FDP Cost Reimbursement Foreign Research Subaward Agreement UMN CON #: 79619

Federal Awarding Agency: Other [Type in Agency]	U.S. Dept of Energy
Pass-Through Entity (PTE):	**Subrecipient:**
Regents of the University of Minnesota	Instituto de Investigaciones de la Amazonia Peruana
PTE PI: Tim Griffis	Sub PI: Dennis del Castillo Torres
PTE Federal Award No: DE-SC0020167	Subaward No: H007829704
Project Title: *Biophysical processes and feedback mechanisms controlling the methane budget of an Amazonian peatland*	
Subaward Period of Performance (Budget Period): Start: 09/01/2019 End: 08/31/2020	Amount Funded This Action (USD): $ 28,160.00
Estimated Project Period (if incrementally funded): Start: 09/01/2019 End: 08/31/2022	Incrementally Estimated Total (USD): $

Terms and Conditions

1. PTE hereby awards a cost reimbursable Subaward, as described above, to Subrecipient. The Statement of Work and budget for this Subaward are as shown in Attachment 5. In its performance of Subaward work, Subrecipient shall be an independent entity and not an employee or agent of PTE. No Party has the authority to bind any other Party in contract or to incur any debts or obligations on behalf of any other Party, and no Party (including an employee or other representative of such Party) shall take any action that attempts or purports to bind any other Party in contract or to incur any debt or obligations on behalf of any other Party, without the affected party's prior written approval.

2. Subrecipient shall submit invoices Monthly for allowable costs incurred. All invoices shall be submitted using PTE's standard invoice shown in Attachment 6, and shall include current and cumulative costs (including cost sharing information if applicable), Subaward number, and certification, as required in 2 CFR 200.415 (a). Invoices that do not reference PTE Subaward number shall be returned to Subrecipient. Invoices and questions concerning invoice receipt or payments shall be directed to the party's Financial Contact, shown in Attachment 3A. Expenditures of Subrecipient shall conform to budget in Attachment 5. All payments will be in U.S. Dollars.

3. A final statement of cumulative costs incurred, including cost sharing, marked "FINAL" must be submitted to PTE's Financial Contact, as shown in Attachment 3A, NO LATER THAN 45 Days after Subaward end date. The final statement of costs shall constitute Subrecipient's final financial report.

4. All payments shall be considered provisional and subject to adjustment within the total estimated cost, in the event such adjustment is necessary as a result of an adverse audit finding against the Subrecipient. Upon the receipt of proper invoices, the PTE agrees to process payments in accordance with this Subaward and 2 CFR 200.305.

5. Matters concerning the technical performance of this Subaward Agreement shall be directed to the appropriate party's Principal Investigator as shown in Attachments 3A and 3B. Technical reports are required as shown in Attachment 4:"Reporting Requirements"

6. Matters concerning the request or negotiation of any changes in the terms, conditions, or amounts cited in this Subaward Agreement and any changes requiring prior approval, shall be directed to the appropriate party's Authorized Official Contact, as shown in Attachments 3A and 3B. Any such change made to this Subaward requires the written approval of each party's Authorized Official, as shown in Attachments 3A and 3B.

7. The PTE may issue non-substantive changes (defined as: documentation of prior approvals, addition of non-competing continuation budget periods / funds and no cost extensions) to the Period of Performance and budget Unilaterally . Unilateral modifications shall be considered valid 14 days after receipt, unless otherwise indicated by Subrecipient. Requests for No Cost Extensions are as shown in Attachment 2.

8. Each Party shall be responsible for its negligent acts or omissions, and the negligent acts or omissions of its employees, officers, or directors, to the extent allowed by law.

9. Either Party may terminate this Subaward Agreement with 30 days written notice to the appropriate Party's Authorized Official Contact, as shown in Attachments 3A and 3B. PTE shall pay Subrecipient for termination costs as allowable under Uniform Guidance, 2 CFR 200, or 45 CFR Part 75 Appendix IX, "Principles for Determining Costs Applicable to Research & Development under Grants and Contracts with Hospitals" as applicable.

10. No Party shall be in default by reason of any failure in performance of this Subaward if such failure arises, directly or indirectly, out of causes *reasonably beyond the direct control or foreseeability of such Party*, including but not limited to, acts of God or of the public enemy, U.S. or foreign governmental acts in either a sovereign or contractual capacity, labor, fire, flood, epidemic and strikes.

11. By signing this Subaward, including the attachments hereto which are hereby incorporated by reference, Subrecipient certifies that it will perform the Statement of Work in accordance with the terms and conditions of this Subaward and the applicable terms of the Federal Award, including the appropriate Research Terms and Conditions ("RTCs") of the Federal Awarding Agency, as referenced in Attachment 2. The parties further agree that they intend this Subaward to comply with all applicable laws, regulations and requirements.

By an Authorized Official of Pass-through Entity:		By an Authorized Official of Subrecipient:	
Amy Bicek-Skog (Digitally signed by Amy Bicek-Skog; Location: University of Minnesota; Sponsored Projects Administration; 200 Oak Street SE, Suite 450; Minneapolis, MN 55455-2070; Date: 2019.12.05 13:40:23 -06'00')	5 Dec. 2019	[signature]	12/03/2019
Name: Amy Bicek-Skog	Date	Name: Ronald Trujillo León	Date
Title: Principal Grant Administrator		Title: Administrator	

Attachment 1
Certifications and Assurances

Subaward Number: H007829704

By signing the Subaward, the Authorized Official of Subrecipient certifies, to the best of his/her knowledge and belief, that:

Certification Regarding Lobbying (2 CFR 200.450)
No U.S. Federal appropriated funds have been paid or will be paid, by or on behalf of the Subrecipient, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any U.S. Federal contract, the making of any U.S. Federal grant, the making of any U.S. Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any U.S. Federal contract, grant, loan, or cooperative agreement.

If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or intending to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the Subrecipient shall complete and submit Standard Form -LLL, "Disclosure Form to Report Lobbying," to the PTE.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by 31 U.S.C. 1352. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Debarment, Suspension, and Other Responsibility Matters (2 CFR 200.213 and 2 CFR 180)
All foreign institutions and international organizations, except for foreign governments or governmental entities, public international organizations, or foreign-government-owned or -controlled entities (in whole or in part) are subject to the Debarment, Suspension and Other Responsibility Matters.

◉ Subrecipient certifies by signing this Subaward that neither it, nor its principals, are presently debarred, suspended, proposed for debarment, declared ineligible or voluntarily excluded from participation in this transaction by any U.S. Federal Department or Agency.

Or

○ Subrecipient is either a foreign government or governmental entity, public international organization, or foreign-government-owned or -controlled entity (in whole or in part); and it IS NOT subject to the debarment or suspension certification requirement or to debarment or suspension under 45 CFR Part 75.

Audit and Access to Records
Subrecipient certifies by signing this Subaward that it complies with the Uniform Guidance, will provide notice of the completion of required audits and any adverse findings which impact this Subaward Agreement as required by parts 200.501- 200.521, and will provide access to records as required by parts 200.336, 200.337, and 200.201 as applicable.

All financial and related documentation, including but not limited to financial reports, invoices, financial audits, or receipts, shall be provided to PTE in English at Subrecipient's expense.

Protecting Life in Global Health Assistance (Mexico City Policy)
Subrecipient certifies that no funds granted under this Subaward will be used to fund organizations or programs that support or participate in the management of a program of coercive abortion or involuntary sterilization. See the NOA, Attachment 2 of this Subaward and/or Federal Awarding Agency's terms and conditions for further details.

☐ This regulation applies to the Federal Award and is flowed down to Subrecipient.

Use of Name
Neither party shall use the other party's name, trademarks, or other logos in any publicity, advertising, or news release without the prior written approval of an authorized representative of that party. The parties agree that each party may use factual information regarding the existence and purpose of the relationship that is the subject of this Subaward for legitimate business purposes, to satisfy any reporting and funding obligations, or as required by applicable law or regulation without written permission from the other party. In any such statement, the relationship of the parties shall be accurately and appropriately described.

