Final Project Report

Title of the grant

MEMORANDUM OF AGREEMENT
Between
The National Forestry Commission of Mexico and the
University of Delaware
Related to the Support for a Postdoctoral Scientist

Report prepared by:
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February 17th, 2016

This work would not have been possible without the collaboration and participation of multiple colleagues. This report includes contributions by multiple colleagues along different stages of the project. Collaborators include:

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<u>Suggested citation:</u>

Vargas R and Sánchez-Mejía ZM. 2016. *Final Project Report: Related to the Support for a Postdoctoral Scientist*. Agreement between The National Forestry Commission of Mexico and the University of Delaware. Newark, DE, USA

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Summary

The National Forestry Commission of Mexico (i.e., CONAFOR) and the University of Delaware signed in February of 2014 an agreement with the goals of: a) advance Mexico's regional understanding of the role of mangrove forests on the national greenhouse gas emissions (GHG) net balance; and b) to support activities and provide recommendations towards the implementation and design of a monitoring system of greenhouse gases from mangrove forests so it contributes to the reporting of the land-use, land-use change and forestry sector. To facilitate this goal, the agreement included hiring a postdoctoral scientist during a period of 24 months to produce information on carbon fluxes and ecosystem productivity at the study site La Encrucijada, Chiapas, Mexico.

The CONAFOR and the University of Delaware contributed in equal parts to the support of the postdoctoral scientist (i.e., 50% of the salary each institution). The work included the collaboration of multiple institutions including: University of Delaware, ECOSUR, CONAFOR/Enhancing REDD+ and South-South collaboration project, CONANP, USFS, USAID, SilvaCarbon, and FMCN. The main products of these agreement were: a) participate in the installation of an eddy covariance tower at La Encrucijada, Chiapas, Mexico; b) participate in capacity building and knowledge transfer to personnel/researcher of ECOSUR; c) provide data related to ecosystem carbon dynamics (length of dataset is dependent on timing of installation of the eddy covariance tower, technical limitations, and weather conditions); and d) contribute with scientific publications as a result from the research efforts at La Encrucijada.

The resulting products were possible through collaboration by the aforementioned institutions. These efforts directly supported the establishment of an Intensive Carbon Monitoring Site (i.e., *Sitio de Monitoreo Intensivo de Carbono*; SMIC) in a coastal wetland. This SMIC is the latest of the Mex-SMIC network, which are study sites that provide detail information on physiological and ecological measurements (e.g., using permanent plots, eddy covariance system information) combined with remote-sensing products and ecosystem models to support national/subnational monitoring systems in a cost-effective manner. An eddy covariance tower provides the capacity to measure the exchange of mass (e.g., CO_2, CH_4) and energy between the land and the atmosphere, and is a key instrumentation to provide information about carbon balance and to validate and parameterize ecosystem models. The SMIC La Encrucijada is located in the Biosphere Reserve La Encrucijada, a RAMSAR wetland, and the only SMIC located in a mangrove forest.

This final report provides the successful achievement of the general goals of the agreement between CONAFOR and the University of Delaware. This agreement was sponsored in equal parts by both institutions, and the results provide a balance between technical deliverables and professional development as detailed in the "*Postdoctoral Mentoring Plan*" of the original Memorandum of Agreement between the parties.

This project accomplished the general goals of participation in the installation of an eddy covariance tower, participate in capacity building, provide available data, and publication of scientific results. Furthermore, the University of Delaware participated in efforts and activities that were not listed in the Memorandum of Agreement (e.g., develop ecological impact assessments, coordination of external

agreements, supplemental funding), but were critical to perform for achieving the main goals. Thus, the personnel from the University of Delaware believe that their efforts have gone beyond their responsibilities, but are proud that this work helped for the successful establishment of this SMIC site and the overall Mex-SMIC network.

The main deliverables include the installation of an eddy covariance tower at La Encrucijada. The University of Delaware participated in the installation of a 40 m (130 ft) tower and the construction of a 50 m (164 ft) boardwalk to access the tower. The University of Delaware actively participated in development of ecological impact assessments, coordinated with contractors for the construction of the boardwalk, and facilitated agreements to allocate construction funds and transfer of equipment to ECOSUR (i.e., instrumentation required for installation of the eddy covariance system). The University of Delaware purchased three solar panels, deep-cycle batteries, and pay technicians to install the electricity supply to provide electrical power for the eddy covariance system. The eddy covariance instrumentation was successfully installed at La Encrucijada in October of 2015.

The University of Delaware participated in workshops, and formal and informal training to develop capacity and transfer knowledge for personnel of ECOSUR and the Mex-SMIC network. Specifically, the University of Delaware trained a technician at ECOSUR to maintain the eddy covariance tower once the post-doctoral researcher left ECOSUR as listed in the Memorandum of Agreement.

This final report includes available data sets as a result of measurements at the study site and collaborations with members of ECOSUR (i.e., Cristian Tovilla). Specifically, we include a dataset of litterfall productivity, remote sensing products of canopy dynamics, and available information from the eddy covariance tower installed at the study site. Furthermore, this report also includes a draft of a scientific publication lead by Zulia Sanchez as a result of her research efforts.

This report includes *Lessons Learned and Future Work* (section 5) from this project. Challenges that were present during these efforts include administrative and technical. Administrative and agreement paperwork took up to 8 months more than originally planned. Unfortunately the University of Delaware had no direct control over these challenges but took a leadership role to facilitate them. Main technical challenges for the eddy covariance system at this site are due to sea breeze, humidity (>65%), and cloud cover. These challenges limit recharge of batteries, and increase the degradation of instrumentation (i.e., corrosion). These meteorological conditions challenge the long-term performance of the eddy covariance tower if no maintenance and preventive care is taken. The University of Delaware strongly recommends that personnel from ECOSUR perform monthly maintenance as detailed in the personnel-training efforts. Furthermore, the wood in the boardwalk and the tower base has to be re-treated once a year to avoid degradation of materials and become a safety hazard. The University of Delaware recognizes that long-term operation of this eddy covariance tower will require future continuous funds.

This document describes the steps and accomplishments of this agreement, and directly contributes to the establishment of SMIC- La Encrucijada as part of the Mex-SMIC network. This work would not have been possible without the collaboration and participation of multiple colleagues listed in the cover-page of this report. We thank them all!

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) in 2006 organized a Guideline for National Greenhouse Gas Inventories (IPCC, 2006). This guideline describes basic steps and methodologies for reporting national inventories on greenhouse gases (GHG) emissions and removals. This report highlights that significant changes occur with land use and land use changes, and Volume 4 of these series is focused on agricultural, forest and other land use categories (AFOLU) to address this topic. The guide includes information on good practices and uncertainty management, in order to prepare inventories for the AFOLU sector. A tier approach is used to prepare national inventories, the higher the tier the more accurate the information, but consequently these higher efforts require more resources (i.e., economic, human). Importantly, different tiers can be used for different variables in the same inventory as long as is well documented. Tier 1 uses IPCC default values for carbon stocks in different ecoregions and country-specific activity data that can come from coarse globally available sources. Tier 2 uses country-specific data about forests and carbon stocks within detailed strata, and country- specific activity data with higher temporal and spatial resolution. Tier 3 uses inventories with repeated direct measurements of changes in carbon stocks, or models parameterized with country-specific data, and country-specific activity data with the least level of uncertainty in the GHG emissions/removals estimates (Paustian et al., 2006).

The design and establishment of an Intensive Carbon Monitoring Site (i.e., *Sitio de Monitoreo Intensivo de Carbono*; SMIC) within the Mex-SMIC network are based to implement this guideline using a Tier 3 level approach (Birdsey et al. 2013, Olguín et al. 2015). These sites represent monitoring and verifying points useful for the Mexican National Forest Commission via the National Forestry and Soils Inventory / Inventario Nacional Forestal y de Suelos (INFyS), Biodiversity Commission (CONABIO), Natural Protected Areas Commission (CONANP). Furthermore, the sites that include measurements of gas, water, energy exchange between the ecosystem and the atmosphere (i.e., eddy covariance technique) contribute to MexFlux network (Vargas and Yepez 2011, Vargas et al. 2012, Vargas et al. 2013). Each site within the Mex-SMIC network has been strategically selected so that individually they provide information from priority ecosystems, and as a network (Olguín et al. 2015) they provide information helpful for decision-making and the implementation of MRV systems (Monitoring, Reporting, Verifying), and programs such as REDD+ (Reducing Emissions from Deforestation and forest Degradation).

The SMIC La Encrucijada, located in La Encrucijada Biosphere Reserve, is the first of its type in a coastal wetland in Mexico. Furthermore, this site is one of the few in the world that is monitoring the exchange of GHG, and energy between a tall mangrove forest and the atmosphere. Only a handful of similar sites exist around the world including the USA, India, Australia, and China. The SMIC La Encrucijada will integrate information on carbon stock changes derived from ground plot data (similar to the national forest inventory system) with direct measurements of GHG fluxes (i.e., CO_2 and CH_4) in a mangrove ecosystem.

This final report is organized following a chronological order of activities toward the accomplishment of the agreement between CONAFOR and the University of Delaware (**Figure 1**). The timeline is divided in three phases (1 to 3) where Phase 1 focused on training of the postdoctoral scientist (Dr. Zulia Sánchez-Mejía), Phase 2 focused on site selection, facilitation of agreements, and training of personnel at ECOSUR, and Phase 3 represents the installation of the eddy covariance tower at La Encrucijada. Finally, this report also includes explicit information on datasets, capacity building, and scientific contributions lead by the University of Delaware.

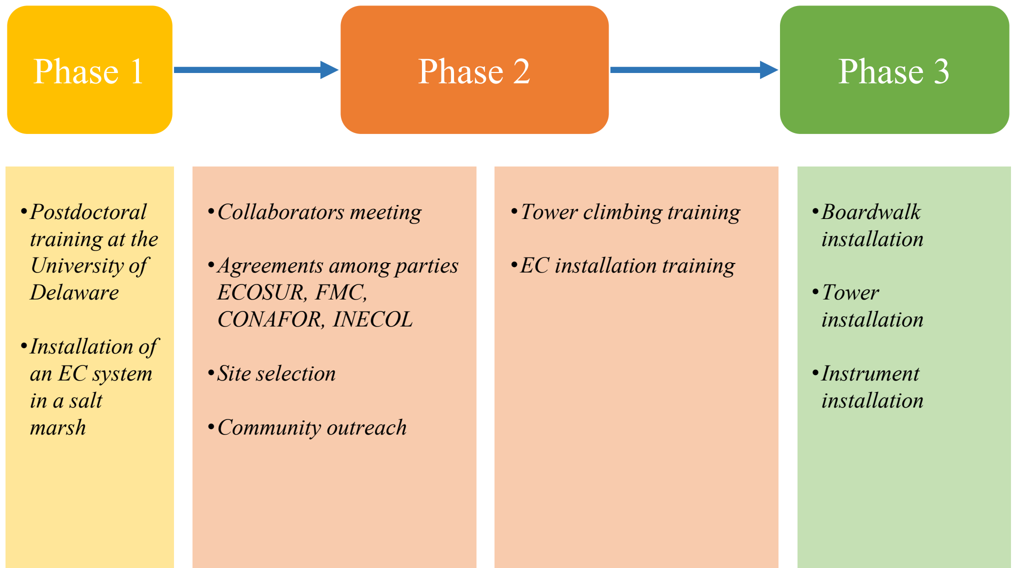

Figure 1. Diagram of the chronological order of activities toward the accomplishment of the agreement between CONAFOR and the University of Delaware

1. Phase 1

Phase 1 included work preformed from February to August 2014. The postdoctoral scientist, Dr. Zulia Mayari Sánchez-Mejía, was hired and received training at the University of Delaware to install an eddy covariance (EC) system very similar to the one installed at La Encrucijada. Such training consisted in ensemble, installation, and programing of an EC system in a salt marsh, a system influenced by tides just like the SMIC La Encrucijada (**Figure 2**). Training also included project planning and developing group leadership.

