Session: C37 Poster: TH81A

Southern Ocean hydrography and circulation: Dissolved chlorofluorocarbons as time dependent tracers of ventilation processes in the Southern Ocean

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As part of the CLIVAR Repeat Hydrography Program, a subset of the sections sampled in the 1990s as part of the World Ocean Circulation Experiment (WOCE) are being re-occupied at approximately decadal intervals. These include a number of sections in the Southern Ocean. Measurements of a suite of physical and chemical properties are being made at full depth, closely spaced (nominally 30 nautical mile) CTD/rosette stations, with water samples collected at 24 (or 36) depths per station. Key goals of the chlorofluorocarbon (CFC) studies in this program are to document the invasion of these compounds into the ocean interior on decadal timescales. These data can be used to evaluate ocean models and to improve understanding of water mass formation processes and rates. Observations show that the concentrations of CFCs in newly formed water masses in the Southern Ocean can be significantly below atmospheric equilibrium levels, due both to limitations in air-sea gas exchange and to mixing with sub-surface components containing low levels of CFCs. Although abyssal waters continue to undergo mixing with low-CFC waters as they move away from the Antarctic shelf formation regions, significant CFC signals have been detected in bottom waters of deep western boundary currents in the south Atlantic, Indian and Pacific basins. These CFC signals can be used to evaluate ventilation and transport rates of Antarctic Bottom Water (AABW). In addition to the CFCs, measurements of sulfur hexafluoride (SF6) have been included on several recent CLIVAR Southern Ocean sections. SF6 levels in the atmosphere have increased rapidly during the past 2 decades, making this anthropogenic compound an especially valuable new transient tracer of recently ventilated waters. When measured simultaneously with the CFCs, SF6/CFC ratios can provide improved estimates of water mass apparent ages. Because of the extraordinarily sensitive techniques available for measuring dissolved CFCs and SF6 in seawater, these compounds act as unique tracers of regions where changes in surface properties (e.g. climate warming signals, anthropogenic CO2) in the Southern Ocean can propagate into the ocean interior on decadal time-scales.