Subaward Number:

H007829704

Foreign Corrupt Practices

Subrecipient agrees to use funds in compliance with (1) the U.S. Foreign Corrupt Practices Act; (2) Subrecipient agrees that, under this Subaward, it will not offer, promise, or provide (or authorize the offer, promise, or provision of), directly or indirectly, anything of value to any government official, political party official, political candidate, or employee thereof, or to any other third party, for the purpose of obtaining or retaining business or obtaining any illegal benefit or advantage.

Export Controls

Each Party is responsible for determining whether its performance is subject to, and in compliance with, U.S. export control laws and regulations ("U.S. Export Controls"), including but not limited to the Export Administration Regulations - EAR (Department of Commerce), the International Traffic in Arms Regulations - ITAR (Department of State), the sanctions programs embodied in regulations administered by the Department of the Treasury's Office of Foreign Assets Control (OFAC), the U.S. anti-boycott laws and regulations (EAA) and U.S. anti-terrorism financing laws and regulations.

☐ Attachment 8 of this Subaward includes additional applicable terms related to Export Controls.

The Subrecipient shall require that the language of the certifications above in this Attachment 1 be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

Attachment 2
Federal Award Terms and Conditions

Subaward Number
H007829704

Required Data Elements

The data elements required by Uniform Guidance are incorporated in the attached Federal Award.

Federal Award Issue Date	FAIN	CFDA No.

CFDA Title

Key Personnel Per NOA

This Subaward Is:

■ Research & Development ■ Subject to FFATA

General Terms and Conditions

By signing this Subaward, Subrecipient agrees to the following:

1. To abide by the conditions on activities and restrictions on expenditure of federal funds in appropriations acts that are applicable to this Subaward to the extent those restrictions are pertinent. This includes any recent legislation noted on the Federal Awarding Agency's website:
   https://www.energy.gov/science/office-science
2. 2 CFR 200
3. The Federal Awarding Agency's grants policy guidance, including addenda in effect as of the beginning date of the period of performance or as amended found at:
   https://science.osti.gov/grants/Policy-and-Guidance
4. Research Terms and Conditions, including any Federal Awarding Agency's Specific Requirements found at:
   https://www.nsf.gov/awards/managing/rtc.jsp except for the following :
   a. No-cost extensions require the written approval of the PTE. Any requests for a no-cost extension shall be directed to the Administrative Contact shown in Attachment 3A, not less than 30 Days prior to the desired effective date of the requested change.
   b. Any payment mechanisms and financial reporting requirements described in the applicable Federal Awarding Agency Terms and Conditions and Agency-Specific Requirements are replaced with Terms and Conditions (1) through (4) of this Subaward; and
   c. Any prior approvals are to be sought from the PTE and not the Federal Awarding Agency.
   d. Title to equipment as defined in 2 CFR 200.33 that is purchased or fabricated with research funds or Subrecipient cost sharing funds, as direct costs of the project or program, shall vest in the Subrecipient subject to the conditions specified in 2 CFR 200.313.
   e. Prior approval must be sought for a change in Subrecipient PI or change in Key Personnel (defined as listed on the NOA).
5. Treatment of program income: Additive

This section intentionally left blank

Special Terms and Conditions:

Copyrights:

Subrecipient Grants to PTE an irrevocable, royalty-free, non-transferable, non-exclusive right and license to use, reproduce, make derivative works, display, and perform publicly any copyrights or copyrighted material (including any computer software and its documentation and/or databases) first developed and delivered under this Subaward solely for the purpose of and only to the extent required to meet PTE's obligations to the Federal Government under its PTE Federal Award.

Subrecipient grants to PTE the right to use any written progress reports and deliverables created under this Subaward solely for the purpose of and only to the extent required to meet PTE's obligations to the Federal Government under its Federal Award.

Data Rights:
Subrecipient grants to PTE the right to use data created in the performance of this Subaward solely for the purpose of and only to the extent required to meet PTE's obligations to the Federal Government under its PTE Federal Award.

Data Sharing and Access (Check if applicable):
☐ Subrecipient agrees to comply with the Federal Awarding Agency's data sharing and access requirements as reflected in the NOA (or in the special terms below) and the Data Management/Sharing Plan submitted to the Federal Awarding Agency and attached

Subaward Number

H007829704

Governing Language:
In the event that a translation of this Subaward is prepared and signed by the parties, and a conflict arises between the English version and other language version, this English language version shall be the official version and shall govern and control.

Governing Law:
The Parties acknowledge that PTE is subject to the laws of the United States. The parties hereby agree that nothing in this Subaward or any of its attachments or references shall be deemed to require either Party to breach any mandatory statutory law under which each Party is operating.

Patents:
Pursuant to Public Law 96-517, as amended by Public law 98-620, title to any invention or discovery made or conceived under this Subaward shall vest in the Subrecipient. Subrecipient shall promptly notify PTE as shown in Attachment 4 hereto.

Subrecipient hereby grants to PTE a royalty-free, non-exclusive license for research purposes to any Subrecipient invention or discovery under this Subaward.

Second Tier Subawards:
Subrecipient may not issue any subawards under this Subaward without the express prior written consent of PTE. In the event that such consent is granted, all assurances, certifications, and terms included in this Subaward shall be flowed down to the second tier subaward.

Disputes:
The Parties shall attempt to resolve disputes through good faith negotiations. Any dispute arising under, or related to, this Subaward shall be resolved to the maximum possible extent through informal dispute resolution. Unresolved issues shall be arbitrated in accordance with the International Arbitration Rules of the American Arbitration Association.
Arbitration Association.

Promoting Objectivity in Research (COI):

Subrecipient must designate herein which entity's Financial Conflicts of Interest policy (COI) will apply: Subrecipient

If applying its own COI policy, by execution of this Subaward, Subrecipient certifies that its policy complies with the requirements of the relevant Federal Awarding Agency as identified herein:

Other Sponsor Agency: U.S. Dept of Energy

Subrecipient shall report any financial conflict of interest to PTE's Administrative Representative or COI contact, as designated on Attachment 3A. Any financial conflicts of interest identified shall, when applicable, subsequently be reported to Federal Awarding Agency. Such report shall be made before expenditure of funds authorized in this Subaward and within 45 days of any subsequently identified COI.

Work Involving Human or Vertebrate Animals (Select Applicable Options)

[x] No Human or Vertebrate Animals

This section left intentionally blank.

Human Subjects Data (Select One) Not Applicable

This section left intentionally blank

Subaward Number

H007829704

Additional Terms

Subaward Number: H007829704

Attachment 3A
Pass-Through Entity (PTE) Contacts

PTE Information

Entity DUNS Name: Regents of the University of Minnesota

Legal Address:
Office of Sponsored Projects Administration
450 McNamara Alumni Center
200 Oak Street SE
Minneapolis, MN 55455-2070

Website: https://research.umn.edu/units/spa

PTE Contacts

Central Email: awards@umn.edu

Principal Investigator Name: Tim Griffis

Email: tgriffis@umn.edu Telephone Number: 612 625 3117

Administrative Contact Name: Amy Bicek-Skog

Email: askog@umn.edu Telephone Number:

COI Contact email (if different to above):

Financial Contact Name: Same as administrative contact

Email: Telephone Number:

Email invoices? (●) Yes ( ) No Invoice email (if different): sub-inv@umn.edu

Authorized Official Name: Pamela Webb, Kevin McKoskey, David Hagen, April Coon, Amy Bicek-Skog

Email: awards@umn.edu Telephone Number: 612-624-5599

PI Address:

Timothy Griffis
Professor
S331 Soil Science Building
1529 Gortner Ave
St. Paul, MN 55108

Administrative Address:

Office of Sponsored Projects Administration
450 McNamara Alumni Center
200 Oak Street SE
Minneapolis, MN 55455-2070

Invoice Address:

Invoices shall reference the subaward number as shown on the face page of this agreement, current and cumulative costs (including cost sharing), and signed certification statement and be submitted in electronic format to sub-inv@umn.edu. Final invoice must be marked "Final."

