J2.9 EDDY-COVARIANCE CO_2 FLUX MEASUREMENTS OVER OPEN OCEAN

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1. INTRODUCTION

Traditionally, air-sea CO2 flux is calculated based on CO2 concentration difference between air and sea(pCO2 – PCO2), assuming transfer velocities. The transfer velocity was mainly evaluated from mass balance with isotopic method. While, air-sea energy fluxes of sensible heat or latent heat are also evaluated with the bulk aerodynamic formula with some transfer coefficients. And the transfer coefficients are normally determined by the direct eddy-covariance method. The bulk estimate of CO2 flux should include the transfer coefficients based on the eddy-covariance CO2 flux measurements. Recently, fast response CO2 turbulence sensor are available as more reliable and higher resolution than a decade ago. The present authors have applied the new CO2 analyzer for the open ocean CO2 flux measurement with eddy-covariance method.

2. HISTORICAL REVIEW OF THE EDDY-COVARIANCE CO2 FLUX MEASUREMENTS

The first micrometeorological eddy-covariance CO2 flux measurement over sea surface is reported by Jones and Smith(1977). And several CO2 eddy flux measurements followed. These measurements report the values of CO2 flux around 0.05 mg m^{-2} s^{-1}. Against these micrometeorological measurements, Liss and Merlivat(1986) and Broecker et al.(1986) mentioned that micrometeorological CO2 flux was 100 times larger than the traditional method, which is based on CO2 partial pressure difference between air and sea. They claimed the accuracy of eddy correlation method. In Japan, Ohtaki et al.(1989) tried eddy correlation measurement with new open-path CO2 sensor and found that CO2 eddy flux was still larger than the traditional values even when the Webb correction was applied. In recent 10 years, eddy covariance results from ASGAMAGE and Gasex98 were reported and their results shows much closer values between eddy covariance and bulk fluxes.

3. ON-BOARD EEDY FLUX MEASUREMENT WITH R/V MIRAI

Present authors are continuing direct eddy flux measurements with eddy covariance method on R/V MIRAI(Fig.1), JAMSTEC, Japan. This on-board eddy flux system including ship motion correction is now extended to CO2 flux as well as sensible/latent heat flux or momentum flux. Our first CO2 eddy flux measurement was carried out in Nov 2001 in tropical

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Fig.1 R/V MIRAI, JAMSTEC

western Pacific throughout a month. This experiment is the first on-board CO_2 eddy flux measurement with the 'open-path' CO_2 analyzer over open ocean. Previous CO_2 eddy flux measurement was based on the coastal tower before the ASGAMAGE. Gasex98 was the first on-board measurement, however they are based on the 'closed-path' CO_2 eddy flux measurement. Standard CO_2 eddy flux measurement is considered as 'open-path' system and it is widely applied over land surface CO_2 exchange projects(e.g. FLUXNET). So, the present authors have applied the 'open-path' CO_2 eddy flux system on-board the R/V MIRAI(Fig.2).

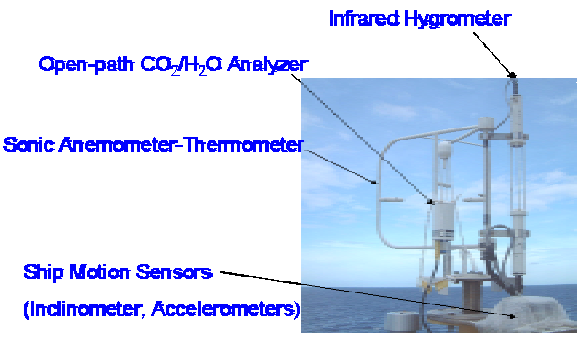

Fig.2 Eddy flux sensors on the top of the foremast

Fig.3 shows an example of time series for CO_2, water vapor(H_2O) as well as motion corrected vertical wind velocity component(W). While CO_2 fluctuation is as small as 1ppm, it has significant negative correlation

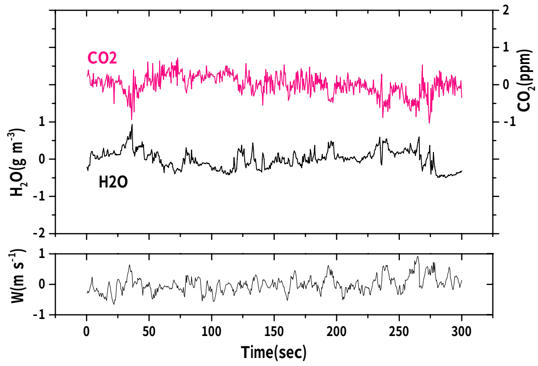

Fig.3 An example of time series of CO2, H20

between H_2O signal. So we can use this CO_2 signal for the eddy-covariance measurement. According to the results of Gasex-98(McGillis, 2001), they had experienced a 'gyroscopic effect' on the CO_2 signal due to ship motion. However, we did not experienced the ship motion contamination for our CO_2 analyzer.

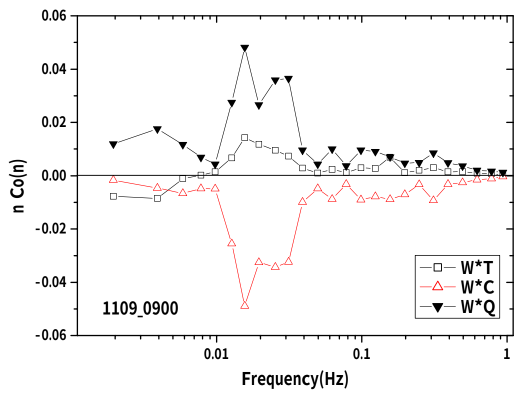

Fig.4 An example of co-spectra for WT,WC and WQ

Fig.4 shows an co-spectra for the sensible heat flux, CO_2 flux and water vapor flux respectively. They show nice similarity with main fluxes ranging 0.01-0.1Hz, which is well outside the ship motion frequency (around 0.1Hz).

