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Statistical modeling the effects of microclimate variables on carbon dioxide flux at the tropical coastal ocean in the southern South China Sea

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ABSTRACT

The global ocean is a net carbon dioxide uptake and a major component of the biogeochemical carbon cycle. We measured carbon dioxide flux and other microclimate variables using the eddy covariance method to determine the effects of the latter on carbon dioxide (CO_2) flux in the intertidal zone of the tropical coastal ocean in the southern South China Sea. The location is in the under-sampled "Eastern Boundary Current" province of the continental shelf in the South China Sea. Fluxes and microclimate variables were collected for more than one year, which encompassed all four Monsoons. Results show that the tropical coastal ocean uptakes CO_2 with an annual average of –2.10 mol C m^{-2} yr^{-1}. The Monsoon cycle decreased the role of the tropical coastal ocean as a CO_2 sink by 60% during the Southwest Monsoon/Fall Transitional Monsoon phase due to increased precipitation. Cluster analysis of all the parameters measured showed two main clusters, the "dry" and "wet" season clusters while factor analysis reduced the number of variables to two main factors, the "weather" and the "CO_2" factors. Thus, the Monsoonal CO_2 flux at the tropical coastal ocean are significantly regulated by cumulative precipitation in comparison to other variables.

1. Introduction

The coastal ocean is a majorcomponent of the biogeochemical carbon cycle (Chen et al., 2013; Gruber et al., 2009). It is regarded as the global zone of carbon transformation and sequestration (Bauer et al., 2013). The coastal ocean contributes to 30% of the total carbon dioxide (CO_2) uptake of the global ocean (Chen and Borges, 2009). Some researchers found that this contribution could be even larger. Tsunogai et al. (1999) reported that the continental shelves can take up to 1 Pg of CO_2 annually (i.e., 50% of the global ocean CO_2 uptake). In low-latitude tropical continental shelves, Cai et al. (2006) found that the shelves were significant sources of CO_2 because of the hot sea water temperature and the large riverine inflow of terrestrial organic carbon while a study by Coronado-Alvarez et al. (2017) found that it is a weak source of carbon. Nevertheless, their work was done outside the tropical regions. A meta-

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analysis of the CO_2 flux observation stations in the tropical regions around the globe showed the opposite trend whereby the tropical continental shelves are found to be carbon sinks (Ballantyne et al., 2012; Bauer et al., 2013; Boutin et al., 2008; Chen and Borges, 2009; Velasco and Roth, 2010). On the other hand, Laruelle et al. (2010) showed that CO_2 exchange between continental shelf seas and the atmosphere is a function of latitudes (with strong irregularities) acting as sources to the atmosphere between 30ºS and 30ºN and as sinks at temperate and high latitudes; (south of 30ºS and north of 30ºN). These incongruent views suggest that the tropical coastal ocean is a heterogeneous source of carbon (Bauer et al., 2013; Reimer et al., 2013; Twilley et al., 1992).

More data and analysis on the tropical coastal ocean are necessary. CO_2 flux data of the tropical coasts is severely under-sampled (Cai et al., 2006). Because of the lack of data and the heterogeneity of CO_2 sources at the coast, the CO_2 contribution of the tropical coastal ocean to the biogeochemical carbon cycle is not even considered in oceanic models (Gruber et al., 2009; Takahashi et al., 2009). Thus, the purpose of this study is to determine the half-hourly CO_2 flux and to model it using selected microclimate variables at the tropical coastal ocean in the southern South China Sea.

Therefore, the objectives of the work are to determine the role of the tropical coastal ocean, whether as a CO_2 emitter or absorber, to identify concealed factors that influence CO_2 flux, and to determine the similarity in the trends based on the CO_2 flux and microclimate variables. The results can assist in integrating tropical coastal ocean into the global carbon cycle, an under-represented component in climate models (Bauer et al., 2013; Reimer et al., 2013).