Attachment 3B

Subrecipient Contacts

Subaward Number: H007829704

Subrecipient Information for FFATA reporting

Entity's DUNS Name: Instituto de Investigaciones de la Amazonía Peruana

EIN No.:

Institution Type: Regional Organization

DUNS: 934725763

Currently registered in SAM.gov: (●) Yes ( ) No

Exempt from reporting executive compensation: ( ) Yes ( ) No *(if no, complete 3Bpg2)*

Parent DUNS:

This section for U.S. Entities: Zip Code Look-up

Congressional District: Zip Code+4:

Place of Performance Address

Subrecipient Contacts

Central Email: presidencia@iiap.gob.pe

Website: www.iiap.gob.pe

Principal Investigator Name: Dennis del Castillo Torres

Email: ddelcastillo@iiap.gob.pe Telephone Number: +51 987565362

Administrative Contact Name: Ronald Trujillo León

Email: rtrujillo@iiap.org.pe Telephone Number: +51 965685012

Financial Contact Name: Julio Izquierdo Sánchez

Email: jizquierdo@iiap.gob.pe Telephone Number: +51 965685067

Invoice Email: jizquierdo@iiap.gob.pe

Authorized Official Name: Ronald Trujillo León

Email: rtrujillo@iiap.org.pe Telephone Number: +51 965685012

Legal Address:

Av. Abelardo Quiñones km 2,5 - Iquitos, Peru

Administrative Address:

Av. Abelardo Quiñones km 2,5 - Iquitos, Peru

Payment Address:

Av. Abelardo Quiñones km 2,5 - Iquitos, Peru

Attachment 3B-2

Highest Compensated Officers

Subaward Number: H007829704

Subrecipient:

Institution Name: Instituto de Investigaciones de la Amazonia Peruana

PI Name: Dennis del Castillo Torres

Highest Compensated Officers

The names and total compensation of the five most highly compensated officers of the entity(ies) must be listed if the entity in the preceding fiscal year received 80 percent or more of its annual gross revenues in Federal awards; and $25,000,000 or more in annual gross revenues from Federal awards; and the public does not have access to this information about the compensation of the senior executives of the entity through periodic reports filed under section 13(a) or 15(d) of the Securities Exchange Act of 1934 (15 U.S.C. §§ 78m(a), 78o(d)) or section 6104 of the Internal Revenue Code of 1986. See FFATA § 2(b)(1) Internal Revenue Code of 1986.

Officer 1 Name:

Officer 1 Compensation:

Officer 2 Name:

Officer 2 Compensation:

Officer 3 Name:

Officer 3 Compensation:

Officer 4 Name:

Officer 4 Compensation:

Officer 5 Name:

Officer 5 Compensation:

Subaward Number: H007829704

Attachment 4
Reporting and Prior Approval Terms

Subrecipient agrees to submit the following reports (PTE contacts are identified in Attachment 3A):

Technical Reports:

☐ Monthly technical/progress reports will be submitted to the PTE's Administrative Contact within 15 days of of the end of the month.

☒ Quarterly technical/progress reports will be submitted within 30 days after the end of each project quarter to the PTE's Principal Investigator

☐ Annual technical / progress reports will be submitted 60 days prior to the end of each budget period to the PTE's Administrative Contact . Such report shall also include a detailed budget for the next Budget Period, updated other support for key personnel, certification of appropriate education in the conduct of human subject research of any new key personnel, and annual IRB or IACUC approval, if applicable.

☒ A Final technical/progress report will be submitted to the PTE's Principal Investigator within 45 days of the end of the Project Period or after termination of this award, whichever comes first.

☐ Technical/progress reports on the project as may be required by PTE's Administrative Contact in order for the PTE to satisfy its reporting obligations to the Federal Awarding Agency.

Prior Approvals:

Carryover:
Carryover is automatic

Other Reports:

☐ In accordance with 37 CFR 401.14, Subrecipient agrees to notify PTE's Administrative Contact 60 days after Subrecipient's inventor discloses invention(s) in writing to Subrecipient's personnel responsible for patent matters. The Subrecipient will submit a final invention report using Federal Awarding Agency specific forms to the PTE's Administrative Contact within 60 days of the end of the Project Period to be included as part of the PTE's final invention report to the Federal Awarding Agency.

A negative report is required:

☐ Property Inventory Report (only when required by Federal Awarding Agency), specific requirements below.

☒ Each invoice must be accompanied by a brief technical report, and: (i) be sequentially numbered; (ii) indicate the date(s) of performance by the Subrecipient; (iii) state the Purchase Order number, the title of the project and the name of the PTE Principal Investigator; (iv) itemize costs in detail, in accordance with the Subaward budget; (v) include both current costs and cumulative costs; (vi) include the Subrecipient certification, with authorized official's signature, that costs are appropriate and accurate and that payment has not yet been received; and (vii)) be supported by a general ledger report originating directly from the Subrecipient's financial record keeping system. PTE may request supporting documentation in certain categories prior to or subsequent to approving the invoice. Supporting documentation includes, but is not limited to, travel receipts, purchase orders, invoices for services or supplies, or time records, Property Inventory Report; frequency, type, and submission instructions listed here and only to be used when required by PTE Federal Award.

Subaward Number

H007829704

Other Special Reporting Requirements:

Subaward Number: H007829704

Attachment 5
Statement of Work, Cost Sharing, Indirects & Budget

Statement of Work

○ Below ◉ Attached, [ ] pages

If award is FFATA eligible and SOW exceeds 4000 characters, include a *Subrecipient Federal Award Project Description*

Budget Information

Indirect Information Indirect Cost Rate (IDC) Applied	%	**Cost Sharing**	No
Rate Type: de minimis rate of 10%		If Yes, include Amount: $	

Budget Details ○ Below ◉ Attached, [ ] pages

Budget Totals

Direct Costs	$	25,736.00
Indirect Costs	$	2,424.00
Total Costs	$	28,160.00

All amounts are in United States Dollars

Subaward Number: H007829704

Attachment 6
Research Subaward
Invoice

BILL TO:	PTE Attention Address line 1 Address line email Subaward Agreement number	Invoice #: Invoice Date: Contract/Award#: Federal ID #:	

Contract Term:
Start Date: End Date:
Period Covered By This Invoice:
From: To:

EXPENDITURES		BUDGETED	CURRENT	CUMULATIVE
SALARIES AND WAGES				
FRINGE BENEFITS				
EQUIPMENT				
MATERIALS				
PUBLICATION COSTS				
OTHER (Specify)				
TUITION				
F&A base	%			
TOTALS				
LESS ADVANCES		–		
TOTAL DUE THIS INVOICE				

CERTIFICATION:
By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the Prime Award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil or administrative penalties for fraud, false statements, false claims or otherwise.

[signature] ADMINISTRATOR 12/05/19

Subrecipient Authorized Officer (Signature) *Title* Date

REMIT TO ADDRESS

PAYMENT AUTHORIZATION:

The subrecipient has demonstrated satisfactory project performance and progress, and the charges represented on this invoice appear to be appropriate with that progress. As Principal Investigator, I approve this payment.

PTE's Authorized Signature

Biophysical processes and feedback mechanisms controlling the methane budget of an Amazonian peatland

T.J. Griffis, Lead, University of Minnesota (Principal Investigator); Erik Lilleskov, USDA-Forest Service (Co-Investigator); Randall Kolka, USDA-Forest Service (Co-Investigator); Hinsby Cadillo-Quiroz, Arizona State University (Co-Investigator); Rod Chimner, Michigan Tech University (Co-Investigator); Jeffrey Wood, University of Missouri (Co-Investigator); Dan Riciutto, Oak Ridge National Lab (Co-Investigator); Daniel Roman, USDA-Forest Service (Senior Personnel); Dennis Del Castillo Torres, Instituto de Investigaciones de la Amazonia Peruana, Iquitos, Peru (Co-Investigator); Lizardo Fachín Malaverri, Instituto de Investigaciones de la Amazonia Peruana, Iquitos, Peru (Senior Personnel)

Problem Statement: Tropical peatlands are a major methane (CH_4) source and represent an important biophysical feedback factor acting on Earth's radiative forcing. There is evidence in recent years for an increase in global CH_4 mixing ratios (> 6.7 ppb per year from 2009 to 2017) with a pronounced increase in equatorial zones. Global top-down and carbon-13 isotope analyses suggest that this increasing trend has largely been driven by changes in natural biogenic sources in response to warmer and wetter tropical conditions. However, large uncertainties in these source estimates persist because of a lack of CH_4 observations in the tropics, and it is difficult to rule out other factors such as increased anthropogenic emissions or reductions in CH_4 sink activity. Furthermore, the largest expanses of tropical peatlands are located in lowland areas of Southeast Asia, the Congo Basin, and the Amazon Basin where observations are sparse. The Loreto Province of Amazonian Peru is comprised of about 36,000 km^2 of peatlands, however, the extent of these low elevation peatlands has only recently been documented and little is known about their biogeochemistry and ecophysiology. Our proposed research, therefore, aims to address these knowledge gaps by providing much needed data regarding the biogeochemistry of CH_4 cycling in tropical Amazonian peatlands and developing and testing an Earth System Model that can be used to forecast how hydrometeorological variations and changes in peatland structure in tropical regions will influence the CH_4 budget of the atmosphere. Here, we propose to use the United States Department of Energy's Energy Exascale Earth System Model (E3SM) land surface component (ELM) in a synergistic fashion with field experiments and modeling activities mutually informing new scientific understanding.