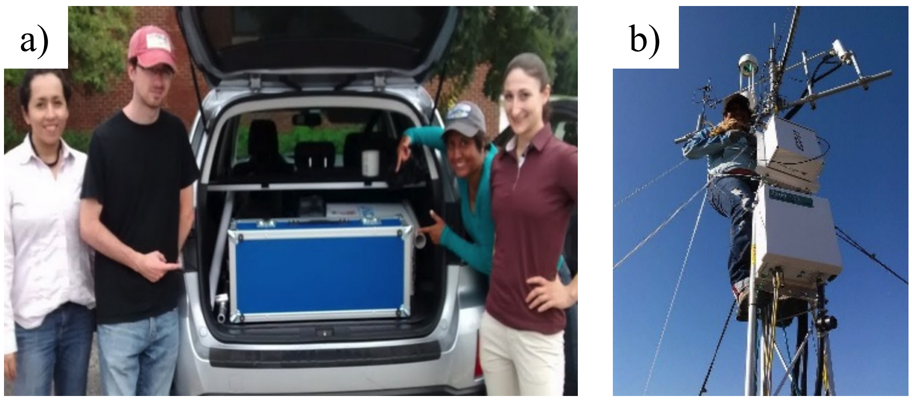

Figure 2. a) Transporting sensors to a salt mash in Delaware, and b) Dr. Zulia Sánchez-Mejía cleaning a methane sensor in a salt marsh.

Specific training activities related to SMIC La Encrucijada installation:

- Energy supply system design
- Configuration of LI-7200 (CO_2 and H_2O closed path infrared gas analyzer)
- Configuration of LI-7700 (CH_4 open path infrared gas analyzer)
- Configuration of LI-7550 (Datalogger)
- Configuration of Sutron XLite 9210

During this training several issues were identified that benefited the future work at SMIC La Encrucijada. For instance the anemometer Gill Wind Master Pro used at La Encrucijada had to be re-configured before installation. Issues with anemometer are related to energy supply, and this information was taken into account when designing the energy supply system for SMIC La Encrucijada. Another issue that was identified, was the easiness that the LI-7200 thermocouples fell apart due to sea breeze, so replacements were bought (with University of Delaware funds) to provide to La Encrucijada.

During this time, several videoconference meetings took place with collaborators to plan activities for SMIC La Encrucijada. Outcomes of these meetings were steps towards action plans for the installation of the boardwalk and the structure of the tower.

Main results of Phase 1:

- Develop an installation plan for the eddy covariance instrumentation at SMIC La Encrucijada
- Design a power supply system for the eddy covariance tower of SMIC La Encrucijada
- Advise and plan for potential challenges for installation of the eddy covariance tower at SMIC La Encrucijada
- Organization and data analysis for litterfall productivity at SMIC La Encrucijada

2. Phase 2

2.1 Planning meeting of SMIC La Encrucijada

A meeting was held in August 2014, from the 19th to the 20th, at Colegio de la Frontera Sur (ECSOUR) Tapachula, Chiapas, Mexico (**Figure 3**).

The objectives of the meeting were:

- Visit and discuss specific site location of the EC system;
- Discuss research objectives of the SMIC La Encrucijada;
- Discuss historic litterfall data collected since 2000 and experimental design with Dr. Cristian Tovilla

Main results of the meeting:

- Tower site location discussion and plan to analyze complementary data (i.e., wind speed and direction);
- Plan to seek contractors with the capabilities to install infrastructure (i.e., boardwalk and tower);
- Systematic biomass sampling design surrounding the EC tower was discussed and analyzed;
- Draft for data analysis and interpretation of historic litterfall data in collaboration with Dr. Cristian Tovilla

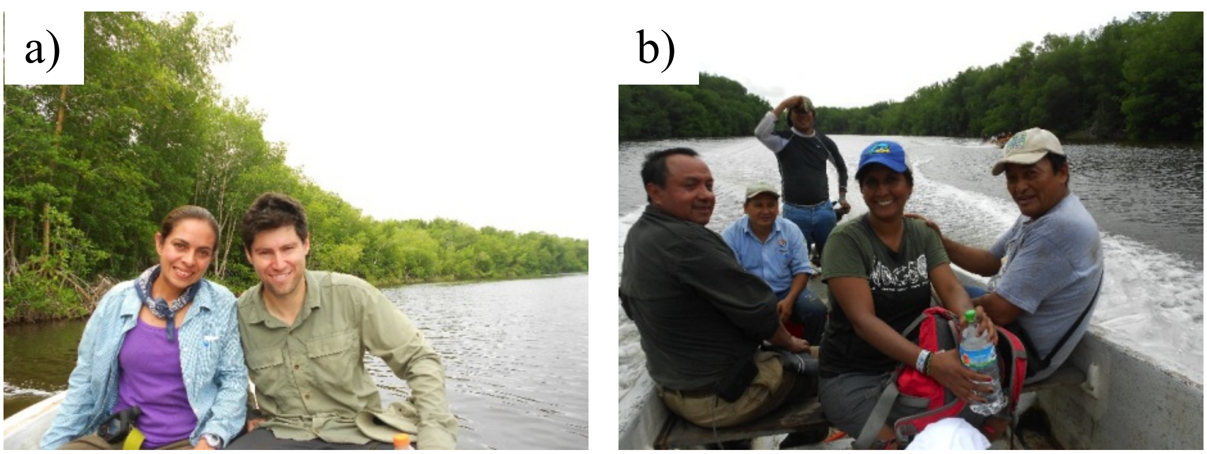

Figure 3. Visit to La Encrucijada Biosphere Reserve to analyze potential location of eddy covariance system, a) Dulce Infante (ECOSUR) and Rodrigo Vargas (UD), a) Leonardo Castro (CONANP), Gregorio Angeles (COLPOS), Zulia Sánchez (UDEL), Cristian Tovilla (ECOSUR).

During this meeting the main components of the eddy covariance equipment arrived to ECOSUR; via a collaboration agreement between CONAFOR and ECOSUR on August 16th 2014. Dr. Cristian Tovilla

(ECOSUR) signed as accountable and responsible of the instrumentation. The agreement was formalized in the project: *00079208 "Fortalecimiento del proceso de preparación para REDD+ en México y fomento a la Cooperación Sur-Sur"*. This equipment was documented by Ada Jimenez and Sánchez-Mejía to be accepted by ECOSUR. To date, legally the equipment is property of PNUD and donation to ECOSUR (i.e., ownership transfer) is an ongoing but unfinished process.

The University of Delaware strongly recommends the transfer of ownership to the end user (i.e., ECOSUR) to have the capacity of sending the equipment for calibration, maintenance, or repair to the manufacturer in Lincoln, NE, USA. Thus, paperwork should be organized to avoid exportation/importation delays in case of repairs.

Meeting Participants:

COLPOS, SMIC-Atopixco	Gregorio Ángeles
CONABIO	Alma Vázquez-Lule
CONABIO	Edgar Villeda
CONAFOR PNUD	Marcela Olguin
CONANP	Edmundo Aguilar López
CONANP	Leonardo Castro
ECOSUR	Cristian Tovilla
ECOSUR	Dulce Infante-Mata
SilvaCarbon	Craig Wayson
UDEL	Rodrigo Vargas
UDEL	Zulia Sánchez-Mejía
USFS	Richard Birdsey
USFS-Mex	Rafael Flores
PRONATURA	Marylin Bejarano

2.2 Environmental Impact Assessment

Because La Encrucijada Biosphere Reserve is a Natural Protected Area and a RAMSAR site, an environmental assessment was required. The University of Delaware in collaboration with CONANP and ECOSUR, presented a non-requirement authorization notification of impact assessment to the Environmental Secretary (SEMARNAT). The proposed activities focused on research, so the impact assessment was considered a "non-requirement authorization notification". *This effort was not a responsibility of the University of Delaware, but Dr. Sánchez-Mejía took leadership of this report, as it was a critical step for the successful accomplishment of the CONAFOR-University of Delaware agreement.* The process for writing and approving the Environmental Impact Assessment took from October 2014 to April 2015.

Annex 1 contains the formal request to SEMARNAT and Annex 2 contains the response from SEMARNAT approving the research activities at La Encrucijada.

2.3 ECOSUR EC System testing and training of personnel

To test the EC system and train personnel at ECOSUR, Dr. Sánchez-Mejía installed the equipment in a 10 m antenna located on the roof of one of the buildings at ECOSUR. This installation was performed with the help of several undergraduate (Universidad Autónoma de Chiapas and Universidad Politécnica de Chiapas) and graduate (Universidad Autonoma de Sinaloa and ECOSUR) students.

As part of the installation process the University of Delaware placed emphasis on tower climbing. *Security is the most important topic during equipment installation in towers*. Students at ECOSUR spent one full day practicing secure ways of climbing and learned how to use climbing equipment. In **Figure 4**, different stages of this training are shown. First, climbing is organized in groups of two, and double check of the equipment is performed on ground. For security purposes climbers are always attached to the tower using a carabiner and a security lanyard.

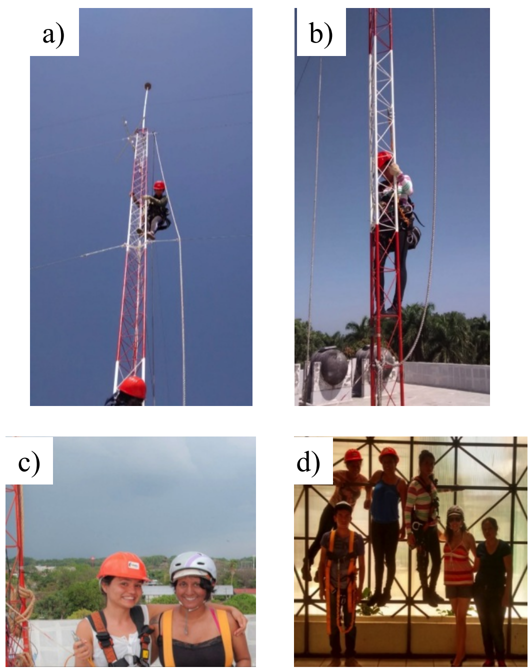

Figure 4. Climbing training with students of University of Guadalajara, and Universidad Autónoma de Chiapas). a) Students practicing climbing up, b) student practicing hook process, c) equipment check before each climb, d) group of students after climbing.

To install the instruments a pulley was installed first, and in **Figure 4.b** we observe the rope to pull things up. Students were trained on a sequential order: first the instruments are installed, then the boxes, connections among instruments are made, and at the end the power is provided to the equipment. The full installation of an EC tower took approximately 4 days working from 8 am to 11 am (heat after 11 am is too high to handle by computer equipment used to program or people) while training the personnel (**Figure 5**).

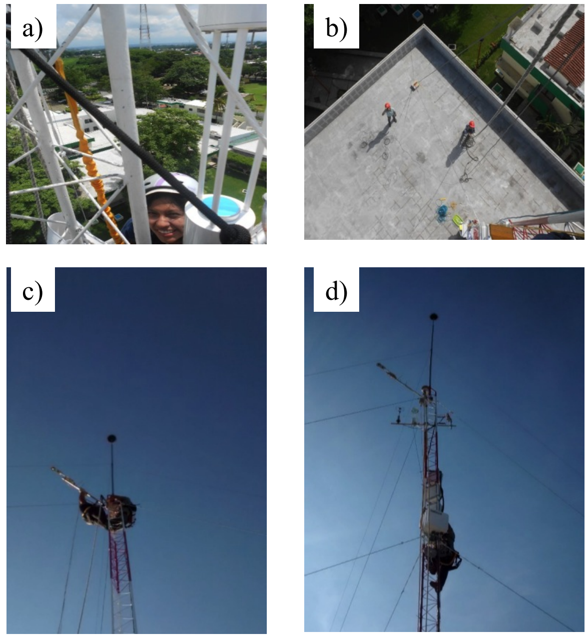

Figure 5. Sequential installation of the EC tower at ECOSUR. a) installation of methane sensor, b) view from the 10 m tower, rope used with pulley to send things up, c) sensor installation, d) data logger and pumps installation. Note the difficulty to work on a reduced space while being attached to the tower >10 m high.

The second most important thing to take into consideration when working with EC systems is power supply. Electricity, should be provided ideally at 12 V, with 3 to 20 Amps depending on the setup. **Figure 6** shows undergraduate students from the Universidad Politécnica de Chiapas (*Licenciatura* in Environmental Technologies) acquiring electrical skills while working with EC sensors.