2. Materials and methods

We analyzed a year of direct measurement of CO_2 using the eddy covariance method in the intertidal zone of the tropical coastal ocean in the southern South China Sea. This is the first few high-resolution eddy covariance measurement of CO_2 flux at this ocean, a location that is severely under sampled in the global network of flux measurements and unrepresented in the climate models. The site can be classified as a narrow continental shelf in the “Eastern Boundary Current” province associated with strong upwelling (Cai et al., 2006). The results can assist in integrating tropical coastal ocean into the global carbon cycle (Bauer et al., 2013; Reimer et al., 2013).

2.1. Site description

Carbon dioxide fluxes and microclimate variables, which include the sea water temperature, were collected at a tropical coastal ocean at the northwestern end of the island of Pulau Pinang, Malaysia (Fig. 1). The station is named the “Muka Head Station”. The site sits on the continental shelf of the Straits of Malacca in the southern South China Sea and can be categorized as a narrow continental shelf with strong upwelling in the “Eastern Boundary Current” province (Cai et al., 2006; Yusup et al., 2018). The Muda River and the Merbok River, located approximately 20 km and 28 km Northeast of the station, respectively, were the nearest significant terrestrial carbon sources with both having an average discharge rate of 100 $m^3\ s^{-1}$ (Fatema et al., 2014). These features make the site a good representative of a typical tropical continental shelf.

Bathymetric chart (Fig. 1**, bottom right panel**) shows that the site is located on a shallow continental shelf with the seabed to the north having a gentle seabed decline of 4 m km^{-1}. Since this site is within an enclosed strait, wave heights are relatively low, at an approximate height of about 0.25 m. The mean water depth beneath the station was 4 m. The location experiences tropical Monsoons seasons: The Northeast Monsoon (NEM) from December to March, the Spring Transitional Monsoon (STM) from April to May, the Southwest Monsoon (SWM) from June to September, and the Fall Transitional Monsoon (FTM) from October to November (Fig. 2). Generally, the features of the Transitional Monsoons are increased precipitation with light and variable wind while the features of Northeast and Southwest Monsoons are decreased precipitation and stronger winds (Yusup et al., 2016, 2018).

Data was collected for more than one year, i.e., November 2015 to January 2017. Wind directions were evenly distributed among all wind quadrants (Fig. 1**, bottom left panel**). The daily averages of the microclimate variables, i.e., the atmospheric temperature, relative humidity, and wind speed were 28 °C, 82%, and 2.5 m s^{-1}, respectively.

2.2. Instrumentation

The CO_2 fluxes were measured using an eddy covariance system, which was installed on a stable stainless-steel platform extending a pre-existing pier so that the system would be directly over the tropical coastal ocean. The eddy covariance system included a 3-D sonic anemometer (model 81000V, RM Young, USA) and an open-path CO_2/H_2O gas analyzer (model LI-7500 A, LI-COR, Inc., USA) installed 4.1 m above the sea water surface. The gas analyzer and sonic anemometer were factory-calibrated before deployment. A data logger (model LI-7550 Analyzer Interface Unit, LI-COR, Inc., USA) was used to record the eddy covariance data at a frequency of 20 Hz. The sonic anemometer was also used to measure wind speed (U) and wind direction (WD). The flux data was averaged in 30-min blocks. The flux movement convention used is, negative CO_2 flux value indicating downward-moving flux (i.e., uptake) while positive value indicating upward-moving flux (i.e., source or emission) (Yusup et al., 2018).

To complement the eddy covariance system, the “Biomet” system of slow-response sensors measured the microclimate variables, the atmospheric temperature (T_A) and relative humidity (RH) sensor (model HMP155, Vaisala, Finland; the accuracy of T_A is ± 0.7 °C and the accuracy of RH is ± 1.7%), a pyranometer (R_G) (model LI-200SL, LI-COR, Inc., USA; error was < 5%), and a net radiometer (R_N) (model NR LITE 2, Kipp & Zonen, Inc., USA; sensitivity was 13.6 μV $W^{-1}\ m^{-2}$). Sea water temperatures (T_S) at depths of 0.5 m (T_{S1}) and 2.5 m (T_{S2}) were measured using two thermistors (LI-COR, Inc., USA) with the accuracy of ± 1 °C. Since T_{S1} was positioned near the water surface, the temperature measurements were assumed to be the sea water surface temperature. An