Objectives:

A. Evaluate and modify algorithms within the ELM land surface model to improve its ability to simulate CH_4 production and consumption in tropical peatlands and assess potential feedbacks acting between hydrometeorological forcings and the carbon balance of these neotropical peatlands;

B. Determine the magnitude of the inter-annual variability of the CH_4 and CO_2 budgets and examine how hydrometeorological and ecophysiological factors influence these budgets;

C. Assess how much CH_4 is produced and transported to the atmosphere *via* living and dead trees compared to the diffusive flux from peat soil and ebullition events;

D. Examine the importance of anaerobic oxidation of methane (AOM) in determining the CH_4 budget and evaluate its representation in ELM;

E. Determine how photosynthetic and respiratory activity varies through time and space and how they influence the CO_2 and CH_4 budgets at short (hourly) to inter-annual timescales.

Potential Impact: The proposed field experiments and modeling activities will advance scientific understanding of biogeochemical cycling dynamics in Amazonian peatlands and the representation of these ecosystems within an Earth System Modeling framework. The experimental and modeling activities will be synergistic and inform one another to reduce the uncertainty regarding future CH_4 emissions and feedbacks to climate in a region where CH_4 cycling is hypothesized to be highly sensitive to climate. The modeling activities will provide new insights regarding CH_4 emissions for an ensemble of plausible climate change scenarios for the region over the time period 2020 to 2080.

Biophysical processes and feedback mechanisms controlling the methane budget of an Amazonian peatland

Timothy J Griffis,
Professor
University of Minnesota
Department of Soil, Water, and Climate
439 Borlaug Hall, 1991 Upper Buford Circle
St. Paul, MN 55108
612-625-3117
timgriffis@umn.edu

Funding Opportunity Announcement Number: DE-FOA-0002043 Research Program: TES

DOE/SC Program Office: Biological and Environmental Research

DOE/SC Program Office Technical Contact: Dr. Daniel Stover

PAMS Pre-Application Tracking Number: PRE-0000017642

Proposal Type: Full/Standard for period of three years.
Proposed FOA science area: Science Area 1, Interactions and Feedbacks between Above- and Belowground Processes
Keywords: Amazon, biogeochemistry, isotopes, methane, peatlands

Name	Institution	Role	Anticipated budget
Tim Griffis	University of Minnesota	Ecosystem scale fluxes and modeling	Year 1: $268,976 Year 2: $149,660 Year 3: $120,699 Total: $539,335
Erik Lilleskov, Randall Kolka, Daniel Roman	USDA-Forest Service	Sub-ecosystem fluxes and scaling	Year 1: $9,714 Year 2: $7,344 Year 3: $8,702 Total: $25,760
Rod Chimner	Michigan Tech University	Hydrologic impacts on fluxes	Year 1: $60,823 Year 2: $56,303 Year 3: $46,203 Total: $163,329
Jeffrey Wood	University of Missouri	Sun induced Fluorescence and ecosystem scale fluxes	Year 1: $14,500 Year 2: $14,925 Year 3: $15,367 Total: $44,792
Dennis Del Castillo Torres, Lizardo Fachín Malaverri	Instituto de Investigaciones de la Amazonia Peruana, Iquitos, Peru	Vegetation and biomass inventories; Tower maintenance	Year 1: $28,160 Year 2: $32,010 Year 3: $28,160 Total: $88,330
Hinsby Cadillo-Quiroz	Arizona State University	Microbial dynamics and isotope tracers	Year 1: $47,450 Year 2: $56,191 Year 3: $34,811 Total: $138,452
Dan Riciutto	Oak Ridge National Lab	Land surface modeling	$0 co-advise postdoc with Griffis
	Total Budget		**$999,998**

Biophysical processes and feedback mechanisms controlling the methane budget of an Amazonian peatland

Project Narrative

1. Background

Tropical peatlands are a major methane (CH_4) source [*Frankenberg et al.*, 2005; *Pangala et al.*, 2017; *Saunois et al.*, 2017] and represent an important biophysical feedback on Earth's radiative forcing [*Kirschke et al.*, 2013]. There is evidence in recent years for an increase in global CH_4 mixing ratios (i.e. 6.7 ppb per year from 2009 to 2013 and 7.5 ppb per year from 2014 to 2017) with a pronounced increase in equatorial zones [*Nisbet et al.*, 2016; 2019]. Global top-down and carbon-13 isotope analyses suggest that this increasing trend has largely been driven by changes in natural biogenic sources in response to warmer and wetter tropical conditions [*Nisbet et al.*, 2016; *Saunois et al.*, 2017]. However, large uncertainties persist in these source estimates because of a lack of CH_4 observations in the tropics [*Saunois et al.*, 2017], and it is difficult to rule out other factors such as increased anthropogenic emissions or reductions in CH_4 sink activity [*Montzka et al.*, 2011; *Schaefer et al.*, 2016]. This highlights the need for increasing our capacity to measure CH_4 fluxes directly (i.e. from chamber to ecosystem scales) to improve process understanding and the modeling of the biogeochemical cycling of CH_4 in tropical peatlands. Our proposed research, therefore, aims to address this knowledge gap by providing much needed data on CH_4 fluxes in tropical peatlands and developing and testing an Earth System Model (ESM) that can be used to forecast how hydrometeorological variations and changes in peatland structure (i.e. species composition, peat depth, etc) in tropical regions will influence the CH_4 budget of the atmosphere. Here, we will use the United States Department of Energy's Energy Exascale Earth System Model (E3SM) land surface component (ELM) and will pursue a synergistic approach so that our field experiments and modeling activities mutually inform new scientific understanding.

The largest expanses of tropical peatlands are located in lowland areas of Southeast Asia, Congo Basin, and the Amazon Basin [*Page et al.*, 2011; *Dargie et al.*, 2017]. The Loreto Province of Amazonian Peru is comprised of about 36,000 km^2 of peatlands within the Pastaza-Marañon Foreland Basin (PMFB) [*Draper et al.*, 2014]. However, the extent of low elevation peatlands in Peru has only recently been documented and little is known about their biogeochemistry and ecophysiology. To help address these knowledge gaps, we established an eddy covariance (EC) flux tower in a pristine palm swamp peatland in Quistococha Forest Reserve (QFR Flux Site), Iquitos, Peru in spring 2017 in collaboration with the Peruvian Amazon Research Institute (IIAP). This research site is now registered with the AmeriFlux network (**https://ameriflux.lbl.gov/sites/siteinfo/PE-QFR**). The preliminary CH_4 budget estimate (approximately 17 g C m^{-2} y^{-1}) is remarkably similar to our long-term (2009 to 2018) estimates for the Bog Lake Fen peatland at the Marcell Experimental Forest near Grand Rapids, Minnesota [*Olson et al.*, 2013], despite vastly different climate, vegetation, and peatland characteristics. Further, the CO_2 budget suggests a major sink of approximately 480 g C m^{-2} y^{-1} that is comparable to other Amazonian forests [*Kruijt et al.*, 2004; *Zeri et al.*, 2014]. The magnitude and biophysical controls acting on the seasonal and inter-annual variability of the budgets is, however, unknown. Further, the knowledge gap with respect to understanding contemporary inter-annual peatland CH_4 budgets calls into question the ability of ESMs to accurately represent how these ecosystems will respond to climate change [*Desai et al.*, 2015].