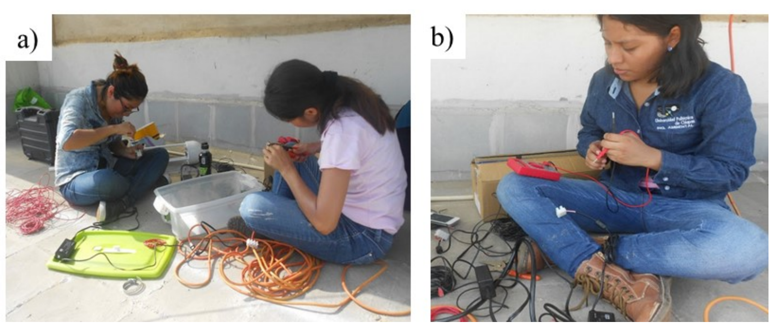

Figure 6. Students being trained to install EC sensors at ECOSUR. a) installation of methane sensor; b) using volt meter to test power supply.

2.4 Community outreach

The University of Delaware with the collaborators have taken two approaches for outreach:

a) The first approach was to use the eddy covariance instrumentation as an outreach tool. With the help of students of Coastal Systems Engineer (UACH), instruments were decorated using popular figures, for instance the methane sensor and the filter of the CO_2/H_2O sensor were painted like minions. The pumps and data loggers were decorated with the representation of leaves, water, gases, radiation, clouds, and wind. Pictures of this instruments installed at site are used to elaborate games such as shoots and ladders and an explanation of a monitoring system is provided to participants, as well as the activities that damage or help preserve mangrove forests, Dr. Sánchez-Mejía developed (see Annex 3).

b) The second approach was community awareness. Mostly we have given talks in the nearby communities, especially La Palma and Barra de Zacapulco. These talks are mostly focused on informing about the project objectives, and the importance of forest carbon monitoring. During one of the meetings a visit to the site was programed and at that moment the discussion also included the usefulness of a boardwalk and activates of low impact such as ecotourism. Additionally, an informative sign was designed and printed on a canvas to be placed at site and people passing can be provided of this information (Annex 4).

    a. As part of community awareness Dr. Sánchez-Mejía motivated a student to produce a video of the installation of the EC tower at La Encrucijada (Annex 5).

Main results of Phase 2:

- Plan for SMIC La Encrucijada location and design of EC system
- Plan for infrastructure (i.e., boardwalk and tower) installation
- Design and approval of the environmental impact assessment
- Initial analyzes and design of litterfall study at La Encrucijada
- Capacity building and human resources training
- Collaboration and network building
- Production of outreach material

4. Phase 3

The site for the EC system tower was selected using historical wind data from a nearby meteorological station. To do this the University of Delaware contacted the department of observation network from the hidrometeorological regional center "Tuxtla Gutierrez", CONAGUA (Comision Nacional del Agua), to obtain historic wind speed and direction for La Encrucijada.

Dr. Sánchez-Mejía used raw historic data (10 minutes sampling interval) from La Encrucijada weather station from 2011 to 2014 to create wind rose with multi-annual monthly means. Results show that higher wind speeds are more frequent from the Northeast, while winds with lower speed are most frequent from the Northwest, but the Southwest also presents stronger wind speeds (**Figure 7**). Results also show that at least during half of the year (May to November) winds from the North are constant, while the rest of the year winds from the Southwest predominate. Therefore, it is recommended that a site should be selected with enough footprint in these directions (**Figure 7**).

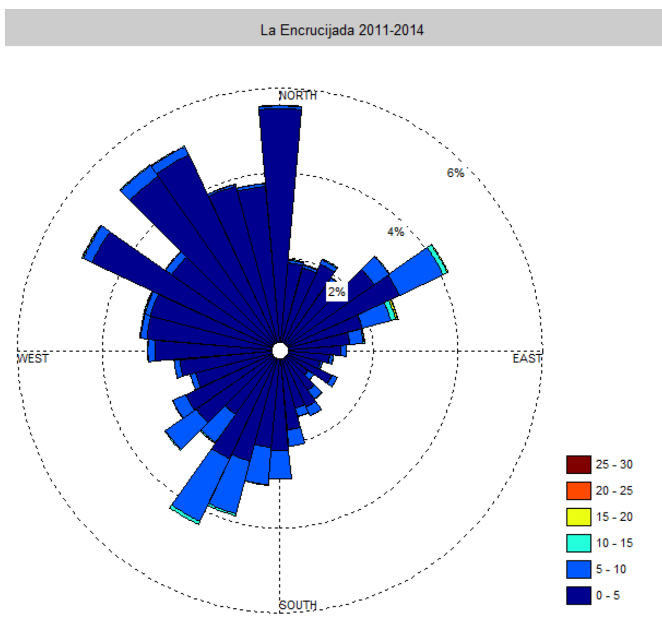

Figure 7. Wind rose using meteorological data from 2011 to 2014 at La Encrucijada.

Based on preliminarily analysis on wind patterns, the University of Delaware proposed two options: Plan A and B (**Figure 8**). Ultimately, Plan B was chosen due to easier access, footprint, and considerations based on wind roses from La Encrucijada weather station. While in plan A, a boardwalk at least 500 m was needed, for plan B a 50 m boardwalk was enough. This was and important decision as it significantly reduced the construction costs and kept the overall project under the available budget. The final decision was discussed among Dr. Rodrigo Vargas, Dr. Richard Birdsey, Dr. Craig Wayson, Dr. Zulia Sanchez-Mejia, Dr. Cristian Tovilla, Dr. Dulce Infante, Marcela Olguin, and Rafael Flores.

Figure 8. Site location (15° 11' 17.805" N, 92° 50' 0.459" W), leaving from embarcadero Las Garzas. Figure shows proposed locations for the EC tower at La Encrucijada. Plan A was initially suggested but required a 500 meters boardwalk, while Plan B (SMIC LE) was selected based on wind patterns and an easier access.

The final location of the EC tower is in a mature mangrove forest, dominated by *Rhizophora mangle* (red mangrove). In some areas a mixture with black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangrove is found. This combination of species is mostly due to higher salinity, and changes in microtopography and hydroperiod. From above the canopy these shifts are observed due to a change in canopy color from lighter to darker shades (**Figure 9**).

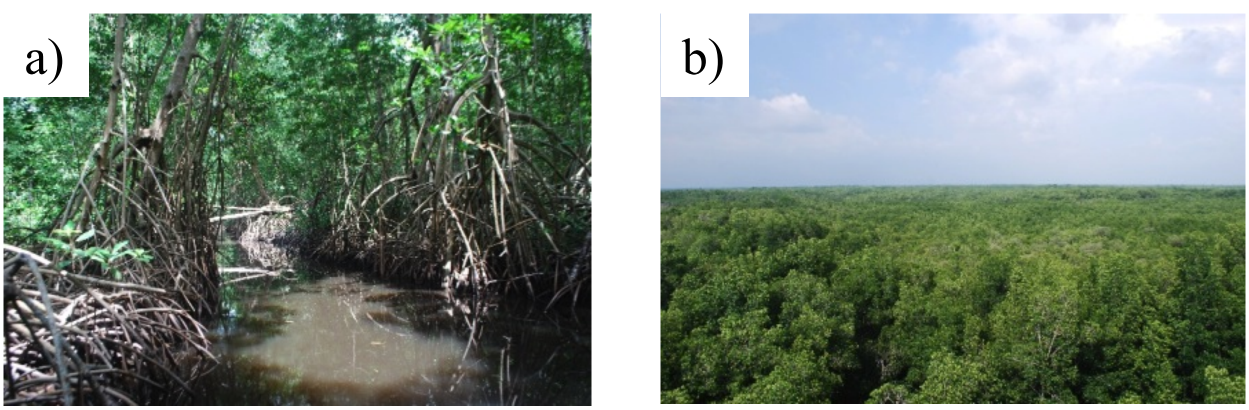

Figure 9. Mangrove forest nearby the EC flux tower, a) under canopy view from entrance channel to site, b) forest sight from the tower view to the East side.

4.1 Infrastructure installation

4.1.1 Boardwalk

The construction of the boardwalk was the most challenging part of the process, mainly due to delays in agreement and collaboration paper work. *These agreements and paperwork were not responsibility of the University of Delaware but Dr. Sánchez-Mejía invested time and effort, as it was a critical step for the successful accomplishment of the CONAFOR-University of Delaware agreement.* Personnel from the University of Delaware acted as facilitators of information; however, internal procedures from ECOSUR, FMC, and INECOL were beyond this role and delayed time accounting for up to 8 months. Low communication and slow information transfer were the largest limitations for the timely installation of the boardwalk.

To move forward towards a successful accomplishment of this CONAFOR-University of Delaware agreement, the collaborators decided on an alternative plan. The structure of the tower and eventual installation of EC sensor were to be expedited despite the absence of a boardwalk. This decision lead to the construction of a radio-tower that was completed in October of 2015. *The University of Delaware disclaims that delays on the installation of the structure of the tower (not responsibility of the University of Delaware) resulted in time and financial losses that ultimately delayed the installation of the EC system at La Encrucijada*. The University of Delaware also understands that multi-institution projects require collaborative efforts and coordination; therefore, personnel from the University of Delaware invested time and efforts to facilitate agreements that culminated in the construction of a boardwalk and the establishment of an EC tower at La Encrucijada. The University of Delaware considers that these collaborative efforts are a positive precedent for the establishment of SMIC La Encrucijada and the Mex-SMIC network.

The installed boardwalk is 40 cm wide, 50 m long, and rises above the root zone in some areas to 1.5 m and in others to 1.8 m (**Figure 10**). The wood used is CCA (chromated cooper arsenate) treated, and stainless steel is used to ensemble every section. Installation was performed by INECOL under supervision and responsibility of ECOSUR. The University of Delaware suggested ideas, but the final decision was performed by ECOSUR. *The boardwalk should be maintained every year due to humidity and temperature, treatment should include a waterproof coating and anti-termite coating. Additionally, leaves should be removed to avoid humidity accumulation, prevent wood decay, and reduce walking hazards.*

Figure 10. Main steps of boardwalk installation at La Encrucijada, a) posts and supporting structure, b) anchoring posts, c) cover installation, and d) finished product.

4.1.2 Tower installation

The base of the tower, guide wires, and tower designs were made with a combination of information including literature review (Rivera-Monroy et al., 2013), and meeting with Jordan Barr (Elder Research Inc) and Jose fuentes (Penn State), and people from Radio Enlaces de Comunicacion, S.A. de C.V (REDCOM). Materials were selected based on strength, durability, stability, and performance under humid, hot, and saline conditions. Wood is the best material, and treated properly has a long durability, so the main structure of base and anchors for the guide wire are based on treated wood (chromated cooper arsenate treated, CCA).

The installation was performed by REDCOM and supervised by the University of Delaware and ECOSUR. The installation process lasted about 3 weeks and was completed in October 2015. During the first 2 weeks the focus was on the base and anchors, both structures have a support system so the tower will not sink. The third week was devoted to the installation of the radio-tower, a triangle tower, including guide wires, and the installation of an energy-supply system including solar panels.

Figure 11 shows images summarizing the installation of the tower. At La Encrucijada a motor boat had to be hired to transport materials (representing a 30 min boat ride), tides influence the time available to work. Tide has to be on the higher end so that boat can circulate in the small channel. A zip line (**Figure**

11b, c) was installed from the channel and 60 m in to transport logs, and construction materials. Everything was basically moved using this zip line and hooks.

To build the base of the tower and to anchor the tower, the first step was to bury the posts 3 m deep. To do so, a stake hammer was moved with a pulley above the post and while two people guide it the other two applied force. Once all the posts were submerged (**Figure 11d**), the horizontal posts were installed to enhance support (**Figure 11e, f**). Finally, the cover is installed (**Figure 11g**) are connectors and hardware is stainless steel. In the anchor, each post supports a guide wire (**Figure 11h**).