The most of the data show the downward CO_2 flux and it is consistent with pCO_2/PCO_2 measurements in sea and air. However, the magnitude of the eddy CO2 flux(-0.037 mg m^{-2} s^{-1}) was much larger than the traditional bulk method. The difference amounts to 2 orders of magnitude even when Webb correction was applied for the eddy CO2 flux. This is the re-appearance of CO2 flux conflict in 1980's even with the higher resolution CO2 sensor and considerable flux corrections. The present eddy flux system also measures sensible/latent heat fluxes and those eddy covariance values are almost consistent with the bulk flux estimates based on wind speed, air-sea temperature or humidity differences. However, CO2 flux shows important conflict.

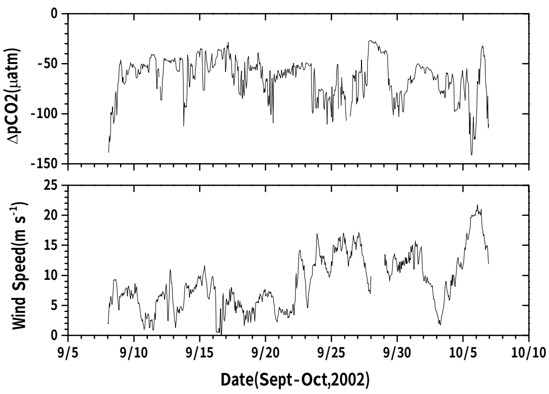

Fig.5 Delta-pCO2 and wind speed during the Arctic cruise

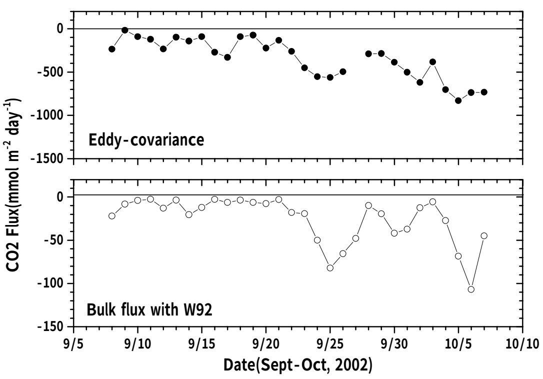

Fig.6 Comparison of CO2 flux from eddy-covariance and bulk estimate with the Wanninkhof 92 model.

The second CO2 eddy flux cruise were carried out in the Arctic area in Sept-Oct 2002. Delta-pCO2 was as large as 100μatm and large CO2 absorption was expected. Both of the eddy flux and the bulk flux of CO2 was consistent as the downward transport, however, the magnitude of the eddy CO2 flux(-0.215 mg m^{-2} s^{-1}) was an order larger than the bulk estimates. The difference was much smaller then the first cruise, as the delta-pCO2 during the first cruise was less than 15μatm. Based on the eddy CO2 flux and delta-pCO2 during the cruise, CO2 transfer velocities were calculated as daily basis as a function of daily mean wind speed. The transfer velocity data shows a clear increase with the mean wind speed, showing an order larger than the previous transfer velocities.

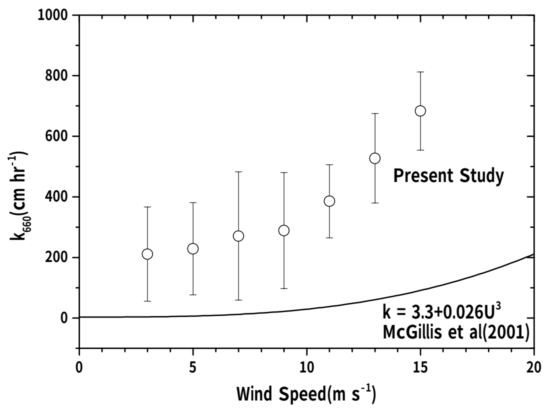

Fig.7 Calculated bin averaged CO2 transfer velocity as a function of wind speed

The important points of the present article are summarized as follows.

1. Higher resolution open-path CO2 analyzer was first deployed on-board the R/V MIRAI to measure the direct eddy covariance CO2 flux over open ocean.
2. Even when the considerable corrections were applied to the eddy CO2 flux, it is at least an order larger than the traditional bulk CO2 flux using the published transfer velocity.
3. Sensible and latent heat fluxes were also evaluated as the eddy covariances and the flux values were

almost consistent with the meteorological bulk energy fluxes.

4. Open-path eddy covariance system are now applied in a lot of land surface projects as the global standard of surface CO_2 flux. Daytime downward CO_2 flux over plant canopies are an order larger than the present CO_2 eddy flux over ocean. However the daily integrated CO_2 flux was almost the same order, as the diurnal variation over plant canopies are very large including the upward transport during the nighttime.

5. Ocean CO_2 flux conflict as discussed in 1980's re-appeared even when the ideal eddy flux system was applied, and the transfer velocity of CO_2 should be re-examined with more eddy-covariance flux datasets.

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