Spectral analyses of high-frequency data during two hour-long periods from the ECHOES system deployed at three sites in the Florida Keys in June 2018

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Project
» Carbon Cycling in Carbonate-Dominated Benthic Ecosystems: Eddy Covariance Hydrogen Ion and Oxygen Fluxes (ECHOES Benthic Ecosystems)

Contributors	Affiliation	Role
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Abstract
Spectral analyses (power spectra and cross power spectral density (CPSD)) of high-frequency data (turbulence; momentum, oxygen and hydrogen ion fluxes) from two hour-long periods during a high-energy wave period (Hr 38) and a low-energy wave period (Hr 116).

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Coverage

Spatial Extent: **N**:25.120328 **E**:-80.300504 **S**:25.11732 **W**:-80.303069
Temporal Extent: 2018-06-24 - 2018-06-29

Dataset Description

An eddy covariance system, known as ECHOES, was deployed at three sites offshore of Key Largo, Florida during June 2018. The ECHOES systems logged the three-dimensional velocity, depth, O2 optode, pH sensor, and triaxial Inertial Measurement Unit. A separate frame at each site contained a photosynthetically active radiation (PAR) sensor and a Seabird SeapHOx, measuring salinity, temperature, depth, O_2, and pH. This dataset contains the spectral analyses (power spectra and cross power spectral density (CPSD)) of high-frequency data (turbulence; momentum, oxygen and hydrogen ion fluxes) from two hour-long periods during a high-energy wave period (Hr 38) and a low-energy wave period (Hr 116).

Methods & Sampling

Background
The basis for the eddy covariance (EC) technique is that turbulent mixing, caused by the interaction of current velocity with the benthic, atmospheric, sea-ice, or cline interfaces, is the dominant vertical transport process in boundary layers. Therefore, vertical fluxes across the ecosystem interfaces can be derived from high-resolution measurements of the vertical velocity and a solute concentration.

Field Sites
The field sites were located ~7 km offshore of Key Largo, Florida, USA at the southern tip of Florida in the Florida Keys. The sites were located on or adjacent to Little Grecian Rocks Reef with a site on the reef crest (25.119016°N, -80.300504°W) at 2.9 m mean depth, in a seagrass bed located ~225 m to the northwest of the reef site (25.120328°N, -80.302222°W) at 4.8 m mean depth, and in a sandy site located ~300 m to the southwest of the reef site (25.117320°N, -80.303069°W) at 6.3 m mean depth. The reef site is described in substantial detail (3-dimensional and species analyses) in Hopkinson et al. (2020), where the EC instrument can be seen near the center of the image analyses (in Figure 6 of Hopkinson et al. 2020) during its deployment in this study. This reef site is substantially degraded with its benthic surface and primary production dominated by octocorals, algae and rubble (Hopkinson et al. 2020). The seagrass site was dominated by dense Thalassia testudinum (turtlegrass) with a canopy height of 0.2 m underlain by carbonate sands. The sandy site was composed of carbonate sands with microalgal mats and migrating bedforms 0.1 m in height. Research was conducted from June 24 to June 29 in 2018 with the seagrass deployment beginning on the 24th and the sand and reef deployment beginning on the 25th of June, 2018.

Instrumentation
The EC systems used here, known as Eddy Covariance Hydrogen Ion and Oxygen Exchange System (ECHOES, Long et al. 2015) consisted of an Acoustic Doppler Velocimeter (ADV, Nortek) that was coupled to a FirestingO_2 Mini fiber-optic O_2 meter with a fast-response (~ 0.3 s) 430 µm diameter optode (Pyroscience) (Long et al. 2015, Long and Nicholson 2018, Long et al. 2019) and a fast-response (~0.6 s) Honeywell Durafet III pH sensor with a preamp Cap Adapter and a custom isolation amplifier (based on Texas Instruments ISO124P).

The ECHOES systems logged the three-dimensional velocity, depth, O_2 optode, pH sensor, and triaxial Inertial Measurement Unit (IMU, MicroStrain model 3DM-GX3) at a frequency of 32 Hz continuously. Using 6 rechargeable lithium ion batteries (50 Watt h, Nortek #220007), the system could operate continuously for ~4.5 days. All instrumentation was mounted to a light-weight, passively rotating carbon fiber frame. A bubble level affixed to the ADV mount allowed for precise leveling during field deployment by SCUBA divers. Stakes (sand and seagrass sites) or lead weights and zip ties (reef site) maintained instrument location and orientation. The measurement height, or location of the ADV measuring volume and sensors, above the sediment surface was determined by placing it at a height that was greater than twice the canopy or bedform height as recommended by terrestrial EC guidelines where twice the canopy height, and up to 5 times the canopy height in patchy environments, is recommended (Burba and Anderson 2010, Long et al. 2015).