Recent measurements from one of the largest Amazonian peatland complexes in Peru (PMFB) indicate that palm swamp peatlands are large CH_4 sources exhibiting strong seasonality related to hydrometeorological conditions [*Teh et al.*, 2017]. Chamber-based flux measurements indicate wet and dry season CH_4 emissions of 53.4 mg CH_4-C m^{-2} d^{-1} and 25.5 mg CH_4-C m^{-2} d^{-1}, respectively, with a mean annual emission of 13.4 g CH_4-C m^{-2} [*Teh et al.*, 2017]. While this annual emission estimate is in reasonably good agreement with our preliminary QFR EC measurements (17 g C m^{-2} y^{-1}), there are considerable uncertainties regarding the importance of non-diffusive CH_4 transport (i.e. ebullition events), plant-mediated emissions, and anaerobic oxidation of methane (AOM). For instance, Teh et al., [2017] observed net ebullition events as large as 973 mg CH_4-C m^{-2} d^{-1}, but it is unclear how such emissions scale spatially and temporally. Further, their research did not attempt to quantify plant-mediated emissions or variations in AOM. Such limitations provide a major barrier for testing ESMs and forecasting CH_4 emissions for the region.

Plant-mediated transport of CH_4 to the atmosphere has received increased attention in recent years and has been the subject of considerable debate [*Keppler et al.*, 2006; *Rice et al.*, 2010; *Covey et al.*, 2012; *Pangala et al.*, 2013; *Carmichael et al.*, 2014]. Covey *et al.*, [2012] concluded that living trees infected by heart rot fungus was an important pathway for CH_4 production. Pangala et al., [2017] have shown that CH_4 emissions from central Amazonian tree stems were up to 200-fold greater than emissions from tropical peat swamp peatlands and the dominant diffusive flux component observed in the Amazonia. Carbon-13 isotope analyses of CH_4 emitted from these tree stems indicated that the CH_4 was produced in the soil and that these stem emissions decreased as a function of stem height relative to the soil. Such measurements have helped reconcile the large disparity observed between top-down and bottom-up CH_4 budget estimates for the Amazon Basin [Pangala *et al.*, 2017]. Understanding this mechanism and its variation among tree species, or broader plant functional types (PFTs), is critical for improving the capacity of ESMs to predict CH_4 emissions.

There is also growing evidence that AOM in wetlands and peatlands is of sufficient magnitude to be of significance to the global CH_4 budget, with consumption estimated at 10–50% of gross production [*Gupta et al.*, 2013; *Segarra et al.*, 2013; *Gauthier et al.*, 2015; *Valenzuela et al.*, 2017]. Anaerobic CH_4 oxidation occurs through coupling with sulfate reduction [*Knittel and Boetius*, 2009; *Milucka et al.*, 2012], and denitrification [*Raghoebarsing et al.*, 2006; *Ettwig et al.*, 2010; *Zhu et al.*, 2012; *Segarra et al.*, 2013], reverse methanogenesis [*Kip et al.*, 2010], with evidence of a yet to be defined pathway in nutrient poor peatlands [*Smemo and Yavitt*, 2011; *Gupta et al.*, 2013]. A probable explanation is that organic electron acceptors mediate AOM in these systems, which is supported by evidence of reduced CH_4 emissions in response to increased levels of humic acids [*Blodau and Deppe*, 2012; *Miller et al.*, 2015]. Although the precise mechanisms are yet to be elucidated, organic layer depth has been a good predictor of biogeochemical controls on CH_4 emissions in arctic wet-sedge tundra ecosystems [*Miller et al.*, 2015]. Further, evidence indicates that there is significant potential for AOM in peatlands, however, there is a paucity of measurements of the rates of AOM *in- situ* [*Smemo and Yavitt*, 2011] and this especially true for tropical peatlands [*Valenzuela et al.*, 2017].

Given the widespread evidence for AOM in peatlands, the fidelity of ESMs that currently neglect this process has been questioned [*Gauthier et al.*, 2015]. We hypothesize that this explains a significant portion of the disagreement between observed CH_4 fluxes versus those simulated by ESMs that do not accurately represent these processes. Another concern is that previous agreement between models and net CH_4 flux measurements are likely an artifact of biased model optimization because they ignored the importance of AOM. Here, we aim to assess and optimize the biogeochemical cycling of CH_4 within the ELM framework, which represents the key flux components (i.e. diffusive flux, ebullition events, plant-mediated emissions, and AOM) outlined above. The **overarching goal** is to improve our ability to forecast how CH_4 emissions from Amazonian peatlands will respond to climate variations and change.

2. Project Objectives

The overall research activities are summarized below in **Figure 1.**

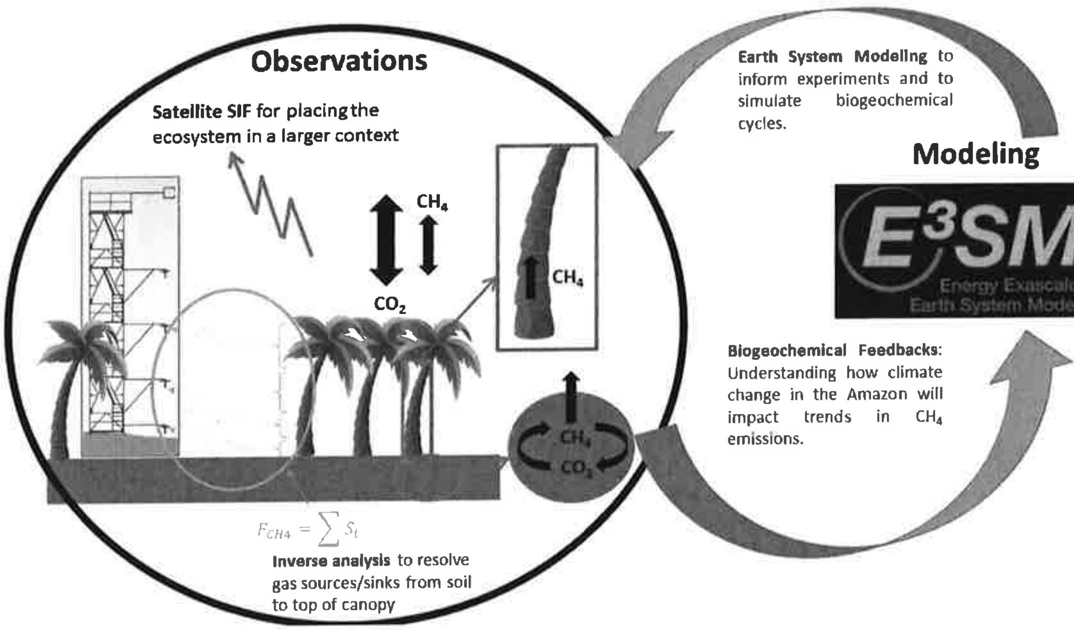

Figure 1. Experimental and E3SM modeling approach illustrating the links among experimental process studies and Earth System Model development, validation, and forecasting. The flux tower is associated with eddy covariance and inverse Lagrangian budget analyses, of which the latter can be used to resolve the vertical source/sink distribution of different gases through the canopy space. Chamber and carbon isotope based observations will be used to bridge our process understanding and constrain emissions from top-down (flux tower) observations and Earth System Modeling of CH_4 diffusive flux, ebullition, plant-mediated emissions, and anaerobic oxidation of CH_4. Satellite sun-induced chlorophyll fluorescence observations will be used to place the ecosystem-level productivity within the regional context.

The project **objectives** are to:

A. Evaluate and modify algorithms within the Energy Exascale Earth System Model (E3SM) land surface component (ELM) to improve its ability to simulate CH_4 production and consumption in tropical peatlands and assess potential feedbacks acting between hydrometeorological forcings and the carbon balance of these neotropical peatlands.