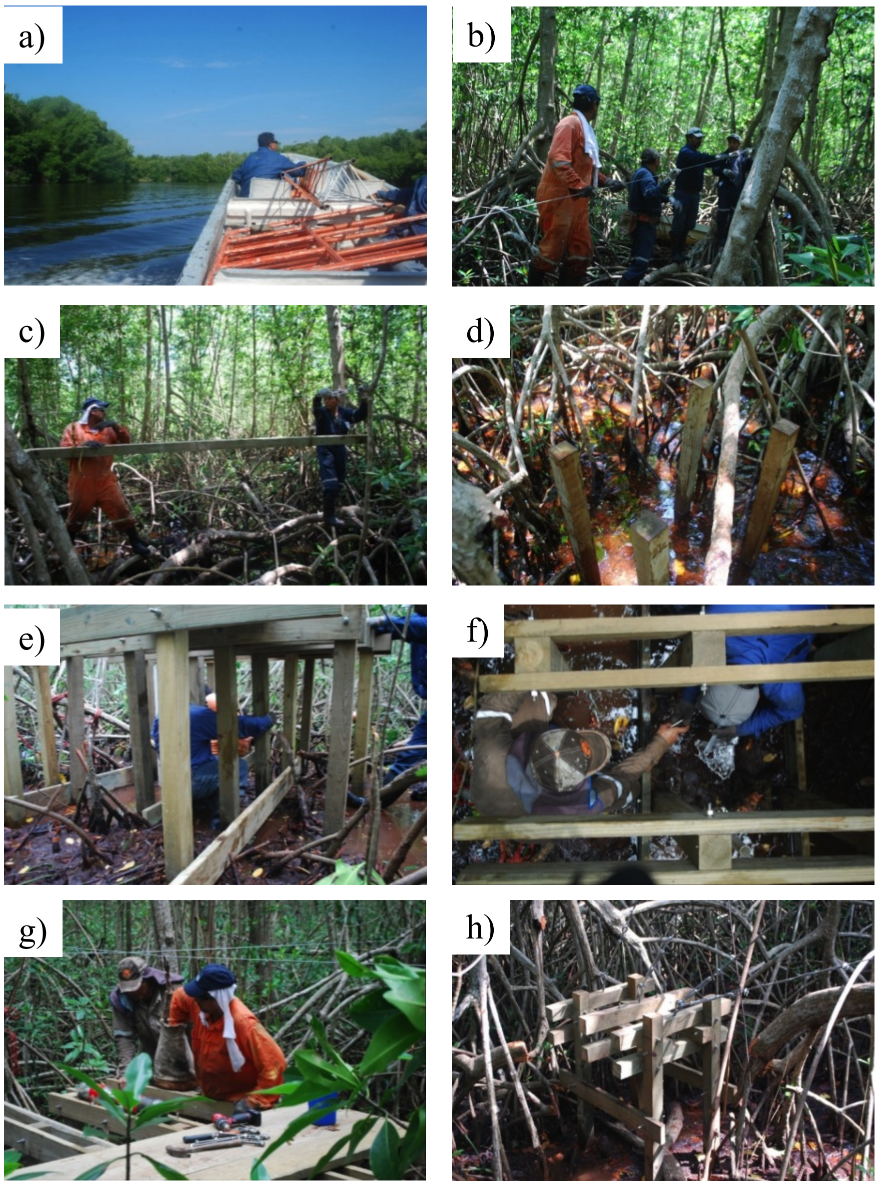

Figure 11. Main steps for installation of the tower; a) boat transport; b, c) transportation of materials; d-h) construction of the base to install the radio-tower.

The tower is supported by guide wires and the highest anchor point is set at 37 m (**Figure 12a, b**). The tower itself is a typical radio-tower with a height of 40 m described as ATA45 R type tower. It has 13 sections of 3 m and one section of 1 m. The tower is located at the center of the base and rises 20 m above the canopy (**Figure 12d**). The grounding system, which protects the tower from electrical atmospheric discharge goes from the tip of the tower down and to each of the anchors. In **Figure 12a** we can observe the "crown" of the discharge system, if an electrical discharge occurs this will pop, and the tower will not be protected anymore. *As part of the maintenance plan, the University of Delaware recommends always having an extra one, especially during storm season.*

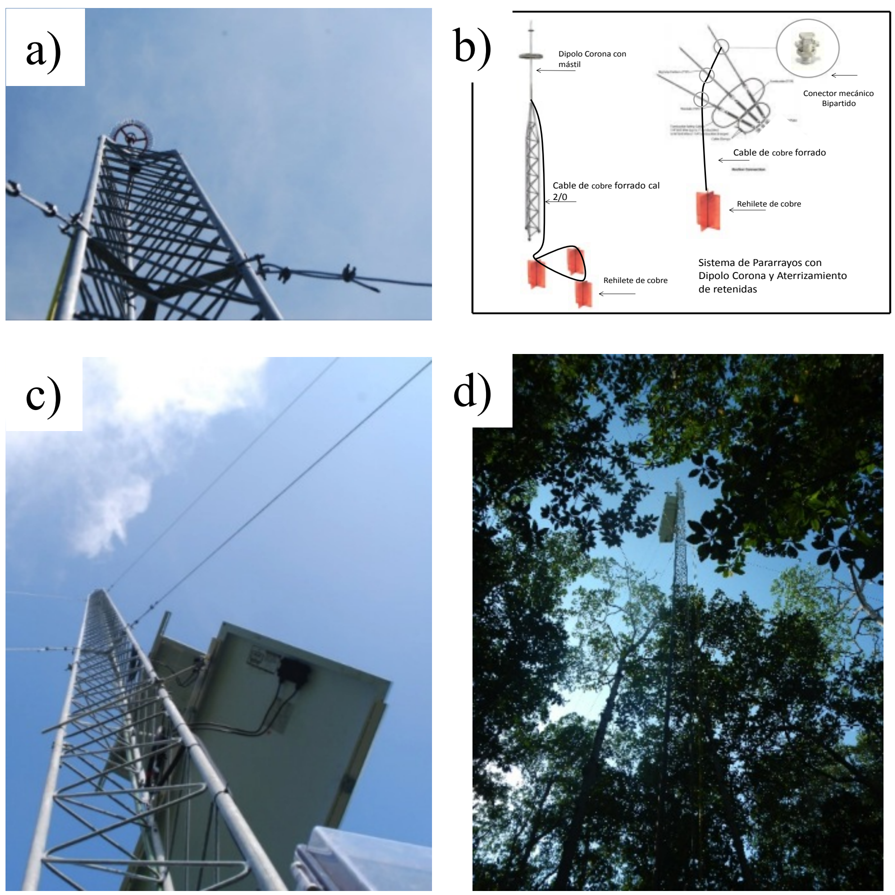

Figure 12. Tower views from different angles. a) "crown" installed for grounding; b) electrical diagram of the electrical ground system; c-d) views of the guide wires and installation of the solar panels.

A pulley system was installed to transport equipment and supplies up to the desired height. Pulley system (**Figure 13**) is stainless steel, and an outdoors plastic rope is used to transport equipment. The rope can be replaced by a stainless steel wire, although the current mechanism works fine at the moment.

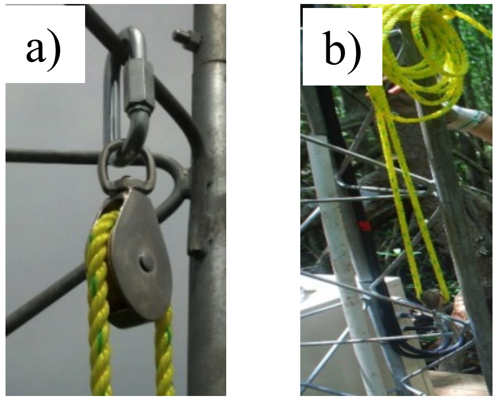

Figure 13. Pulley system showing the top (a) and bottom (b) anchor points.

4.1.3 Installation of energy supply

The energy supply system is composed of 3 subsystems. This was designed to avoid energy problems due to the power needs of the equipment; especially the methane (LI-7700) and the pump of the CO_2/H_20 (LI-7200) sensor.

The Biomet subsystem is composed by: one 85 watts solar panel, one 10 amp charge controller, one 110 AH 12 volts deep cycle AGM battery. This system maintains the ancillary meteorological instruments such as air temperature, relative humidity, net radiation, etc.

LI-7700 subsystem is composed by: one 150 watts solar panel, one 20 amp charge controller, two 110 AH 12 volts deep cycle AGM battery (total AH= 220). This system maintains the methane sensor (LI-7700).

LI-7200/7550 & anemometer subsystem is composed by: two 150 watts solar panel, one 20 amp charge controller, and four 110 AH 12 volts deep cycle AGM battery (total AH= 440). This system maintains the LI-7200/7550 and the sonic anemometer.

The complete system is powered by solar panels facing south (**Figure 14a**), a power distribution box (**Figure 14b**), and the deep cycle backup battery pack (**Figure 14c**). *The University of Delaware paid for the installation of the solar panels and the 3 electrical power subsystems for the proper functioning of the eddy covariance tower at La Encrucijada.*

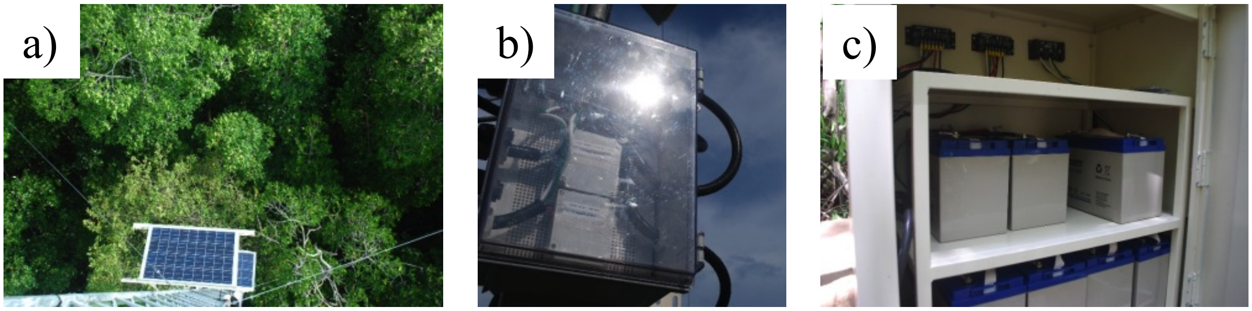

Figure 14. Solar power system including solar panels (a), power distribution box (b), and deep cycle backup battery pack (c).

4.2 Instrument installation

The EC instruments were installed using the same pulley mechanism as the one used to transport the material for the construction of the tower. In **Figure 15a** we show the guide wire, and **Figure 15ba** shows the bucket used to transport the equipment up the tower.

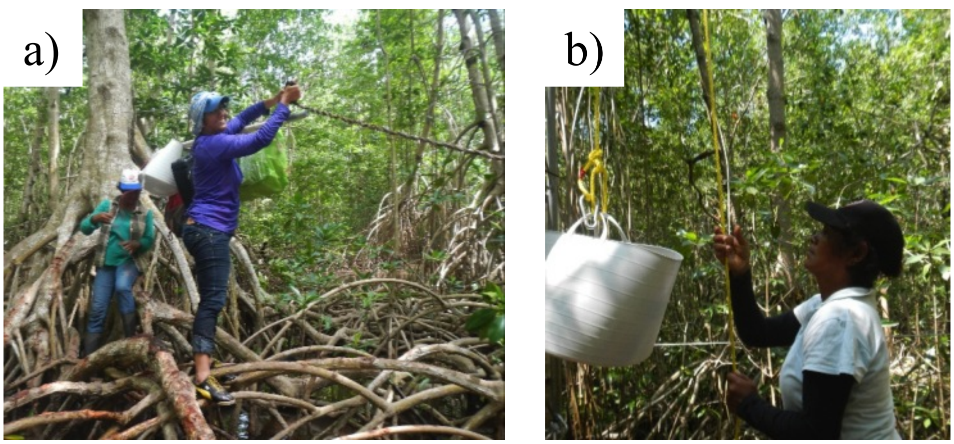

Figure 15. Installation process of the eddy covariance and associates biometeorological instruments showing the guide wire to transport the instruments to the base of the tower (a), and the pulley system to lift the instruments to the top of the tower (b).