The microfluidic flow-through sensor design has a small volume (0.33 cm^3) and a KNF Micropump (model NF10) with a flow rate (100 mL min^{-1}) that combine to have a quick flush rate (5 Hz) while protecting and preventing light interference for both O_2 and pH sensors. The microfluidic intake was located 0.025 m behind the ADV measuring volume (see Donis et al. 2015, Berg et al. 2015) to prevent disruption of ADV-measured flow rates (Long et al. 2015). The microfluidic housing mounted tightly over the Durafet III sensor tip and has a small chamber for inserting the O_2 optode, that is located at the end of a 0.04 m long, 0.003 m inside diameter copper intake tube and filter, with the outlet of the microfluidic chamber connected to the pump intake. A passive flow meter (0-100 ml min^{-1}) connected to the pump outlet was used to confirm pumping rates during deployment.

A separate frame at each site contained an Odyssey (Dataflow Systems, New Zealand) photosynthetically active radiation (PAR) sensor and a Seabird SeapHOx (measuring salinity, temperature, depth, O_2, and pH). The SeapHOx was factory calibrated and the Odyssey PAR sensors were calibrated to a HR-4 spectroradiometer system (HOBI Labs HydroRAD-4) using the methods of Long et al. (2012).

Eddy Covariance Analysis
The 32 Hz data were averaged to 8 Hz for analysis. The ECHOES O_2 and pH sensors were calibrated to the slow-response SeapHOx sensors by least-squares regression. The ADV velocity data was removed from analysis when the beam correlation was < 50%. The means for Reynolds decomposition were determined using a 5 minute moving average window. The period over which the flux was determined, or burst length, was 15 minutes, with subsequent averaging to hourly rates. Rotations were conducted automatically by Nortek software (Vector v1.39.09) to East, North, and Up coordinates based on the IMU data (see Long and Nicholson 2018) followed by a planar rotation (see Lorke et al. 2013) for each instrument deployment.

Standard eddy covariance analysis was conducted to calculate O_2, H^+, and momentum fluxes. Cross Power Spectral Densities were also used to calculate O_2, H^+ and momentum fluxes and were determined with the Matlab function "CPSD", with the removal of wave frequencies conducted by accumulating the CPSD at frequencies below approximately $1/(2T_d)$. A storage correction was applied to all biogeochemical fluxes due to the presence of biological canopies and the high measuring heights used (Lorrai et al. 2010, Rheuban et al. 2014, Long and Nicholson 2018). Power spectral densities were determined using the Matlab function "PWELCH". The T_d was determined by finding the maximum of the momentum CPSD at the frequencies where the waves were expected for the study sites (e.g. 0.1 > Hz < 1).

Refer to the Supplemental File "ECHOES_methods_FL2018.pdf" for the equations used to determine wave velocities and O_2, H^+, and momentum fluxes.

Data Processing Description

BCO-DMO Processing:
- concatenated data from the three different sites into one dataset;
- renamed fields;
- added latitude and longitude columns.

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Data Files

File
Fl_spectral_analyses.csv (Comma Separated Values (.csv), 1.73 MB) MD5:cb485afb964d5865a68236585904d606 Primary data file for dataset ID 821294

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Supplemental Files

File
ECHOES FL 2018 Methods filename: ECHOES_methods_FL2018.pdf (Portable Document Format (.pdf), 615.40 KB) MD5:32e714361f0a5aee33baae62748d4333 Study site and methods description for Florida Keys 2018 datasets from the project "Carbon Cycling in Carbonate-Dominated Benthic Ecosystems: Eddy Covariance Hydrogen Ion and Oxygen Fluxes".

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Related Publications

Berg, P., Reimers, C. E., Rosman, J. H., Huettel, M., Delgard, M. L., Reidenbach, M. A., & Özkan-Haller, T. (2015). Technical Note: Time lag correction of aquatic eddy covariance data measured in the presence of waves. Biogeosciences Discussions, 12(11), 8395–8427. doi:10.5194/bgd-12-8395-2015
Methods

Burba GG, & DJ, A. (2010). A Brief Practical Guide to Eddy Covariance Flux Measurements: Principles and Workflow Examples for Scientific and Industrial Applications. LI-COR Biosciences. https://doi.org/10.13140/RG.2.1.1626.4161
Methods

Donis, D., Holtappels, M., Noss, C., Cathalot, C., Hancke, K., Polsenaere, P., … McGinnis, D. F. (2015). An Assessment of the Precision and Confidence of Aquatic Eddy Correlation Measurements. Journal of Atmospheric and Oceanic Technology, 32(3), 642–655. doi:10.1175/jtech-d-14-00089.1

https://doi.org/10.1175/JTECH-D-14-00089.1
Methods

Hopkinson, B. M., King, A. C., Owen, D. P., Johnson-Roberson, M., Long, M. H., & Bhandarkar, S. M. (2020). Automated classification of three-dimensional reconstructions of coral reefs using convolutional neural networks. PLOS ONE, 15(3), e0230671. doi:10.1371/journal.pone.0230671
Methods

