

Introduction

According to the latest report from Intergovernmental Panel on Climate Change, concentrations of CO₂ in the atmosphere have increased by 40% since pre-industrial times owing to human activities such as burning of fossil fuels, deforestation, and cement production. It is evaluated that the ocean has absorbed about 30% of the emitted anthropogenic CO₂. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO₂, and to clarify the mechanism of the CO₂ absorption, because the magnitude of future global warming depends on the levels of CO₂ in the atmosphere.

The eastern part of the Indian Ocean is one of the regions where uncertainty of uptake of anthropogenic CO₂ is large. One of the reasons is that there exist few data for CO₂. In addition, the area corresponds to where influences of the Indian Ocean Dipole (IOD) mode appear distinctly. In this cruise, therefore, we were aimed at quantifying how much anthropogenic CO₂ is absorbed in the area. For the purpose, we measured atmospheric and surface seawater partial pressures of CO₂ (pCO₂).

Apparatus and shipboard measurement

Continuous underway measurements of atmospheric and surface seawater pCO₂ were made with the CO₂ measuring system (Nippon ANS, Ltd) installed in the R/V *Mirai* of JAMSTEC. The system comprises of a non-dispersive infrared gas analyzer (Li-COR LI-7000), an air-circulation module and a showerhead-type equilibrator. To measure concentrations (mole fraction) of CO₂ in dry air (xCO_{2a}), air sampled from the bow of the ship (approx. 13 m above the sea level) was introduced into the NDIR through a dehydrating route with an electric dehumidifier (kept at ~2 °C), a Perma Pure dryer (GL Sciences Inc.), and a chemical desiccant (Mg(ClO₄)₂). The flow rate of the air was 500 ml min⁻¹. To measure surface seawater concentrations of CO₂ in dry air (xCO_{2s}), the air equilibrated with seawater within the equilibrator was introduced into the NDIR through the same flow route as the dehydrated air used in measuring xCO_{2a}. The flow rate of the equilibrated air was 700 – 800 ml min⁻¹. The seawater was taken by a pump from the intake placed at the approx. 4.5 m below the sea surface. The flow rate of seawater in the equilibrator was 400 – 500 ml min⁻¹.

The CO₂ measuring system was set to repeat the measurement cycle such as 4 kinds of CO₂ standard gases (Table 2.5.1), xCO_{2a} (twice), xCO_{2s} (7 times). This measuring system was run automatically throughout the cruise by PC control.

Quality control

Concentrations of CO₂ of the standard gases are listed in Table 1, which were calibrated after cruise by the JAMSTEC primary standard gases. The CO₂ concentrations of the primary standard gases were calibrated by the Scripps Institution of Oceanography, La Jolla, CA, USA.

In actual shipboard observations, the signals of NDIR usually reveal a trend. The trends were adjusted linearly using the signals of the standard gases analyzed before and after the sample measurements.

Effects of water temperature increased between the inlet of surface seawater and the equilibrator on xCO₂s were adjusted based on Takahashi *et al.* (1993), although the temperature increases were slight, being ~0.2 °C.

We checked values of xCO₂a and xCO₂s by examining signals of the NDIR by plotting the xCO₂a and xCO₂s as a function of sequential day, longitude, sea surface temperature and sea surface salinity.

Meta data summary

Method Description:

Sampling and Equilibrator Design:

Depth of Sea Water Intake: 4.5 m

Location of Sea Water Intake: side at bow

Equilibrator Type: showerhead-type equilibrator

Equilibrator Volume: approx. 1 L

Water Flow Rate: 400 - 500 mL min⁻¹

Headspace Gas Flow Rate: 700 - 800 mL min⁻¹

Vented: Yes

Drying Method for CO₂ in Water: Electron Cooler, Perma Pure dryer, Chemical Desiccant with Mg(ClO₄)₂

Additional Information:

System Design:

Measurement Method:

Manufacturer of Calibration Gas:

CO₂ Sensor:

Measurement Method: dispersive infrared gas analyzer

Manufacturer: Nihon ANS, Ltd.

Model: Underway pCO₂ measurement system using LI-7000 CO₂ Analyzer by LI-COR

Environmental Control: none

Frequency: 4.5 min. for CO₂air (2 analysis), and then 7 min. for CO₂water (7 analysis)

(except during calibration routines)

Precision of CO₂water: 0.1 ppm

Precision of CO₂air: 0.05 ppm

Accuracy of CO₂water: 1-2 ppm

Accuracy of CO₂air: ~0.1 ppm

CO₂ Sensor Calibration:

Manufacturer of CO₂ calibration gases: Taiyo Nippon Sanso Corporation, Japan 249.26, 330.29, 360.28, and 420.22 ppm.

Method References:

CO₂ in Marine Air:

Measurement: yes

Location and Height: foremast, 13 m high

Sea Surface Temperature:

Location: bow thruster room

Manufacturer: Sea-Bird Electronics Inc.

Model: SBE38

Accuracy: 0.002 degree

Precision: 0.0002 degree

Calibration: Manufacturer calibration every one year.

Other comments:

Sea Surface Salinity:

Location: sea surface monitoring laboratory

Manufacturer: Sea-Bird Electronics Inc.

Model: SBE45

Accuracy: 0.005

Precision: 0.003

Calibration: Manufacturer calibration every one year.

Other comments:

Equilibrator Temperature:

Location: just upstream of shower head

Manufacturer: THERMOTEX CO. LTD, Japan

Model: Pt100 ohm

Accuracy: 0.08 degree

Precision: 0.03 degree

Calibration: Calibration is performed by a traceable mercury thermometer before the

measurement.

Other comments:

Equilibrator Pressure:

Location: equilibration sector of equilibrator

Manufacturer: Druck

Model: RPT410V

Accuracy: 0.5 hPa

Precision:

Calibration: Certified calibration is performed every 2 years.

Other comments:

Atmospheric Pressure:

Location: Weather observation room at captain deck (13m)

Manufacturer: Setra System, USA

Model: Model-370

Accuracy: $\pm 0.02\%$

Precision: 0.010% FS

Calibration: Comparison with the portable barometer value, PTB220, VAISALA

Other Sensors:

Manufacturer::

Model:

resolution:

Uncertainty:

Calibration:

Other Comments:

Accuracy Info:

Method References:

Reference

Takahashi, T., J. Olafsson, J. G. Goddard, D. W. Chipman, and S. C. Southerland (1993)
Seasonal variation of CO₂ and nutrients in the high-latitude surface oceans: a
comparative study, *Global Biogeochem. Cycles*, 7, 843–878.

Table 2.5.1. Concentrations of CO₂ standard gases used during the cruise.

Cylinder no.	Concentrations (ppmv)
CQB06511	249.26
CRC00046	330.29
CRC00047	360.28
CRC00048	420.22