins have been made between 1972 and 1997. These observations also imply that the TTDs have $\Delta \sim \Gamma$. This is illustrated below.



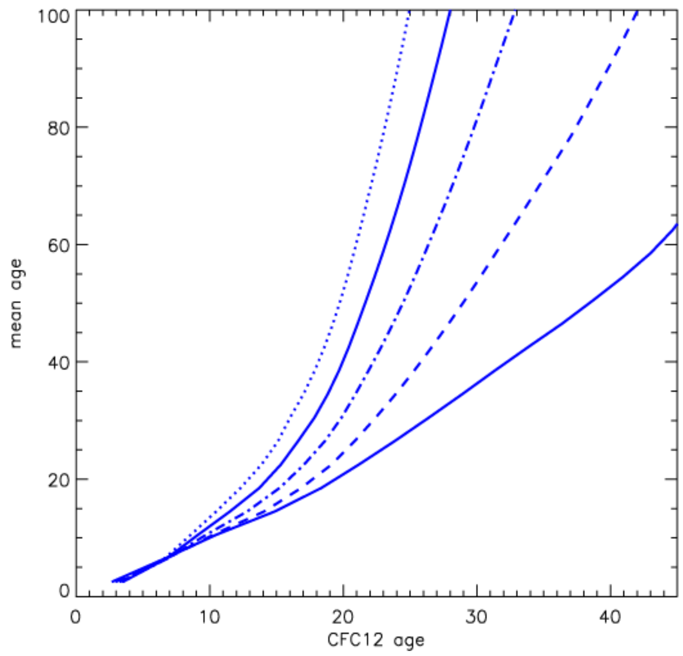
Observed time variation of tritium (symbols) at 1500 m in Newfoundland and West European Basins and predictions for TTDs with Δ/Γ equal to 0.75 (blue curves), 1.0 (black), and 1.25 (red).

The analysis of tracer-tracer relationships and temporal evolution of tritium shows that the Δ ~ Γ for TTDs in the subpolar North Atlantic Ocean. Such TTDs are very broad with large range of transit time, see examples below.



TTDs with Δ = Γ that produce (in 1994) CFC12 age equal to 15 (blue curve), 20 (black), and 25 (red) yrs. Vertical dashed lines show Γ for each TTD.

Broad TTDs imply that mixing plays an important role in the transport over decadal timescales, and also that tracer ages can be significantly different from the mean transit time Γ. In fact, for TTDs with Δ = Γ the CFC12 age, for water masses with CFC12 age > 15 yrs, is much smaller than Γ. This is illustrated below



Variation of mean age Γ with CFC12 age for TTDs with Δ/Γ equal to 1.25 (dotted), 1.0 (solid), 0.75 (dot-dash), 0.5 (dash) and 0.25 (solid).

Summary

The relationships between CFCs, tritium and helium and the temporal evolution of tritium all indicate that the transit time distributions (TTDs) in the subpolar North Atlantic ocean are very broad. These broad TTDs imply that mixing plays a major role in transport over decadal timescales and must be taken into account when interpreting tracers. One application of the transient tracers where accounting for mixing is particularly important is estimation of the distribution and uptake of anthropogenic carbon .

For more details see Waugh et al., DSR, 2003 .

Back to Transit Times in Geophysical Flows.