Long, M. H., & Nicholson, D. P. (2017). Surface gas exchange determined from an aquatic eddy covariance floating platform. Limnology and Oceanography: Methods, 16(3), 145–159. doi:10.1002/lom3.10233
Methods

Long, M. H., Charette, M. A., Martin, W. R., & McCorkle, D. C. (2015). Oxygen metabolism and pH in coastal ecosystems: Eddy Covariance Hydrogen ion and Oxygen Exchange System (ECHOES). Limnology and Oceanography: Methods, 13(8), 438–450. doi:10.1002/lom3.10038
Methods

Long, M. H., Koopmans, D., Berg, P., Rysgaard, S., Glud, R. N., & Søgaard, D. H. (2012). Oxygen exchange and ice melt measured at the ice-water interface by eddy correlation. Biogeosciences, 9(6), 1957–1967. doi:10.5194/bg-9-1957-2012
Methods

Long, M. H., Rheuban, J. E., McCorkle, D. C., Burdige, D. J., & Zimmerman, R. C. (2019). Closing the oxygen mass balance in shallow coastal ecosystems. Limnology and Oceanography, 64(6), 2694–2708. doi:10.1002/lno.11248
Methods

Lorke, A., McGinnis, D. F., & Maeck, A. (2013). Eddy-correlation measurements of benthic fluxes under complex flow conditions: Effects of coordinate transformations and averaging time scales. Limnology and Oceanography: Methods, 11(8), 425–437. doi:10.4319/lom.2013.11.425
Methods

Lorrai, C., McGinnis, D. F., Berg, P., Brand, A., & Wüest, A. (2010). Application of Oxygen Eddy Correlation in Aquatic Systems. Journal of Atmospheric and Oceanic Technology, 27(9), 1533–1546. doi:10.1175/2010jtecho723.1 https://doi.org/10.1175/2010JTECHO723.1
Methods

Rheuban, J. E., Berg, P., & McGlathery, K. J. (2014). Ecosystem metabolism along a colonization gradient of eelgrass (Zostera marina) measured by eddy correlation. Limnology and Oceanography, 59(4), 1376–1387. doi:10.4319/lo.2014.59.4.1376
Methods

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Parameters

Parameter	Description	Units
site	Site description	unitless
lat	Site latitude	decimal degrees North
lon	Site longitude	decimal degrees East
Hz_for_Hour_116	Hz for Hour 116	Hz
Cumulative_O2_CPSD_from_Hour_116	Cumulative O2 CPSD from Hour 116	normalized (0-1)

Cumulative_H_CPSD_from_Hour_116	Cumulative H CPSD from Hour 116	normalized (0-1)
Cumulative_Momentum_CPSD_from_Hour_116	Cumulative Momentum CPSD from Hour 116	normalized (0-1)
Vertical_Velocity_Power_Spectra_from_Hour_116	Vertical Velocity Power Spectra from Hour 116	(m s-1)^2
Horizontal_Velocity_Power_Spectra_from_Hour_116	Horizontal Velocity Power Spectra from Hour 116	(m s-1)^2
O2_Power_Spectra_from_Hour_116	O2 Power Spectra from Hour 116	(uMol L-1)^2
H_Power_Spectra_from_Hour_116	H Power Spectra from Hour 116	(uMol L-1)^2
Hz_for_Hour_38	Hz for Hour 38	Hz
Cumulative_O2_CPSD_from_Hour_38	Cumulative O2 CPSD from Hour 38	normalized (0-1)
Cumulative_H_CPSD_from_Hour_38	Cumulative H CPSD from Hour 38	normalized (0-1)
Cumulative_Momentum_CPSD_from_Hour_38	Cumulative Momentum CPSD from Hour 38	normalized (0-1)
Vertical_Velocity_Power_Spectra_from_Hour_38	Vertical Velocity Power Spectra from Hour 38	(m s-1)^2
Horizontal_Velocity_Power_Spectra_from_Hour_38	Horizontal Velocity Power Spectra from Hour 38	(m s-1)^2
O2_Power_Spectra_from_Hour_38	O2 Power Spectra from Hour 38	(uMol L-1)^2
H_Power_Spectra_from_Hour_38	H Power Spectra from Hour 38	(uMol L-1)^2