<u>EC instrumentation</u>

Equipment is installed just above the last guide wire, at 37 m above the soil and 17 m above the canopy line. The average canopy height is 18 m, displacement height is 12.73 m, and roughness length is 2.85 m, these heights have an influence on the wind turbulence due to roughness and shear.

The instrumentation installed at the SMIC La Encrucijada includes infrared gas analyzers (IRGA) CO_2/H_2O (LI-7200) and methane (LI-7700), these instruments give the concentration of gases in a given area in a given time. Next to this IRGA we have a sonic wind anemometer to measure wind speed and direction (**Figures 16, 17**). With these two instruments, physical and mathematical assumptions, and Reynolds decomposition we calculate the flux from the ecosystem to the atmosphere and vice versa using the covariance of the wind speed and concentration of our gas of interest. Additional to flux information, wind sensor provides speed and direction, and in combination with shear footprint can be estimated. This is important to know exactly where the flux is coming from.

Because environmental parameters influence and drive processes in the ecosystem, supplemental measurements are made. These include radiation, relative humidity, pressure, air temperature, soil moisture, soil temperature, salinity, water level, soil heat flux (**Figure 18, 19**).

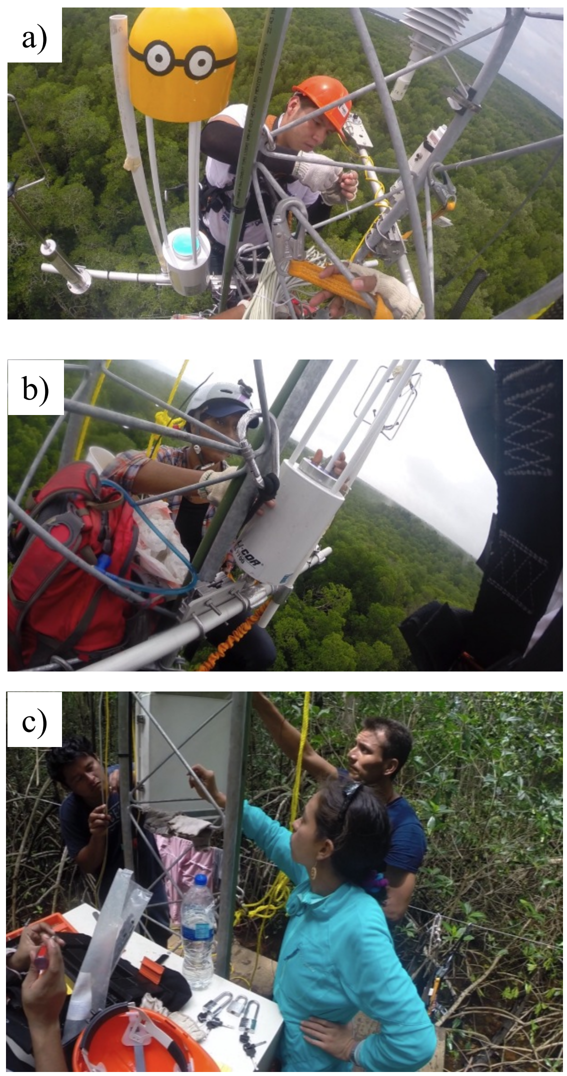

Figure 16. Installation of a) LI 7200 CO_2/H_2O sensor, b) LI-7700 methane sensor, c) datalogger box for biometrorological sensors.

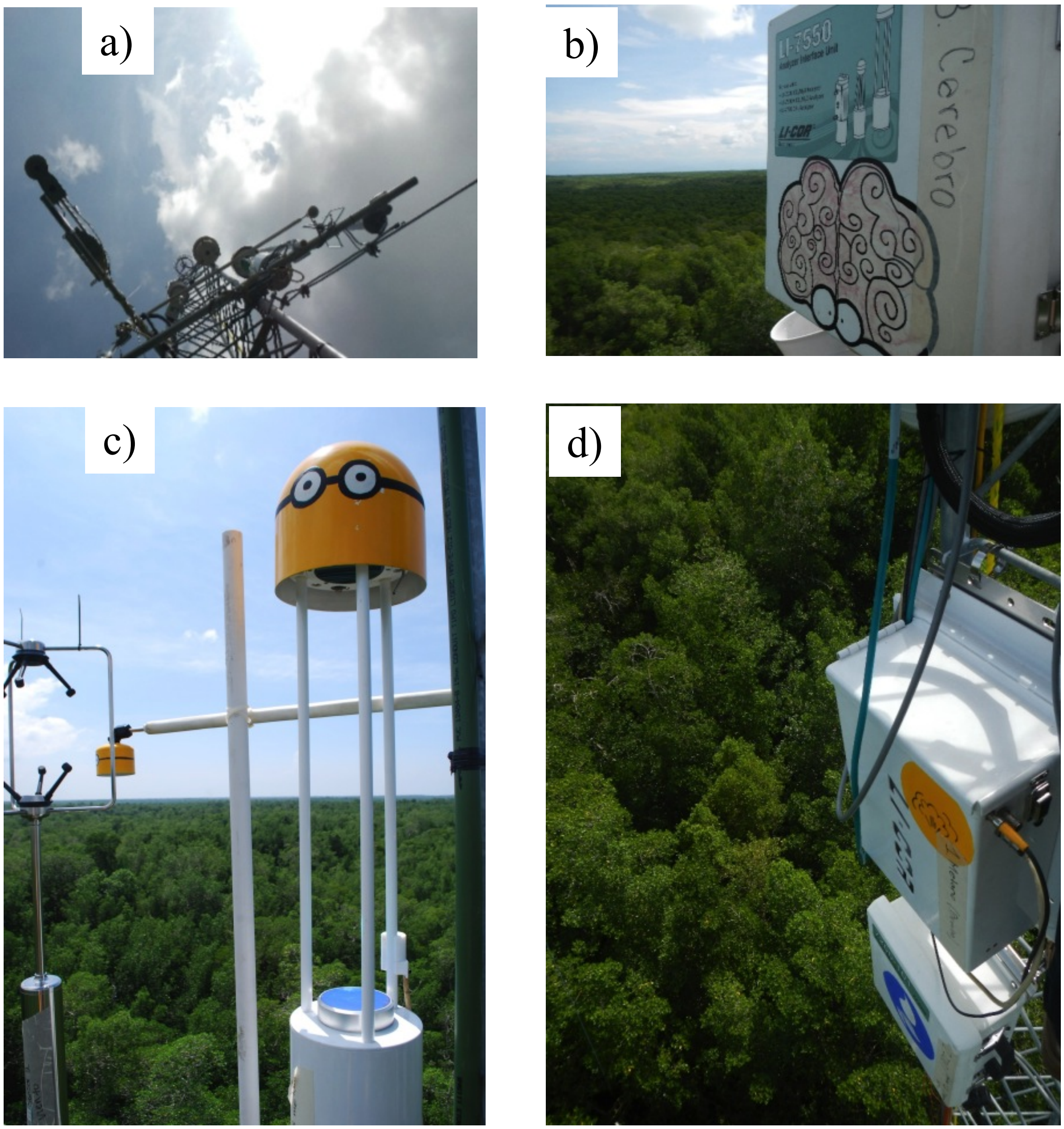

Figure 17. Detailed view of micrometeorological sensors in the eddy covariance tower. a) upside down view of sensors GEI system and biomet; b) main datalogger of the system LI 7550; c) side view of methane, CO_2 and wind sensor; d) IRGA pumps.

Figure 18. Meteorological sensors including: a) 4 way radiation sensor for long and shortwave incoming and outgoing, and photosynthetic active radiation sensor; b) rain gauge; c) relative humidity and air temperature sensor.

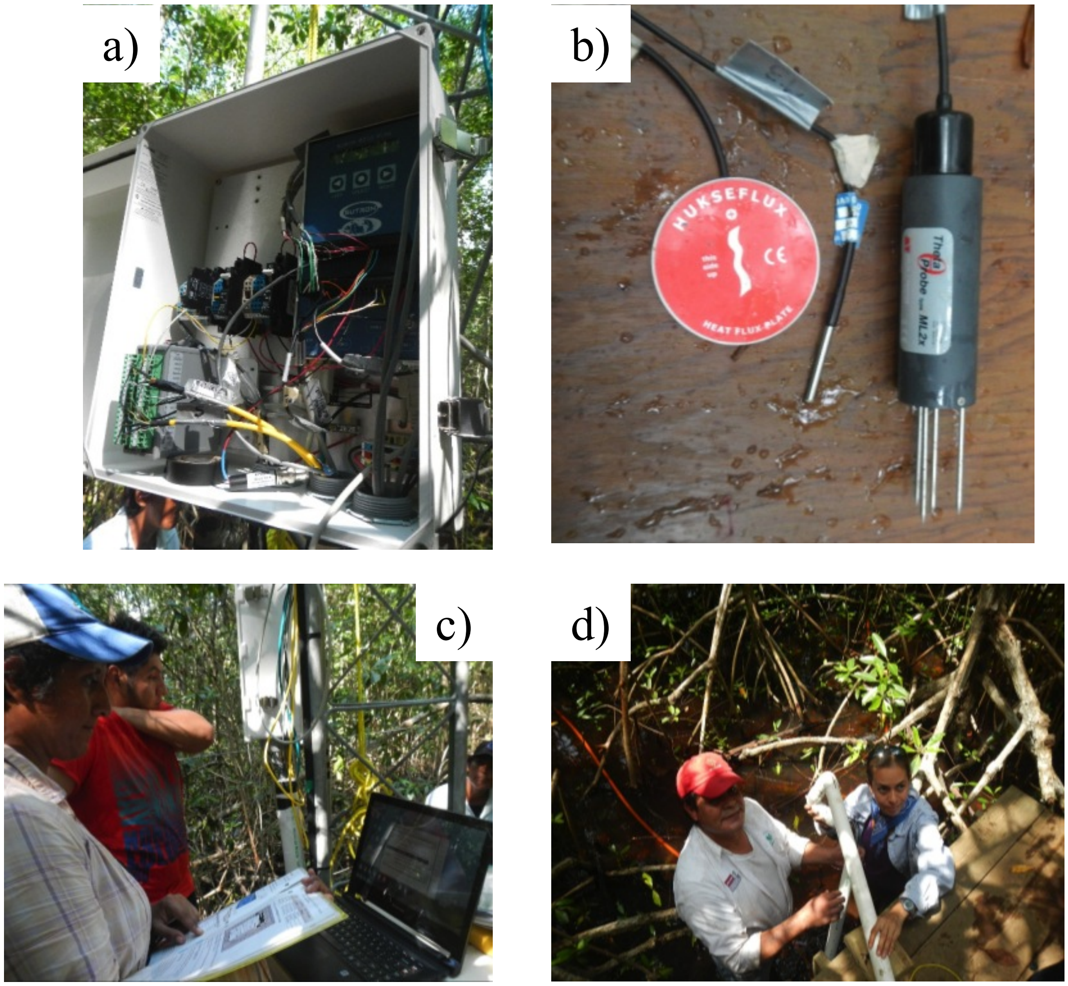

Figure 19. Detailed view of sensors and installation of ancillary sensors at the eddy covariance tower in La Encrucijada. a) biomet data logger where supplemental sensors are installed; b) soil sensors; c) programing of data logger; d) soil sensor protection installation.

In this eddy covariance tower, the main data logger is the LI-7550, however, the biomet data logger Sutron Xlite 9210 is recording information as well as a backup. The advantage is that the LI-7550 stores all raw data in one single file .ghg and this format is convenient for storage and processing.

To program, calibrate, store, download and process data six different software programs are needed for this eddy covariance system in La Encrucijada (**Figure 20**).