B. Determine the magnitude of the inter-annual variability of the CH_4 and CO_2 budgets and examine how hydrometeorological and ecophysiological factors influence these budgets;

C. Assess how much CH_4 is produced and transported to the atmosphere *via* living and dead trees compared to the diffusive flux from peat soil and ebullition events;

D. Examine the importance of anaerobic oxidation of methane (AOM) in determining the CH_4 budget and evaluate its representation in ELM;

E. Determine how photosynthetic and respiratory activity varies through time and space and how they influence the CO_2 and CH_4 budgets at short (hourly) to inter-annual timescales;

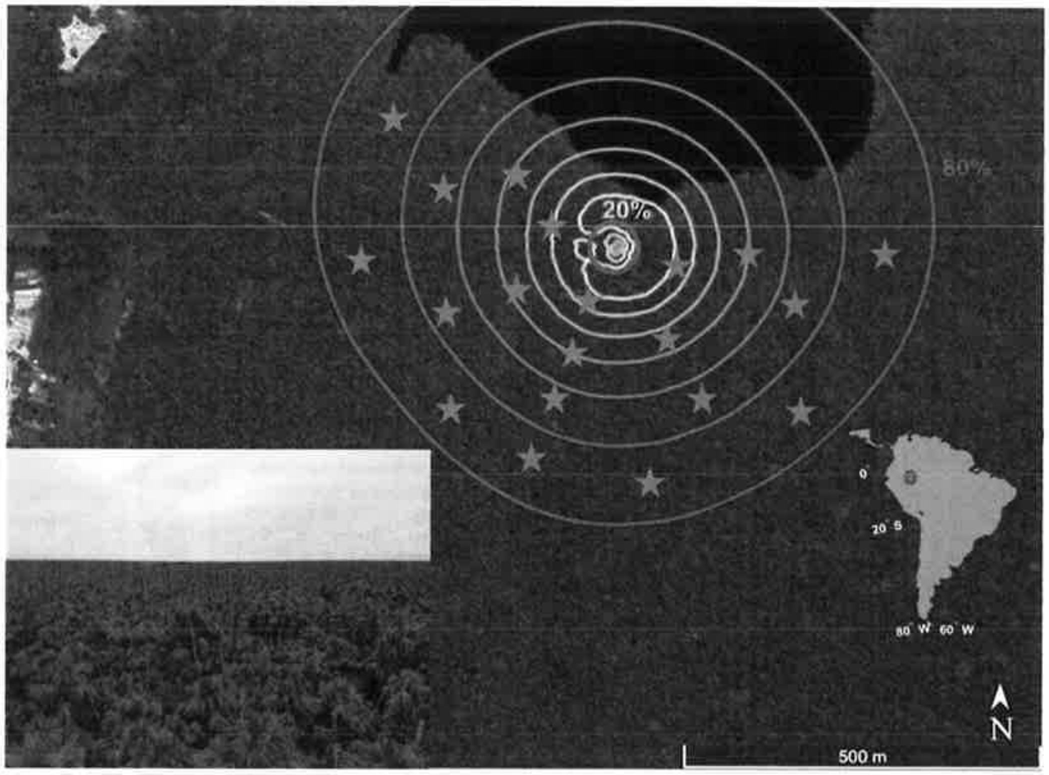

Figure 2. Location of research site in Iquitos, Peru and eddy covariance flux footprint associated with the 40 m level. Isolines represent the cumulative contribution to the observed flux. Note that quality control procedures filter out observations with northerly flow given these fetch limitations. Inset photograph (lower left) was taken from the 40 m level on the eddy covariance flux tower at Quistococha, illustrating the relatively uniform and undisturbed palm swamp forest. Inner red circle represents the footprint of intensive automated flux chamber measurements. Red stars represent approximate location of sub-ecosystem plots for extensive measurements of CH_4 fluxes, with exact locations adjusted to be evenly divided between palm and non-palm dominated plots. All chamber locations represent proposed new measurements.

3. Proposed Research, Methods, and Hypotheses

3.1. Research site: The study site is located at Quistococha on the outskirts of Iquitos, Loreto region, Peru. Quistococha is a natural protected forest reserve and an official scientific research area for IIAP. The EC flux tower (42 m tall with instruments mounted at 40 m) is located at 73° 19' 08.1" W; 3° 50' 03.9" S within a pristine palm swamp peatland that is within the reserve (**Figure 2**). **Figure 2** shows the flux tower location and the flux footprint climatology for the tower, where the isopleths indicate the cumulative probability of particle contribution to the total flux. We note that fetch is inadequate for northerly wind flow. These data are filtered according to quality control assessment.

The major vegetation type is *Mauritia flexuosa* (moriche palm, or aguaje in Spanish, reaching 22 m height). This palm species is the dominant species over a large part of the Pastaza-Marañon basin, with palm swamps covering an estimated 27,732 km^2, and is indicative of minerotrophic peatlands and floodplain forests that are seasonally or intermittently inundated by the flood waters of major rivers [*Draper et al.* 2014]. Aguaje has been under major anthropogenic pressure within the region for its valuable source of palm fruits, with destructive harvest reducing population density in unprotected forests. The mean annual temperature at the site is approximately 25°C with annual precipitation of about 2740 mm. The site is characterized by a long wet season and a shorter dry season (June-August). The water table position at this site is located at or near the peat surface for much of the year. The underlying peat layer has an average thickness of 2.45 m [*Lähteenoja et al.*, 2009].

3.2. Land surface modeling activities with ELM

Hypothesis 1: *ELM algorithms describing plant-mediated CH_4 emissions are underestimated for tropical palm swamp plant function groups and AOM is poorly constrained in terms of its absolute magnitude and its seasonality.*

Hypothesis 2: *The trend toward warmer and wetter hydrometeorological conditions in the Amazonian Basin will act to increase CH_4 emissions to the atmosphere because of increased CH_4 production and reduced AOM consumption.*

We will use the Energy Exascale Earth System Model (E3SM) and land surface component (ELM) to investigate the influence of hydrometeorological and ecophysiological factors on the biogeochemical cycling of CH_4 in Amazonian palm swamp peatlands. A better understanding of peatland CH_4 production and consumption in relation to the properties of humic materials, microbial activity, plant ecophysiology, and hydrometeorological drivers is needed to better interpret measured CH_4 flux data and to more accurately represent these mechanisms in models. A version of this model, ELM-SPRUCE, has been used to simulate boreal peatlands [*Shi et al.*, 2015] and connected to a biogeochemistry methane model [*Xu et al.*, 2015]. Here, the ELM model algorithms will be evaluated for our QFR peatland site by comparing simulated emissions against sub-ecosystem scale component measurements and ecosystem scale CH_4 flux observations (eddy covariance and inverse Lagrangian fluxes). The optimized ELM model will then be used to investigate potential biophysical feedback factors acting between hydrometeorological factors and the CH_4 and CO_2 budget of these neotropical peatlands.

The essential equations and parameterization of the net CH_4 flux in ELM have been derived from those implemented in the CH_4 biogeochemistry model of the Community Land Model (CLM4Me) and are described as follows [*Riley et al.*, 2011; *Xu et al.*, 2015]:

$$\frac{\partial(RC)}{\partial t} = \frac{\partial F_D}{\partial z} + P(z,t) - E(z,t) - A(z,t) - O(z,t) \qquad [1]$$

where z (m) is the vertical dimension, t is time (s), $\frac{\partial(RC)}{\partial t}$ is the rate of change of the CH_4 concentration, C (mol m^{-3}), accounting for gas in aqueous and gaseous phases through the R term, F_D represents the diffusive flux (mol m^{-2} s^{-1}), $P(z,t)$ is CH_4 production, $E(z,t)$ is ebullition, A(z,t) is the aerenchyma transport and $O(z,t)$ is CH_4 oxidation. The latter four terms all have units of mol m^{-3} s^{-1}. The model solves **Equation** 1 and an analogous equation for O_2 that does not include the E and P terms. Oxidation, $O(z,t)$, is currently parameterized according to a double Michaelis-Menten function:

$$R_{oxic} = R_{o,\max}\left[\frac{C_{CH_4}}{K_{CH_4} + C_{CH_4}}\right]\left[\frac{C_{O_2}}{K_{O_2} + C_{O_2}}\right]Q_{10}F_9 \qquad [2]$$

where R_{oxic} is the oxidation rate (mol m^{-3} s^{-1}), $R_{o,max}$ is the maximum oxidation rate (mol m^{-3} s^{-1}), K_{CH4} and K_{O2} are half saturation coefficients for CH_4 and O_2 (mol m^{-3}), respectively, C_{CH4} and C_{O2} are the CH_4 and oxygen concentrations (mol m^{-3}), respectively, Q_{10} accounts for the effect of temperature relative to a base temperature of 12°C, and F_9 is a soil moisture limitation factor that is parameterized according to