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Instruments

Dataset-specific Instrument Name	Acoustic Doppler Velocimeter (ADV, Nortek)
Generic Instrument Name	Acoustic Doppler Velocimeter
Generic Instrument Description	ADV is the acronym for acoustic doppler velocimeter. The ADV is a remote-sensing, three-dimensional velocity sensor. Its operation is based on the Doppler shift effect. The sensor can be deployed either as a moored instrument or attached to a still structure near the seabed. Reference: G. Voulgaris and J. H. Trowbridge, 1998. Evaluation of the Acoustic Doppler Velocimeter (ADV) for Turbulence Measurements. J. Atmos. Oceanic Technol., 15, 272–289. doi: http://dx.doi.org/10.1175/1520-0426(1998)0152.0.CO;2

Dataset-specific Instrument Name	triaxial Inertial Measurement Unit (IMU, MicroStrain model 3DM-GX3)
Generic Instrument Name	Microstrain 3DM-GX1 Gyro Enhanced Orientation Sensor
Generic Instrument Description	The MicroStrain 3DM-GX3 is a triaxial accelerometer designed to measure 360 degrees of angular motion on three orthogonal axes. The 3DM-GX1 has now been retired in favour of later MicroStrain products. The 3DM-GX1 featured on-board processing/filtering of accelerometer, gyro and magnetometer channels, with standard RS-232 and RS-485 outputs, and optional analog output. It offers 16 bit A/D resolution, accuracy of +/-0.5 degrees for static test conditions or +/-2 degrees for dynamic test conditions, 100 Hz digital output rate for Euler, Matrix and Quaternion, and operates in temperatures of -40 to 70 degrees C with enclosure (or +85 degrees C without enclosure).

Dataset-specific Instrument Name	FirestingO2 Mini fiber-optic O2 meter
Generic Instrument Name	Oxygen Sensor
Generic Instrument Description	An electronic device that measures the proportion of oxygen (O2) in the gas or liquid being analyzed

Dataset-specific Instrument Name	Honeywell Durafet III pH sensor
Generic Instrument Name	pH Sensor
Generic Instrument Description	An instrument that measures the hydrogen ion activity in solutions. The overall concentration of hydrogen ions is inversely related to its pH. The pH scale ranges from 0 to 14 and indicates whether acidic (more H+) or basic (less H+).

Dataset-specific Instrument Name	KNF Micropump (model NF10)
Generic Instrument Name	Pump
Generic Instrument Description	A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps

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Project Information

Carbon Cycling in Carbonate-Dominated Benthic Ecosystems: Eddy Covariance Hydrogen Ion and Oxygen Fluxes (ECHOES Benthic Ecosystems)

Website: https://www2.whoi.edu/staff/mlong/projects/project-4/

Coverage: Bermuda

NSF Award Abstract:

Chemical and biological processes that occur in and on the seafloor can create chemical exchange of elements with seawater and make significant contributions to carbon and nutrient cycling in shallow coastal systems. However, these processes are exceedingly difficult to measure directly in the ocean, with no satisfactory methods currently available to quantify their full impact. The researchers undertaking this project have developed a unique, field instrument referred to as the Eddy Covariance H+ and O2 Exchange System (ECHOES). These novel measurements of hydrogen ion (H^+) and oxygen (O_2) exchange between the seafloor and the overlying seawater will allow unique, direct evaluation of the important linked biological and chemical reactions. Data from ECHOES will transform understanding of the potentially critical contribution of seafloor processes to the resilience of coastal ecosystems experiencing rapid changes in seawater chemistry. Results from this project will provide critical data for improved models of the consequences of coastal acidification. Additionally, this project will fund an early career scientist and the mentorship of undergraduate students in ocean science research through the Woods Hole Oceanographic Institute's Summer Student Fellowship Program.

Laboratory experiments have successfully examined the benthic response of individual organisms and chemical reactions to stress related to changing seawater chemistry but the integrated response of intact ecosystems has been very difficult to quantify due to unsatisfactory methods for in situ measurements of the required suite of biogeochemical fluxes. This deployment of ECHOES at a variety of carbonate-dominated seafloor sites in Bermuda is a pioneering effort to simultaneously measure net community production (NCP) and net community calcification (NCC). The study will focus on traditionally difficult-to-study systems including complex reefs, vertical seagrass canopies, and bare permeable sediments, evaluating diel variability, patchiness, and the impact of upstream fluxes on downstream ecosystems. Important biogeochemical parameters (e.g. pH, CO_2, O_2, alkalinity, etc.) in these productive shallow environments can experience daily fluctuations over a greater dynamic range than 100-year model projections for the open ocean due to increasing atmospheric CO_2. Therefore, the novel field data generated by this research will help define the potentially critical and heretofore ill-defined role for shallow, productive carbonate sediments in predictive models of ecosystem response to ocean acidification.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1657727

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