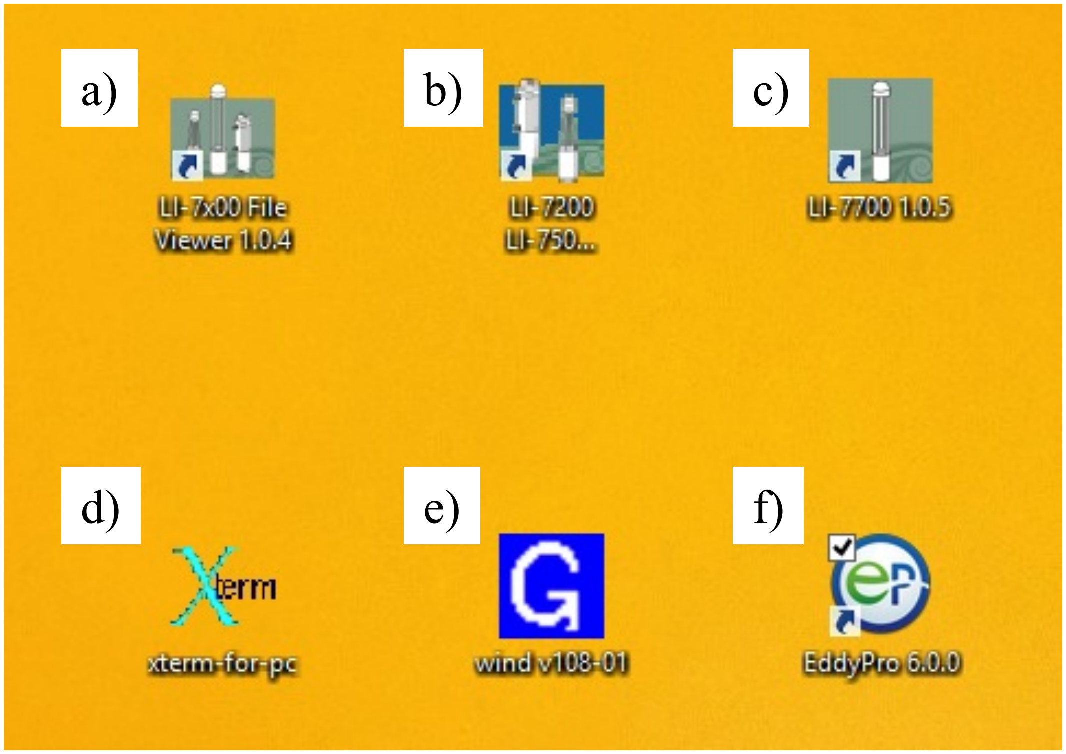

Figure 20. Programs needed to manage the SMIC La Encrucijada eddy covariance system. a) program used to load and graph the raw 10 Hz data using the .ghg file; b) program used to set up the system, calibrate the LI-7200, log data, save configuration file for the system; c) program to calibrate the methane LI-7700 sensor; d) program to communicate with biomet data logger Sutron Xlite 9210; e) program to configure the wind Gill Wind Mater Pro sensor; f) program to process data. Programs a),b),c), and f) can be directly downloaded from LICOR web page, while program d) from the Sutron web page, and e) from the Gill web page. Depending on the computer used in the field, when using the adaptor RS-232 to connect sensors to usb, a driver should be installed.

A critical part besides energy supply is the configuration process which is done using program (b) form **Figure 20**. One can use Ethernet or RS-232 (**Figure 21a**) port to connect (**Figure 21b**), once the connection is stablished configuration of settings, and site setup are the steps to follow. The site setup will be saved as metadata to use in EddyPro therefore its important to double check this step (detailed information in LICOR manuals).

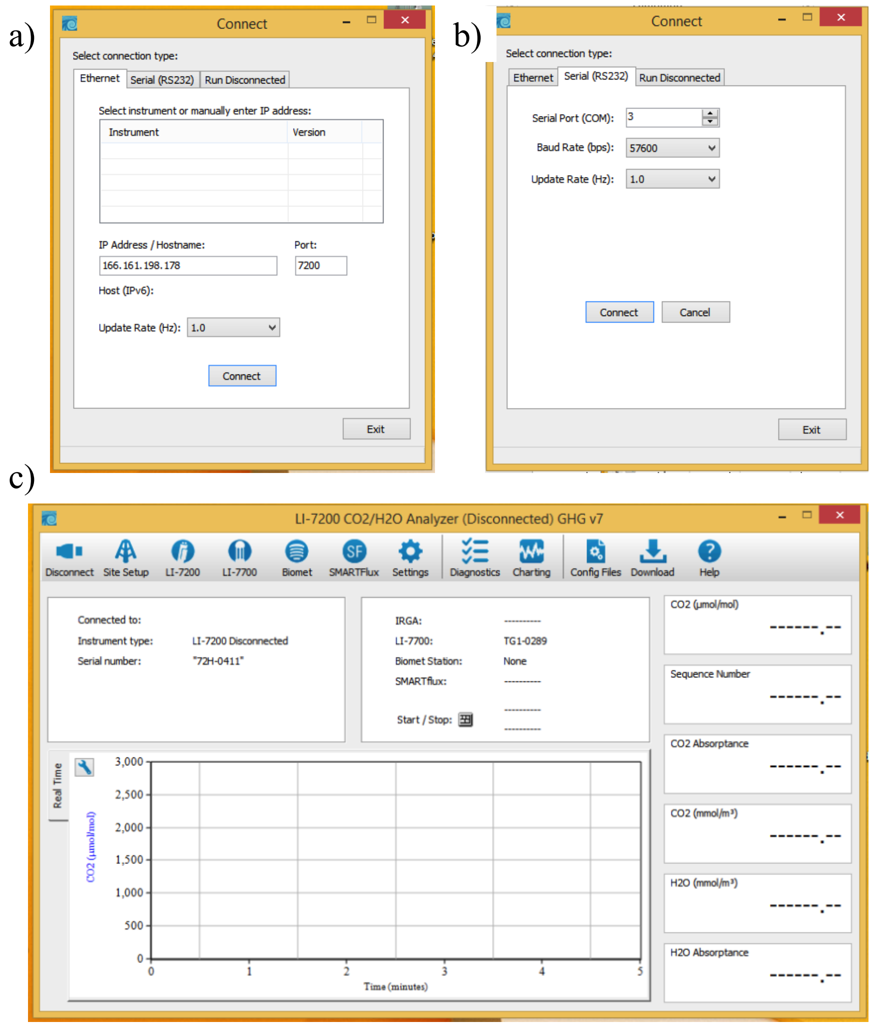

Figure 21. Main steps of configuration process, a, b) connecting to the eddy covariance system, c) configuration of settings and set up.

A detailed description of the instrumentation used at the eddy covariance tower, and basic guidelines on how to operate the instrumentation can be found in Annex 6. The University of Delaware disclaims that Annex 6 should NOT be considered a manual, since every program and each sensor already has one. Annex 6 should be considered a basic guideline so that a technician and collaborations can communicate about topics concerning the instrumentation, data analyses, processing, and storage. The information included in Annex 6 must continue to improve as needed at ECOSUR.

4.3. Eddy covariance database

The University of Delaware uses standardized protocols for archiving and processing eddy covariance data. The used protocols are freely available in international repositories such as the AmeriFlux network (http://ameriflux.lbl.gov) and FLUXNET (http://fluxnet.fluxdata.org). Furthermore, we advocate for standardization and data sharing, so data can be comparable, reproducible and useful within networks and among networks. Therefore, the University of Delaware suggests following these international protocols that have been adopted by the MexFlux network (Vargas and Yepez 2011, Vargas et al. 2012, Vargas et al. 2013).

Detail descriptions of the datasets are reported in Annex 7. Here is a description of the metadata and to be more useful to the end-user we present this information in Spanish.

Table 1. General description of the eddy covariance database

Sitio	**Sitio de Monitoreo Intensivo de Carbono La Encrucijada**
Proyecto	Monitoreo de gases de efecto invernadero en el manglar de la reserva de la biósfera La Encrucijada, Chiapas México
Última modificación a metadatos	23 de octubre de 2015
Investigador(es) responsable(s)	Rodrigo Vargas (University of Delaware, USA) Cristian Tovilla (El Colegio de la Frontera Sur, México)
Email	rvargas@udel.edu, ctovilla@ecosur.mx
Teléfono	rvargas: (302) 831-1386 USA; ctovilla: (962) 628-9800 MX
Otros participantes	Zulia M. Sanchez-Mejia (UDEL) Dulce Infante-Mata (ECOSUR)
Ubicación geográfica	Reserva de la Biosfera La Encrucijada, Chiapas Mx
Latitud y longitud	15° 11' 17.805" N, 92° 50' 0.459" W
Coordenadas UTM	Zona 15P, Easting 517888.46, Northing 1679157.49
Elevación	13 msnm
Municipio, Estado	Acapetahua, Chiapas, Mexico
Tipo de ecosistema	Manglar
Altura del dosel	19 m
Clasificación Climática	Ax2 cálido subhúmedo (Köppen)
Tipo de Suelo (FAO)	Solonchak (50%), Regosol (30%), Cambisol (20%)
Historia de manejo o perturbaciones	No hay actividades de manejo. Bosque primario. Huracán Stan 2005
Descripción del proyecto	El objetivo general es caracterizar el intercambio de energía, vapor de agua, CO2, y CH4 entre un humedal costero y la atmósfera. Los humedales costeros han sido poco estudiados, y por ello la importancia de establecer un sitio de monitoreo en vegetación de manglar. De igual forma se monitorean las variables ambientales que controlan el intercambio a diferentes escalas temporales.

Fecha de inicio de operaciones	2 de Octubre del 2015
Contacto	Cristian Tovilla
Email	ctovilla@ecosur.mx
Teléfono	

All available data has been processed into half-hour time-steps and missing values have been reported as NAN (not a number). All data are reported in .cvs files (comma delimited), processed using EddyPro (Licor, Lincoln, NE). All eddy covariance files are reported as site name, initial half hour and final half hour (i.e., smic.encrucijada_flux_mmddyyyyhhhh-mmddyyyyhhhh.csv). All meteorological files are reported ast .txt files with site name, initial half hour and final half hour (i.e., (smic.encrucijada_biomet_mmddyyyyhhhh- mmddyyyyhhhh.txt). See Annex 7 for details. Tables 2 and 3 describe the variables stored in the eddy covariance fliles (i.e., flux) and the meteorological files (i.e., biomet).

Table 2. Description of the variables stored in the eddy covariance fliles (i.e., flux)

Variable	Unidades	Descripción
YEAR	yyyy	year
DTIME	ddd.ft	Julian day and fractional time
DOY	ddd	Julian day
HRMIN	hhmm	Half and hour and minutes
CO2	µmol CO2 mol-1	Carbon dioxide (CO2) mole fraction
H2O	mmol H2O mol-1	Water (H2O) vapor mole fraction
CH4	nmol CH4 mol-1	Methane (CH4) mole fraction
FC	µmol CO2 m-2 s-1	Carbon dioxide (CO2) flux
FH2O	µmol H2O m-2 s-1	Water vapor (H2O) flux
FCH4	nmol CH4 m-2 s-1	Methane (CH4) flux
Fetch_max	m	Distance at which footrprint contribution is maximum
Fetch_90	m	Distance at which footprint cumulative probability is 90%
Fetch_55	m	Distance at which footprint cumulative probability is 55%
Fetch_40	m	Distance at which footprint cumulative probability is 40%
H	W/m^2	Sensible heat flux
LE	W/m^2	Latent heat flux
G	W/m^2	Soil heat flux
WD	Decimal degrees	Wind direction
WS	m s-1	Wind Speed
USTAR	m s-1	Friction velocity
ZL	adimensional	Stability parameter
u*	m s-1	Momentum flux
RH	%	Relative humidity
VPD	hPa	Vapor Pressure Deficit
TA	Deg C	Air temperatura

Table 3. Description of the variables stored in the meteorological fliles (i.e., biomet)

Variable	Unidades	Descripción
Date	mm/dd/yyy	Month/day/year
Time	HH:MM:SS	Hour and minute averaged
SWC_1_1_1	m3/m3	Soil moisture
SWC_2_1_1	m3/m3	Soil moisture
SWC_3_1_1	m3/m3	Soil moisture
Ts_1_1_1	C	Soil Temperature
Ta_1_1_1	C	Water Temperature
PPFD_1_1_1	$\mu mol/(m^2\ s)$	PAR (400-700 nm) incoming
Ta_1_1_1	C	Air Temperature
RH_1_1_1	%	Relative humidity
P_rain_1_1_1	mm	Precipitation
Rn_1_1_1	W/m^2	Net Radiation
SWin_1_1_1	W/m^2	Shortwave radiation incoming
SWout_1_1_1	W/m^2	Shortwave radiation outcoming
LWin_1_1_1	W/m^2	Longwave radiation incoming
LWout_1_1_1	W/m^2	Longwave radiation outcoming
SHF_1_1_1	W/m^2	Soil heat flux
SHF_2_1_1	W/m^2	Soil heat flux
SHF_3_1_1	W/m^2	Soil heat flux

All available datasets are reported in Annex 8 and 9. Annex 8 represents available "flux" data and Annex 8 represents available "biomet" data.