$F_g = e^{-P/P_c}$ where P is the soil moisture potential and P_c = -2.4×10^{-5} mm. Here, we propose to split the oxidation term into oxic and anaerobic, R_{ana}, components and will parameterize R_{ana} according to

$$R_{ana} = R_{ana,\max}\left[\frac{C_{CH_4}}{K_{ana,CH_4} + C_{CH_4}}\right]Q_{ana,10}F_{\phi}, \qquad [3]$$

where $R_{ana,max}$ is the maximum oxidation rate (mol m^{-3} s^{-1}), $K_{ana,CH4}$ is the half saturation coefficient for AOM (mol m^{-3}), $Q_{ana,10}$ accounts for the temperature effect on AOM, and F_ϕ is an empirical depth function. The parameters in **Equation 3** will be obtained from our chamber and carbon-13 isotope-based measurements described below in **section 3.4**.

We will optimize the parameters underlying the processes represented in **Equation 1** independently of ELM where the algorithms can be forced using direct hydrometeorological observations from the site. In this way, we aim to avoid biasing optimal parameter values resulting from other potential model artifacts such as deficiencies in the representation of energy balance, thermal properties, water table position, etc. The model parameters will be optimized by using field observations (initially with data collected in year 1) in combination with objective model cost function optimization procedures [*Wang et al.*, 2001]. Prior to optimization, we will evaluate **Hypothesis 1** in order to identify the most serious model deficiencies and biases. For instance, our preliminary data indicate that plant-mediated CH_4 emissions can be categorized broadly into two main PFTs including palm and non-palm species (**see section 3.4. below for species information**). This PFT approach is compatible with the current ELM architecture. However, if this distinction is not made in the model, ELM will grossly underestimate plant-mediated CH_4 emissions for these tropical peatland sites because of the large differences that have been observed under field conditions. Further, we will take a similar approach to evaluating and optimizing algorithms representing other key model processes such as ebullition and AOM.

Initially, we will restrict the optimization procedure described above to data from year 1. In the first half of year 2, we will run these independently optimized model algorithms and forced with hydrometeorological observations (collected in year 2) to evaluate model biases. Additional parameters (e.g., leaf-level photosynthesis) may be optimized in the full ELM to reduce biases. Because of computational expense, we will use surrogate-based uncertainty quantification approaches for ELM [*Safta et al.*, 2015; *Lu et al.*, 2018] to inform the types of additional or modified field experiments that would lead to the largest improvements in ELM. These modified, or new, experiments will be implemented in the latter half of year 2 and year 3 and will be used to pursue further model testing and optimization. Finally, we will conduct another set of ELM evaluations using the optimized model to assess remaining biases that are dependent on model implementation and propagated errors associated with the representation of energy, water, and biogeochemical cycling processes within the ELM framework.

We will use ELM to test **Hypothesis 2** and to evaluate other potential biophysical feedback mechanisms associated with CH_4 biogeochemical cycling in palm swamp peatlands of the Amazonian Basin. Recent studies have hypothesized that warmer and wetter conditions in the tropics have enhanced CH_4 emissions within the region and have contributed to the increasing trend of global CH_4 concentrations [*Nisbet et al.*, 2016; *Saunois et al.*, 2017]. Using the optimized ELM model, we will perform simulations over the period 1990 to 2022 for palm swamp peatlands of the broader PMFB region to assess the extent to which CH_4 emissions vary spatiotemporally and examine if these peatlands are implicated in the recent increase in tropical CH_4 concentrations. Following our previous work using the Community Land Model [*Chen et al.*, 2015, 2018] we will force ELM with hourly hydrometeorological data using available observations and reanalysis (i.e. NCEP, National Centers for Environmental Prediction) data products (i.e. solar radiation, air temperature, precipitation, air humidity, air pressure, wind speed, soil temperature, and soil water content). To ensure that modeled soil carbon pools are at steady state, the model will be spun up for over 1000 years by re-cycling the available site meteorological data. Following this step, the model will be forced by the hydrometeorological data at the QFR site and for palm swamp sites within the PMFB region. The temporal and spatial resolution of these model simulations will be set to 1 hour and 10 km^2, respectively. Finally, the temporal and spatial trends in CH_4 emissions from palm swamp peatlands will be assessed over the period 1990 to 2022 to gain insights regarding the extent to, which climate variations and change influence CH_4 concentrations within the region. Further we will extend these analyses into the future using ensemble climate simulations (i.e. based on CMIP5 results) for a number of standard representative concentration pathways (i.e. RCP 8.5 W m^{-2}). The CMIP5 simulations will extend from 2020 to 2080 with a spatial resolution of 1.125° × 1.125°.

3.3. Ecosystem-scale measurements and processes

Hypothesis 3: *The ecosystem-scale CH_4 budget is dominated by plant-mediated emissions and ebullition events.*

Hypothesis 4: *Soil CH_4 emissions are offset by significant canopy uptake of CH_4.*

Hypothesis 5: *The seasonality of ecosystem-scale CH_4 emissions are driven by the temporal variability in AOM and plant-mediated biogeochemical processes.*

Hypothesis 6: *Net ecosystem-scale CO_2 uptake offsets the CH_4 emissions across all seasons and years when considering their global warming potentials.*

Hypothesis 7: *A general GPP-SIF empirical scaling relation exists for Amazonian palm swamp forests, and spatial variations of SIF will reveal that our net ecosystem-scale CO_2 measurements are representative of the region.*

Eddy covariance flux measurements of energy, water, and CO_2 have been ongoing at this site since spring 2017, while CH_4 flux measurements have been made sporadically due to sensor failure related to a manufacturer defect. The EC system consists of open-path instruments for CH_4 (LI-7700, Li-Cor Inc. Lincoln, NE, USA) and CO_2 (LI-7500, Li-Cor Inc.) with turbulence measured with a 3D sonic anemometer (CSAT3, Campbell Scientific Inc. Logan, UT, USA). In February 2019 a brand new LI-7700 was installed at the site for continuous/reliable CH_4 flux measurements. All measurements are made at 10 Hz and recorded on a data logger (CR5000, Campbell Scientific Inc.). Our preliminary EC data indicate that median CH_4 fluxes are about 55 nmol m^{-2} s^{-1} with peak emissions of 200 to 450 nmol m^{-2} s^{-1}. Although we have limited CH_4 data, it appears that there is a peak in CH_4 emissions in the early morning hours (4 am to 9 am) that does not seem to be explained by the onset of turbulence, but rather, the onset of photosynthesis. These preliminary data, therefore, suggest a link to plant-mediated CH_4 transport.

Through this proposal we plan to add an air sampling profile system so that we can better measure changes in CO_2, CH_4, and water vapor storage below the height of the sonic anemometer. Further, this profile system will be used as part of our inverse Lagrangian CO_2 and CH_4 budget analyses (described below). This profile system will make use of a new low power and portable gas analyzer that measures all three gas species (CH_4, CO_2 and water vapor) simultaneously (LI-7810, Li-Cor Inc.). Our EC flux processing follows AmeriFlux protocols using custom software that has been tested and validated at numerous AmeriFlux sites (agricultural, grassland, lakes, and peatlands) in Minnesota. Our group has also tested and evaluated the long-term (> 3 years) performance of open (i.e. LI-7700, Li-Cor Inc.) and closed-path (TGA100A, Campbell Scientific Inc.) CH_4 EC systems at a temperate peatland site [*Deventer et al.*, 2019] and have demonstrated excellent agreement in half-hourly fluxes and annual budgets. Supporting hydrometeorological measurements will include net radiation, solar radiation, photosynthetically active radiation, air temperature and relative humidity, precipitation, soil water content, water table position, soil heat flux, and dissolved oxygen.

