

## Surface water $f\text{CO}_2$ in the Equatorial Atlantic Ocean

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### Abstract

Fugacity of carbon dioxide ( $f\text{CO}_2$ ) in surface water was related to salinity and temperature for the equatorial Atlantic Ocean in late northern spring. The complex pattern of currents was unravelled using the ship's drift direction. Biological activity was low. Surface water  $f\text{CO}_2$  was closely related to watermasses and changed abruptly at oceanographic fronts. Upwelling was characterised by high  $f\text{CO}_2$ , high salinity and low temperature. Undersaturation of  $f\text{CO}_2$  north of the equator was ascribed to heavy precipitation and a thin mixed layer in the Intertropical Convergence Zone. The region between 15°S and 15°N was a slight source for atmospheric  $\text{CO}_2$ .

### 1. INTRODUCTION

The oceans take up 20 to 40 % of the carbon dioxide ( $\text{CO}_2$ ) emitted by fossil fuel burning and cement making. Causes of the uncertainty are the enormous inorganic carbon reservoir, which the oceans constitute, and the large dynamic  $\text{CO}_2$  air-sea exchange, variable with time and location. Continuous measurements of the fugacity of  $\text{CO}_2$  ( $f\text{CO}_2$ ) in marine air and surface water in relation to salinity, water temperature and chlorophyll *a* were performed during five cruises in the (South) Atlantic Ocean at R.V. Polarstern. Aim of the project is to improve the estimate of  $\text{CO}_2$  air-sea exchange and our understanding of its mechanisms for the South Atlantic Ocean. The paper presents surface water  $f\text{CO}_2$  and  $\text{CO}_2$  air-sea exchange in the equatorial Atlantic on a straight track between 15°S 3°E and 15°N 22°W from May 26 to June 3 1994 during one of those cruises, ANT XI/5.

$\text{CO}_2$  air-sea exchange can be estimated as the product of a wind speed dependent gas transfer velocity and the difference of the concentration dissolved  $\text{CO}_2$  at the sea surface and in the mixed layer. Biological, chemical and physical processes affect dissolved  $\text{CO}_2$  in the mixed layer.

The equatorial current system with "currents" and "countercurrents" is variable over ranges of time and space and responds strongly to changes in the wind field (1). Surface air ascents and precipitation is high in the Intertropical Convergence Zone (ITCZ), which shifts between 2°N and 8°N during the year. Trade winds come from the southeast south of the ITCZ, from the northeast north of it. Trade winds are relatively steady in direction and speed and generally weaker than 11 m·s<sup>-1</sup>.

## 2. METHODS

$f\text{CO}_2$  of surface water and air, total inorganic carbon and skin temperature were measured continuously. A showerhead type equilibrator was used for sampling of surface water  $f\text{CO}_2$ . Gaseous  $\text{CO}_2$  was determined by a custom-built gaschromatograph with a methaniser and an FID-detector. The temperature correction of Copin-Montégut (2, 3) was applied. Total  $\text{CO}_2$  was detected by coulometry (4). Alkalinity and nutrients were determined at regular intervals.  $\text{CO}_2$  air-sea exchange was estimated from the concentrations dissolved  $\text{CO}_2$  in the mixed layer and at the sea surface using the Wanninkhof (5) relationship neglecting the skin effect. The ship's data acquisition system supplied water temperature, salinity, fluorescence, wind speed and direction, atmospheric pressure and moisture content, air temperature, the ship's drift speed and direction. Dr. K. Schaumann (AWI) determined chlorophyll a.

The region was characterised by steady trade winds from the southeast ( $140^\circ$ ) south of the ITCZ at  $6^\circ\text{N}$  and from the northeast ( $30^\circ$ ) further north. Ship's drift partly into the wind indicated a persistent current; a method already used by Rennell (6).

## 3. RESULTS

The complex pattern of currents and countercurrents in the equatorial region was reflected in salinity, water temperature and  $f\text{CO}_2$  (figure 1). The ship's drift suggested southward currents roughly between  $9.3^\circ$  and  $8.2^\circ\text{S}$  and between  $5.8$  and  $4.7^\circ\text{S}$  (both the South Equatorial Countercurrent), eastward between  $0.7^\circ\text{S}$  and  $0.6^\circ\text{N}$  (Equatorial Divergence) and between  $3.7^\circ$  and  $5.7^\circ\text{N}$  (North Equatorial Countercurrent). Trends for  $f\text{CO}_2$  and salinity were strikingly similar, water temperature had a reverse pattern. Biological activity was low throughout the area as indicated by fluorescence (not shown) and chlorophyll a (Schaumann, personal communication). Surface water  $f\text{CO}_2$  and, hence,  $\text{CO}_2$  air-sea exchange were affected by the same physical processes as salinity and temperature, either directly or indirectly. Upwelled water had relatively low temperature, high salinity and high  $f\text{CO}_2$ . Upwelling had clearly occurred on both sides of the equator in the Equatorial Divergence and probably near the North Equatorial Countercurrent too.

