Ocean Tracers

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Relevance

Tracers help you understand ocean circulation in ways that are fundamental to our understanding of the ocean’s

• Uptake of anthropogenic heat and CO₂

• Changes in ocean interior circulation

• Changes in global climate

• Changes in ocean ecosystems
Relevance

NOAA goals:

• Understand oceanic uptake, storage and transport of heat, and impact on climate

• Ocean uptake of CO$_2$

• Changes in ecosystems
Background

- Man-made gases
- Inert in seawater
- Well-known history at sea surface

\[ \therefore \text{Tracer in the ocean interior used to ‘date’ water masses} \]

- High Signal-Noise

\[ \therefore \text{See anthropogenic changes that are small relative to background variability} \]
Background

Chlorofluorocarbons - CFCs

- CFC-11 (F-11) - CCl$_3$F
- CFC-12 (F-12) - CCl$_2$F$_2$

Carbon tetrachloride - CCl$_4$

Sulfur Hexafluoride - SF$_6$

Nitrous Oxide - N$_2$O

*CO$_2$ increase (ppm)
Background
Background

CLIVAR Hydrographic Program
Performance
Background

CFC tracers provide rates...

1) Ocean circulation and mixing
2) Water mass formation and changes
3) Uptake of anthropogenic CO$_2$
4) Rates of key biogeochemical processes
   - Biological production rates
5) Test of numerical ocean models’ uptake of the anthropogenic perturbation
Performance

Atmospheric Histories of trace gases (ppt) and CO$_2$ (ppm)

$p$CFC-11 = 135 ppt

CO$_2$ increase

1978

56 ppm CO$_2$
Anthropogenic carbon in the ocean

Khatiwala et. al., (2009)
Quality

- Recognized as a world leader in the accurate, ultra-low level measurements of these compounds
- CLIVAR I5, I8S/I9S, P16N, P18, A16N, A16S, A10, A13.5 cruises
PMEL has led in development of tracer techniques

- Pioneered ocean CFC observations (1980s and 1990s)
- Developed SF$_6$, N$_2$O methods in past 5 years
- Designed and built analytical systems for academic laboratories (U. Washington, U. Texas)
- Developed water sampling bottles and sampling gear widely used on CLIVAR expeditions
Quality/Relevance

- CFC and SF$_6$ calibration standards for International CLIVAR groups
- N$_2$O and CH$_4$ standards for SCOR
Quality

• Water Mass Formation Rates from CFC Inventories
  • Inventory = formation rate * CFC in surface waters
  • Water Mass formation rates have been determined for AABW, GSDW, LSW, NADW

CFCs document changes in Labrador Sea water over time [Kieke et al., 2008]
CFCs a tool to directly assess rate of change of nitrogen levels in the ocean

Performance

Kim et al., Science, in review
Future Directions

$\text{SF}_6$ observations concurrent with CFCs on $\sim 1/3$ of repeat hydrography cruises
Future Directions

• Model-data comparisons
• Mixing in the ocean interior from CFCs and SF$_6$
• Oxygen and nitrogen cycling rates in the ocean
• Anthropogenic CO$_2$ uptake from CFCs
• Nitrous oxide observations
Future Directions

Nitrous oxide (N$_2$O) is an important greenhouse and ozone depleting gas.

The strength of the ocean source may be linked to changes in dissolved oxygen.

Pursuing Isotopic ($^{15}$N, and $^{18}$O) N$_2$O measurements to understand sources and sinks in the ocean.
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