Preliminarily results show a strong diurnal pattern of carbon assimilation between 8 am and 5 pm at La Encrucijada (**Figure 22, Annex 10**). The high emission rates of CO_2 between 6 and 8 am could be a result of canopy CO_2 storage, which is a common effect in forests with dense canopies. The only way to solve this issue is to purchase a CO_2 profile system to account for CO_2 storage, but this will require significant investment and power supply. Although, this is an important issue to understand carbon dynamics, the University of Delaware would not recommended as a priority because of power limitations and high purchasing costs.

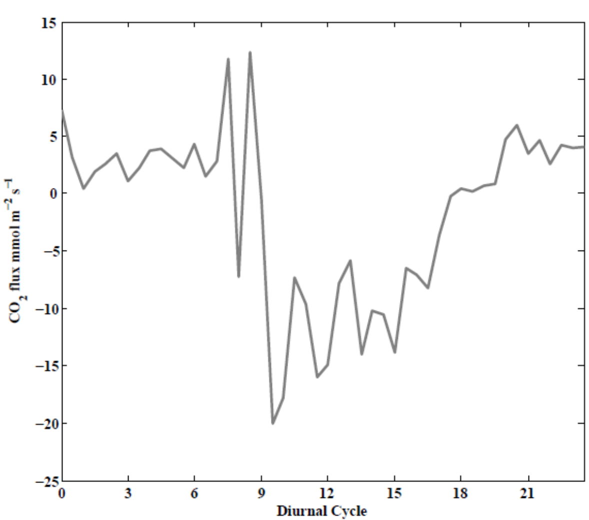

Figure 22. Diurnal pattern of CO_2 fluxes (NEE; net ecosystem exchange) at La Encrucijada.

4.4. Litterfall database

We selected 11 sites around the core protected area of the LEBR (Table 1) following a gradient from inland to coastline. Average tree height in this area is 26.7 ± 3.9 m, while DBH is 28.17 ± 5.35 cm, sites with *R. mangle* have an average root height of 3.2 ± 0.5 m. Seven sites are dominated by *R. mangle*, with sporadic presence of *A. germinans*, *Pachira aquatica*, *Ficus sp.*, and lianas (Table 4). Four sites are mixed mangrove forest with presence of *A. germinans* and *L. racemosa.* Sampling of litter and measurements of environmental variables were conducted monthly from August 2000 to August 2003.

Detail descriptions of the datasets are reported in Annex 11. Here is a description of the metadata and to be more useful to the end-user we present this information in Spanish.

Table 4. General description of the litterfall database

Sitio	**Sitio de Monitoreo Intensivo de Carbono La Encrucijada**
Proyecto	Caracterizar el rol de los manglares en el ciclo del carbono y las variables ambientales que controlan procesos como la productividad de hojarasca
Última modificación a metadatos	23 de octubre de 2015
Investigador(es) responsable(s)	Cristian Tovilla (El Colegio de la Frontera Sur, México) Rodrigo Vargas (University of Delaware, USA)
Email	rvargas@udel.edu, ctovilla@ecosur.mx
Teléfono	rvargas: (302) 831-1386 USA; ctovilla: (962) 628-9800 MX
Otros participantes	Zulia Sanchez-Mejia Alma D. Vázquez-Lule Domingo Alcaraz-Segura
Ubicación geográfica	Reserva de la Biosfera La Encrucijada, Chiapas Mx
Latitud y longitud	La Encrucijada cubre un área de 144, 848 ha entre las coordenadas extremas 14.77° y 15.56 ° de latitud y -92.46° y -93.34° de longitud.
Elevación	13 msnm
Municipio, Estado	Acapetahua, Chiapas, Mexico
Tipo de ecosistema	Manglar
Altura del dosel	19 m
Clasificación Climática	Ax2 cálido subhúmedo (Köppen)
Tipo de Suelo (FAO)	Solonchak (50%), Regosol (30%), Cambisol (20%)
Historia de manejo o perturbaciones	No hay actividades de manejo. Bosque primario. Huracán Stan 2005
Descripción del proyecto	El objetivo general es caracterizar la dinámica de hojarasca y las variables ambientales que controlan esta productividad. La producción de hojarasca es uno de los componentes de flujos laterales y verticales (hacia el suelo) de carbono en estos humedales costeros.
Fecha de inicio de operaciones	Agosto de 2000
Fecha de inicio de operaciones	Agosto de 2003

Contacto	Cristian Tovilla
Email	ctovilla@ecosur.mx

Table 5. Name and location of sites used for collection of litterfall in the standardize database

	Sitio	Tipo	Coordenadas	Vegetación	Estructura	Suelo
1	Rio Vado Ancho 1	ripario	15°8' 36.23"N 92°44'30.39"O	*R. mangle (99%)* *R. harrisonii* *P. aquatica* *Ficus*	Altura: 33.5 m DAP: 33.7 cm Altura de raíz: 3.2 m	limo-arcilloso
2	Rió Vado Ancho 2	ripario	15°8' 44.09"N 92°44'42.97"O	*R. mangle*	Altura: 26.5 m DAP: 26.2 cm Altura de raíz: 2.47m	limo-arcilloso
3	Laguna de Panzacola	ripario	15°6' 45.92"N 92°45'6.29"O	*R. mangle (99%)* *R. harrisonii*	Altura: 30 m DAP: 29.7 cm Altura de raíz: 2.89m	limo-arcilloso
4	Laguna de Cerritos 1	ripario	15°9'6.07"N 92°45'45.18"O	*R. mangle*	Altura: 29 m DAP: 28.5 cm Altura de raíz: 2.54m	limo-arcilloso
5	Laguna de Cerritos 2	ripario	15°9'8.11"N 92°45'9.58"O	*R. mangle*	Altura: 25.5 m DAP: 28.5 cm Altura de raíz: 1.75m	areno-francoarcilloso
6	Laguna de Teculapa	ripario	15°9'34.64"N 92°46'45.60"O	*R. mangle (68%)* *L. racemosa (32%)*	Altura: 30.5 m DAP: 27.6 cm Altura de raíz: 1.81m	areno-francoarcilloso
7	El Estero	ripario-borde	15°10'7.82"N 92°49'0.42"O	*R. mangle (69%)* *L. racemosa (31%)*	Altura: 26.5 m DAP: 24.3 cm Altura de raíz: 1.62m	areno-francoarcilloso
8	La Palma	cuenca	15°10'49.95"N 92°50'17.16"O	*A. germinans (63%)* *L. racemosa (37%)*	Altura: 18.5 m DAP: 17.2 cm Altura de raíz: NA	areno-limoso
9	Santa Chila	ripario-borde	15°10'22.85"N 92°51'18.95"O	*R. mangle (92%)* *A. germinans (9%)*	Altura: 22.5 m DAP: 28.4 cm Altura de raíz: ND	areno-limoso
10	Barra de San Juan 1	ripario-borde	15°10'8.86"N 92°51'16.79"O	*R. mangle (93%)* *A. germinans (7%)*	Altura: 27.5 m DAP: 25.9 cm Altura de raíz: ND	areno-limoso
11	Barra de San Juan-Playa	borde	15° 9'16.11"N 92°51'1.93"O	*A. germinans (53%)* *R. mangle (33%)* *L. racemosa (14%)* *Hibiscus tilliaceus*	Altura: 24.5 m DAP: 39.9 cm Altura de raíz: ND	francoarenoso

Enhanced Vegetation Index (EVI) 16-day composites (MODIS Terra, MOD13Q1, spatial resolution 250 m) were downloaded from Land Processes Distributed Active Archive Center (LP DAAC, https://lpdaac.usgs.gov/). Pre-processing of this product was performed with the MODIS Reprojection Tool (MRT). Each 16-day composite subset was obtained using extreme coordinates (upper left: 462000, 1725000, and low right: 553000, 1635000) and projected to 15 N UTM (Universal Transversal Mercator) with a WGS84 datum. Mangrove EVI descriptive statistics and timeseries was used for further analyses in this study.

Annex 12 contains the .cvs file with all variables stored in this database. Furthermore, these variables are being used to write a scientific work as a deliverable of this agreement (Sánchez-Mejía in preparation; Annex 13).

Table 6. Description of the variables stored in the meteorological fliles (i.e., biomet)

Variable	**Unidades**	**Descripción**
Año	yyyy	Año de muestreo
Mes	mm	Mes de muestro
Día	ddd	Día de muestreo
JDía	jdjdjd	Día juliano de muestreo
T_7320	C	Datos diarios de temperatura de la estación 7320
PP_7320	mm	Datos diarios de precipitación de la estación 7320
T_1 a T_11	C	Temperatura para cada sitio
SI_1 a SI_11	o/oo	Salinidad intersticial para cada sitio
S_1 a S_11	o/oo	Salinidad superficial para cada sitio
HR_1 a HR_11	%	Humedad relative para cada sitio
pH_1 a pH_11	dimensional	pH para cada sitio
Nivel_1 a Nivel_11	cm	Nivel de inundación, si el nivel es freático el valor es negativo
MO_1 a MO_11	%	Materia orgánica
Hojarasca_1 a Hojaraaca_11	gr m^{-2}	Peso seco de la cantidad de hojas colectadas en las trampas
EVI_1 a EVI_11	dimensional	Enhanced Vegetation Index

4.5. Capacity Building

The University of Delaware participated in capacity building using formal and informal interactions.

Informal interactions were mainly focused on personnel of ECOSUR to train students and technicians to install and maintain the eddy covariance tower at La Encrucijada. The goal was to transfer technology and knowledge to empower personnel at ECOSUR to be responsible in the long-term of the instrumentation, data processing, and eventual data analysis and publication of results and generation of knowledge. Personnel of ECOSUR is expected to maintain the tower once the postdoctoral researcher installed the tower and returned to the University of Delaware (in November 2015) as described in the “Mentoring Plan”. Dr. Sánchez-Mejía devoted time and efforts for informal training of a technician (Eder A. Hernández-Martínez) who, to the best of our knowledge, is responsible to the day-a-day mantainance of the tower and data processing. Proven record of this training is Annex 6, a document containing guidelines for sensor installation and data processing prepared by Dr. Sánchez-Mejía and Eder A. Hernández-Martínez.

Formal interactions were focused on workshops (i.e, “Talleres”) at ECOSUR. The University of Delaware actively participated in coordinating two workshops.

The first workshop was entitled *“Taller de capacitación en el monitoreo de gases de efecto invernadero (CO_2/H_2O, CH_4) en el ecosistema de manglar, empleando la técnica de covarianza de vórtices (EC, eddy covariance)”* (October 29-31, 2015; see Annex 14). The specific objectives for this workshop were:

1) Define the role of the EC system at the SMIC La Encrucijada
2) Define the basic concepts of the EC technique
3) Define the utility of the EC in context of ecological processes at different scales
4) Define the utility of the EC in context of REDD+ and decision making
5) Describe challenges and needs to implement the EC technique
6) Provide a general introduction of EC data processing and data interretation
7) Site visit at the SMIC La Encrucijada

A detailed agenda for this workshop is provided in Annex 14, and presentations from this workshop can be found in Annex 15.

The second workshop was entitled *“Curso-Taller de Capacitación en Seguridad para la operación de la Torre de Covarianza de Vórtices*” (December 3-5, 2015). This workshop was lead by Dr. Dulce Infante Mata of ECOSUR in collaboration with a consortium of institutions including the University of Delaware. A description of this workshop was provided by Dr. Dulce Infante Mata:

“As part of the implementation of the SMIC La Encrucijada, Chiapas, the United States Forest Service (USFS), the United States Agency for International Development (USAID) the SilvaCarbon Program and the Mexican Fund for the Conservation of Nature AC (FMCN) in coordination with the Colegio de la Frontera Sur (ECOSUR), held from 3 to 5 December the “Curso-Taller de Capacitación en Seguridad para la operación de la Torre de Covarianza de Vórtices”, with the instructor Robert Evans

from the US Forest Service Research. Project leaders were ECOSUR by Dr. Cristian Tovilla Hernandez and Dra. Dulce Maria Infante Mata, in collaboration with Dr. Zulia Sanchez and Dr. Rodrigo Vargas of the University of Delaware".