The salinity minimum at  $5^\circ\text{N}$  coincides with a minimum of water temperature and could have been caused by heavy precipitation of the ITCZ. The considerable undersaturation of surface water  $f\text{CO}_2$  roughly between  $0.7$  and  $9.0^\circ\text{N}$  was unlikely to have been caused by the past or actual low biological activity. Thus, physical and/or chemical processes were responsible for the undersaturation. Upwelling would have elevated  $f\text{CO}_2$ , rather than have lowered it. Cooling of the water with 1 to  $3^\circ\text{C}$ , necessary to cause the undersaturation thermodynamically, was unlikely with currents flowing parallel to the equator in an area of maximum surface water temperatures in late northern spring. Dilution of a thin mixed surface layer by heavy rains of the ITCZ could have caused the undersaturation.

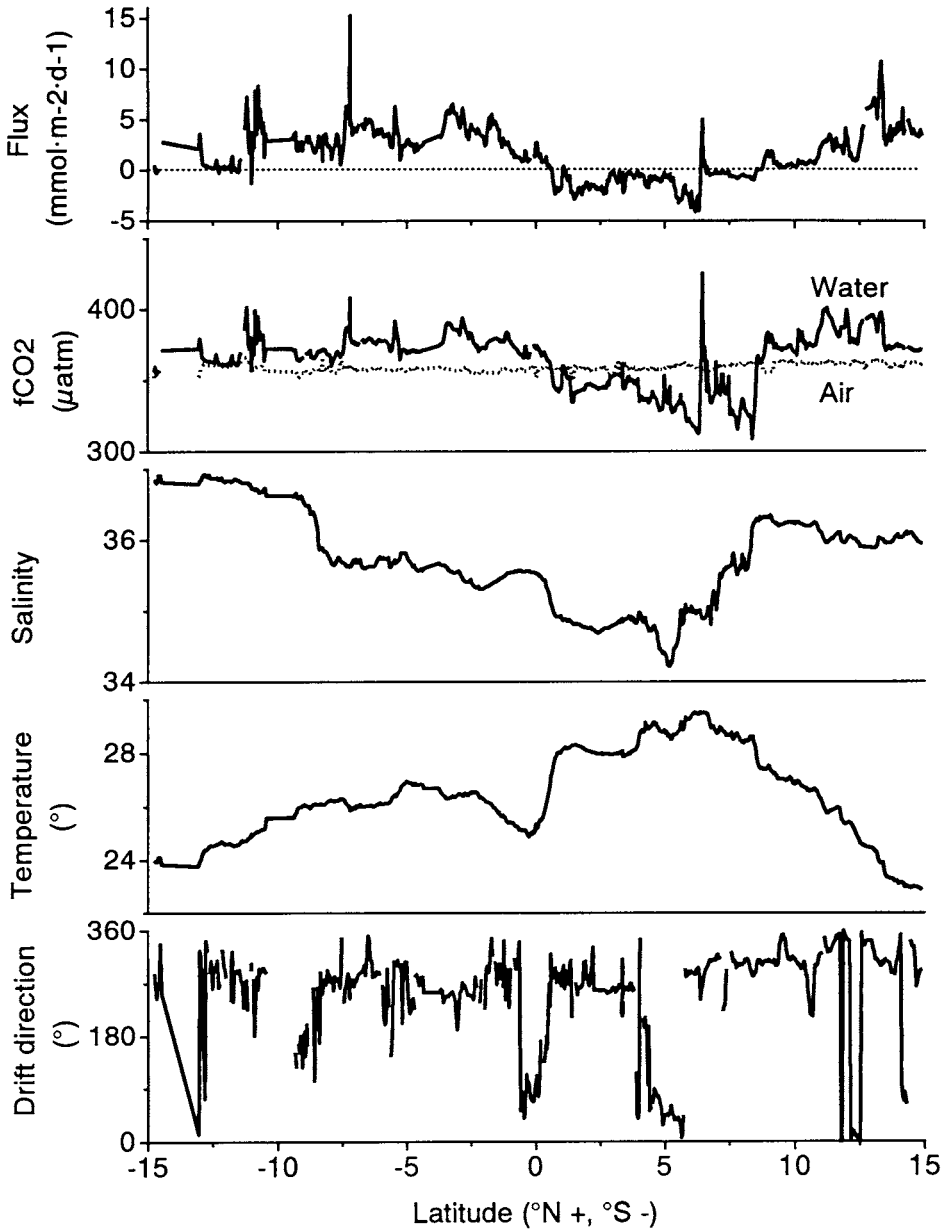


Figure 1. CO<sub>2</sub> air-sea exchange, fCO<sub>2</sub> in water and air, salinity, water temperature and ship's drift direction between 15°S and 15°N, ANT XI/5.

#### 4. CONCLUSION

CO<sub>2</sub> air-sea exchange was closely related to oceanic watermasses, as demonstrated by reflection of the complex pattern of currents in the equatorial region in salinity, temperature and fCO<sub>2</sub>. Abrupt changes of surface water fCO<sub>2</sub> occurred at oceanographic fronts. The CO<sub>2</sub> signature of each watermass was due to the common history of mainly physical, chemical and biological processes.

These data will be combined with data from four additional cruises and compared with results by other researchers. Spatial and seasonal variation will be studied in relation to watermasses. Specific aspects of the equatorial region, like the pattern of currents and countercurrents, upwelling and undersaturation will receive attention.

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