With the completion of this training the participants had the opportunity to become certified in safety techniques for working at heights, thus fulfilling the protocols to follow up monitoring work at the eddy covariance tower at La Encrucijada (**Figure 23**).

Participants included
Mexico
Juan Carlos de la Presa
Eder Andreí Hérnandez
Gerardo de la Cruz Montes
Rubén García Alfaro
Matilde Rincón
Cristina Contreras Meda

Ecuador
Guillermo Sánchez Rueda
Gabriela Vinueza
Angel Aguilar

Colombia
Lina María Peláez

SIlva-Carbón-USFS
Craig Wayson

USFS-IP México
Rafael Flores Hernández

Figure 23. Workshop participants at ECOSUR. "Curso-Taller de Capacitación en Seguridad para la operación de la Torre de Covarianza de Vórtices" (December 3-5, 2015).

4.6 Scientific contributions

Dr. Sánchez-Mejía has shared her research on scientific meeting, workshops, and formal peer-reviewed publications. Here is a list of current products.

Publications in preparation

Sánchez-Mejía ZM, Tovilla C., Vazquez-Lule Alma D, Colditz R., **Vargas R**. Litterfall contributions to carbon dynamics in mangrove ecosystem, Chiapas. In preparation for: Ecosystems (Annex 13)

Oral presentations

Sánchez-Mejía ZM, Vargas_terminel ML, Rodriguez RC, Yepez E, **Vargas R**. *Flujos de carbono azul en México: intercambio de gases de efecto invernadero entre el manglar y la atmósfera.* Mexican Carbon Program (PMC, Programa Mexicano del Carbono)- VI International Carbon Symposium in México. May 20-22, *2015.* Villahermosa, Tabasco, México (Annex 16)

Sánchez-Mejía ZM. *Olfateando gases de efecto invernadero: monitoreo con covarianza de vórtices*. 2nd Seminar on Water and Forest Resources. April, 2015. Universidad Autónoma de Chiapas, Facultad de Ciencias Agrícolas Campus IV Huehuetán, Chiapas, México. (Annex 17)

Poster presentations

Sánchez-Mejía ZM, Tovilla C, Infante-Mata DM, Birdsey R, Aguilar E, Castro L, Ochoa-Avelar C, Olguín M, Velasco E, Wayson C, **Vargas R**. *Monitoreo en bosques de mangle: pre-instalacion de un sistema de covarianza turbulenta para medir flujos de carbono.* Mexican Carbon Program (PMC, Programa Mexicano del Carbono)- VI International Carbon Symposium in México. May 20-22, *2015.* Villahermosa, Tabasco, México (Annex 18)

Sánchez-Mejía ZM, Vázquez-Lule AD, Tovilla C, Colditz R, **Vargas R**. *Leaning into La Encrucijada Chiapas mangroves: NPP from ground measurements and MODIS*. North American Carbon Program AIM5. January 26-29, *2015*. Washington, DC, USA. (Annex 19)

4.7 Ending of contract of the postdoctoral researcher

Dr. Sánchez-Mejía started working at the University of Delaware in February of 2014 on topics related to SMIC La Encrucijada, and ended her contract on December 31st, 2015. The reason for ending her contract at that time was that she accepted a tenure-track faculty position at Instituto Tecnologico de Sonora (ITSON). Although she wanted to finish her 24-month appointment with the University of Delaware, the ITSON did not allow her to delay her new appointment. One of the priorities of the "Mentoring Plan" of the agreement between CONAFOR and the University of Delaware was prioritizing the professional development of the postdoctoral researcher. Thus, the fact that Dr. Sánchez-Mejía is now a tenure track faculty is a *major accomplishment of this agreement*. Dr. Sánchez-Mejía, now as an independent researcher, contributed to write this report and is engaged in activities for maintenance of the EC tower at La Encrucijada.

5. Lessons learned, recommendations and future efforts

The EC technique is a very powerful tool to measure the exchange of energy and matter between the land and the atmosphere. This information is extremely valuable for parameterization of ecosystem models, upscaling approaches, and to understand annual and short-term ecosystem responses. To the best of our knowledge there are two EC towers in short mangroves of Sonora, Mexico, but the tower at La Encrucijada is the only tower in Mexico in a tall mature mangrove forest. This opens unique opportunities to test this technology, the applicability of the data for GHG emissions, and to better understand the underlying ecophysiological mechanisms of mangrove forests.

That said, this technique is not the "silver bullet" and installation of EC systems must be taken very seriously as investments are high and maintenance is expensive and difficult. These costs and associated risks are higher in a coastal ecosystem subject to marine breeze and salt deposition, which increase corrosion and sensor degradation. There are many basic questions open for research, mainly in mangrove forests, that could be easily addressed with lower investment/technical costs (e.g., understanding how above and belowground stocks change with time) and using remote sensing products (e.g., Landsat and MODIS) and derived variables (e.g., net primary productivity, gross primary productivity). Preliminarily results show that MODIS products (i.e., EVI and NDVI) cannot represent canopy dynamics (i.e., litter production) but different algorithms (i.e., ecosystem functional types) could solve for spatial variability at this complex ecosystem (Annex 13). Future investments should consider a balance between costs and knowledge gain based on baseline information and potential outcomes (**Figure 24**).

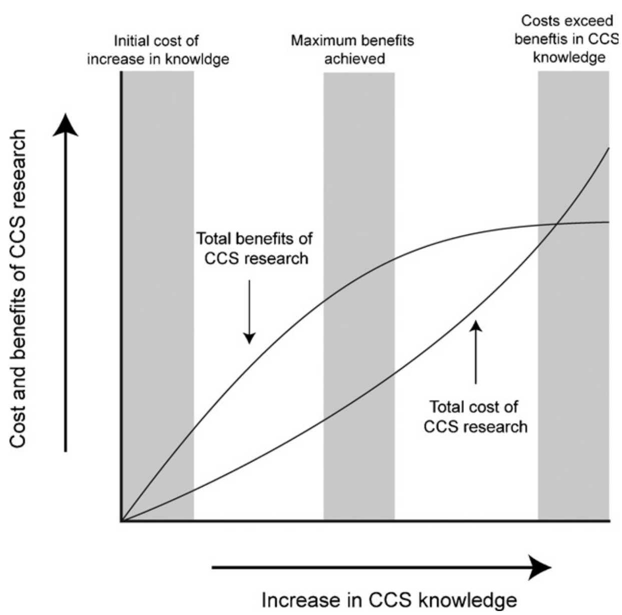

Figure 24. Schematic representation of relationship between cost–benefit of carbon cycle science (CCS) research and increase in CCS knowledge (Vargas et al 2012).

Lessons learned and recommendations are divided in technical and planning issues.

Technical issues

There are multiple challenges to maintain and operate the EC tower at La Encrucijada. They include the lack of human resources (i.e., long-term contract for a specialized technician), economic resources (to cover trips, maintenance, and replacement), and harsh weather conditions. The University of Delaware trained one technician at ECOSUR, and we expect that now that institution will take the lead on the long-term maintenance. The harsh weather conditions create specific challenges for this EC system. These include constant replacement of thermocouples and filters and constant cleaning of instrumentation mirrors and solar panels (monthly visits or more frequently when there are sensor failures). Each thermocouple for the LI7200 costs about $60 USD, and nearly $150 USD for the LI7700; the life of each thermocouple can vary from 3 weeks to 6 months, so it is clear that constant maintenance needs to be included in the planning. The University of Delaware purchased several thermocouples to help maintaining the site, but these may not last for over 1 year.

A major challenge for all Mex-SMIC sites is the lack of sensor calibration. All sites must calibrate for CO_2, H_2O, and in case of La Encrucijada for CH_4; calibration gases do not exist in Mexico and is a major goal of the MexFlux network. Salt deposition increase corrosion and sensor degradation, thus it is likely that sensors at La Encrucijada should be sent back to the manufacturer for calibration within one year. The manufacturer is outside Mexico so importation/exportation paperwork should be organized. The University of Delaware strongly recommends the transfer of ownership to the end user (i.e., ECOSUR) to have the capacity of sending the equipment for calibration, maintenance, or repair to the manufacturer in Lincoln, NE, USA. The University of Delaware is aware that the LI7200 installed at La Encrucijada could be upgraded to avoid “UV contamination” when opening the sensor to replace the thermocouple. This is not a critical upgrade but it is important to be aware of this. Importantly, the sonic anemometer is affected by a general software “bug” that could bias the readings up to 20%. This issue is not unique for La Encrucijada and affect many users, thus the FLUXNET community is recommending all owners of Gill anemometers to send them to the factory for calibration and upgrades. Finally, the wood of the boardwalk and the basement of the tower needs to be treated every year to reduce degradation and to prevent becoming a safety hazard; treatment should include a waterproof coating and anti-termite coating. Additionally, leaves should be removed to avoid humidity accumulation, prevent wood decay, and reduce walking hazards.

Planning issues

The construction of the boardwalk was a challenging issue, mainly due to delays in agreement and collaboration paper work. Low communication and slow transfer of information were the largest limitations for the timely installation of the boardwalk. The University of Delaware recommends that there should be improvements on administrative paper work and inter-institutional agreements. It is expected that future work could reach milestones in a timely manner, as many of the agreements and protocols have already been approved among institutions and within ECOSUR.

It is recommended to hire a company with administrative experience for installation of infrastructure (i.e., boardwalk, tower structure). It takes less time to hire a company using COMPRANET (Mexican

National System to hire companies), besides there is a guaranty bail that the company has to provide to ensure the quality of their work. This is not the case when there is an agreement between academic institutions, which are mostly focused on research.

The University of Delaware recommends designing a planning vision to keep hired the trained technician to maintain the tower in the long-term. Unfortunately, long-term (i.e., beyond project expectancies of 1-3 years usually) maintenance of monitoring sites and networks is always challenging. There are no easy solutions but the first step is to recognize these programmatic challenges as described for other networks in Mexico (Vargas et al 2012, 2013). On a positive note, the University of Delaware recommends to continue the outreach efforts to engage the local community at La Encrucijada. There is a risk of thief and vandalism that could destroy the infrastructure, so community engagement is critical at this site.

Overall recommendations

Maintaining the short-term (i.e., beyond 1 year) functionality of the tower at La Encrucijada will be very challenging. Assuming that there is a trained technician and there are no sensor failures (i.e., sensors need to be send for calibration or repair), the minimum maintenance costs should include transportation, thermocouple replacements, and filter replacements. Power supply is known to be a critical issue at the site, so adding 1 or 2 extra solar panels and multiple deep-cycle batteries is recommended. To reduce the power consumption, the University of Delaware reduced the cleaning cycle of the LI7700, which compromise electricity consumption for quality of data (i.e., less data storage of CH_4 concentrations). This is a known challenge for any EC tower using a LI7700 in remote environments. The selection of the LI7200 (not done by the University of Delaware) was likely done to increase the capacity of the sensor to measure under conditions with high relative humidity, but it has a pump (increasing energy consumption) and the associated costs of thermocouple failure. The University of Delaware recommends considering the purchase of an open path analyzer to reduce power consumption at this and other sites, although it is understandable that this decision is not possible.

Future efforts

The University of Delaware is committed to continue helping ECOSUR to maintain and operate the tower. The University of Delaware has trained a technician to maintain the EC tower and has advocated for external funding to extend the contract of this technician until August of 2016, but it is unknown the status of the contract. The University of Delaware and now the Institutio Tecnologico de Sonora (ITSON), where Dr. Sánchez-Mejía works, are interested in providing intellectual and economic support depending on availability of funds. Dr. Vargas is continuously applying for federal grants in the United States and has included La Encrucijada in one proposal to provide partial support if funded.

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