3.3.1. Inverse Lagrangian budget analyses

We will use an inverse Lagrangian budget approach to estimate CH_4 and CO_2 sinks/sources for discrete vertical layers through the forest volume (**Figure 1**) [*Denmead et al.*, 2000; *Leuning et al.*, 2000; *Raupach*, 2001; *Zimmermann et al.*, 2008; *Santos et al.*, 2011; *Jardine et al.*, 2016]. This method will help us to constrain CH_4 and CO_2 emissions from soils, tree stems, and CH_4 and CO_2 uptake by the canopy. Here, we note that preliminary leaf chamber observations at the site suggest that canopy uptake of CH_4 could be an important sink. For instance, the two dominant palms *Mauritia flexuosa* and *Mauretiella armata* have measured consumption rates ranging from 2 to 7 mg C-CH_4 m^{-2} h^{-1} (calculated per area of leaves) [Cadillo-Quiroz, *unpublished data*], which would significantly influence the net CH_4 exchange at QRF. We will measure the mixing ratios of CH_4, CO_2, and water vapor within and above the canopy at 12 different measurement levels. We will base the sample height intervals on detailed measurement of canopy structure with the number of measurement levels and source/sink layer thickness decreasing as function of height. Further, we will use three 3D sonic anemometers to measure wind and turbulence statistics at one height above the canopy and two heights below the canopy. From these measurements we will estimate the sink/source strength of 5 layers (**Figure 1**) ranging from a shallow layer extending above the soil surface (i.e. less than 1.5 m) to a layer containing the upper canopy. Briefly, we will follow the strategy outlined by *Denmead et al., [2005]*:

$$C_i - C_R = \sum_{j=1}^{m} D_{ij} S_j \Delta z_j \quad [4]$$

where, S_j represents the sink/source strength of layer j, C_i is the concentration of CH_4 or CO_2 measured at 12 sample heights ranging from 1 m to 38 m and C_R represents the concentration measured at a reference height above the canopy (i.e. at about 42 m). D_{ij} represents the dispersion matrix that is obtained from solutions to the far-field and near-field dispersion equations. This solution requires profiles (measured or modeled) of turbulence statistics (i.e. the standard deviation of vertical wind velocity) and an estimate of the Lagrangian timescale (T_L). Research has shown that this approach can provide robust estimates of the sink/source terms provided that the number of concentration measurement heights is substantially greater than the number of source layers being solved. Further, the quality of results can be improved by using interpolation techniques between measurement levels [*Siqueira et al.*, 2000].

From these measurements and budget analyses will we estimate the sink/source behavior through the canopy profile and will address **Hypotheses 3 and 4**. We believe that we can provide an important constraint on CH_4 emissions from the soil and canopy tree stems independent of our sub-ecosystem measurements. Further, this approach will provide critical information regarding the potential for net CH_4 uptake by the canopy. Such information will be critical for assessing and optimizing the ELM model algorithms described above.

3.3.2. Continuous wavelet transform and coherence analyses

Continuous wavelet transform (CWT) and wavelet coherence analyses [*Torrence and Compo*, 1998; *Grinsted et al.*, 2004; *Griffis et al.*, 2016a] will be used to assess the dominant temporal and spatial scales associated with CH_4 transport (**Hypothesis 3**). Computation of the eddy flux based on CWT techniques allows investigation of short (i.e. timescales of seconds to minutes) and non-stationary flux transport and offers potential insights into identifying ebullition events and plant-mediated transport processes that would be difficult to detect using standard (i.e. 30 to 60-min block averaging) eddy flux processing. These observations and CWT analyses will link directly to our Inverse Lagrangian analyses described above and the sub-ecosystem scale measurements and hypothesis testing (described below in **section 3.4**).

In addition to our standard flux processing (i.e. covariances derived from 30 to 60-min block averaging), eddy covariances will be calculated by reconstructing the time-frequency spectra W_w (vertical wind) and W_c (concentration scalar of interest such as CH_4) obtained from the CWT using a Mexican Hat wavelet at time scales ranging from seconds to about 1 hour. The fluxes (F) will be computed using the continuous wavelet transform as:

$$F = \overline{w'c'} = \frac{\delta t}{3.541}\frac{\delta j}{N}\sum_{n=0}^{N-1}\sum_{j=0}^{J}\frac{[W_w \cdot W_c]}{a(j)} \quad [5]$$

where $\overline{w'c'}$ is the covariance between vertical wind fluctuations and a scalar of interest (i.e. CH_4); parameter a is the wavelet scale (here it will range from about 0.1s to about 60 minutes); j is the scale index (j = 0, 1, … J); δj is the scale step size = 0.5 s; δt is the sampling interval 0.1 s and N is the length of the time series. The factor 3.541 is the wavelet reconstruction factor for the Mexican Hat mother wavelet that is an approximation that converts wavelet scale to frequency domain. The CWT will be performed for all available data in order to diagnose non-stationary events (i.e. ebullition events) that contribute significantly to CH_4 emissions. The median absolute deviation (MAD) approach using 7 to 14 day moving windows will be used to identify important non-stationary events:

$$\text{MAD} = \text{median}(F_i - median(F)). \quad [6]$$

Here a non-stationary event will be identified as:

$$F_i - median(F) > \frac{z}{0.6745} \cdot MAD \quad [7]$$

where z is an outlier factor. Here, we are experimenting with z ranging from 4 to 7 (based on data and analyses from Bog Lake Fen in Minnesota) and will be modified according to the observations and sensitivity analyses performed at QFR. Because the above approach is computationally very intensive, these analyses will be performed at the University of Minnesota Supercomputing Institute (**www.msi.umn.edu**), where the PI (Griffis) serves on the High Performance Computing Allocation Committee. **Figure 3** shows an example of detecting non-stationary fluxes at the Bog Lake Fen site in Minnesota. Based on these observations and analyses, in concert with the sub-ecosystem measurements described below, we believe we can provide an improved constraint on the contribution of ebullition events and plant-mediated transport to the total CH_4 budget at QFR (**Hypothesis 3**).

Further, wavelet coherence analyses will be performed to shed new light on plant-mediated emissions. Here, we will use wavelet coherence analyses [*Torrence and Compo*, 1998; *Grinsted et al.*, 2004] to examine the temporal scales and timing of plant-mediated emissions by assessing the coherence between transpiration and CH_4 emissions and photosynthetic flux and CH_4 emissions at time scales ranging from a few minutes to several days. We have applied similar techniques to help identify the controls on the isotope composition of atmospheric water vapor and nitrous oxide emissions in the Upper Midwestern United States [*Griffis et al.*, 2016b, 2017]. The cross-wavelet spectrum identifies regions of high common power. To examine the coherency of the cross-wavelet transform in time-frequency space we will calculate the wavelet coherence spectrum, $R^2_n(s)$,

$$R_n^2(s) = \frac{\left|\wedge\left(s^{-1}S_n^{XY}(s)\right)\right|^2}{\wedge\left(s^{-1}\left|S_n^X(s)\right|^2\right)\wedge\left(s^{-1}\left|S_n^Y(s)\right|^2\right)} \quad [8]$$

where $\wedge$ represents a smoothing operator [*Grinsted et al.*, 2004]. The cross-wavelet spectrum, $S_n^{XY}(s)$, of time series X_n and Y_n will be obtained as,

$$S_n^{XY}(s) = W_n^X(s)W_n^Y(s)^* \quad [9]$$

where * represents complex conjugation, n is time, s is scale; and $W_n^X(s)$ and $W_n^Y(s)$ are the wavelet transforms of signals X_n and Y_n, respectively. Values of $R^2_n(s)$ can be interpreted as local correlation coefficients in time-frequency space. Statistical significance testing will be performed using the Monte Carlo approach presented by *Grinsted et al.*, [2004]. The cross-wavelet and coherence spectrums will be computed for eddy covariance fluxes of CO_2 vs CH_4 and water vapor and CH_4 fluxes, and will also be computed separately for corresponding pairs of mixing ratios. These observations and analyses will be used to test **Hypotheses 3 and 5**.

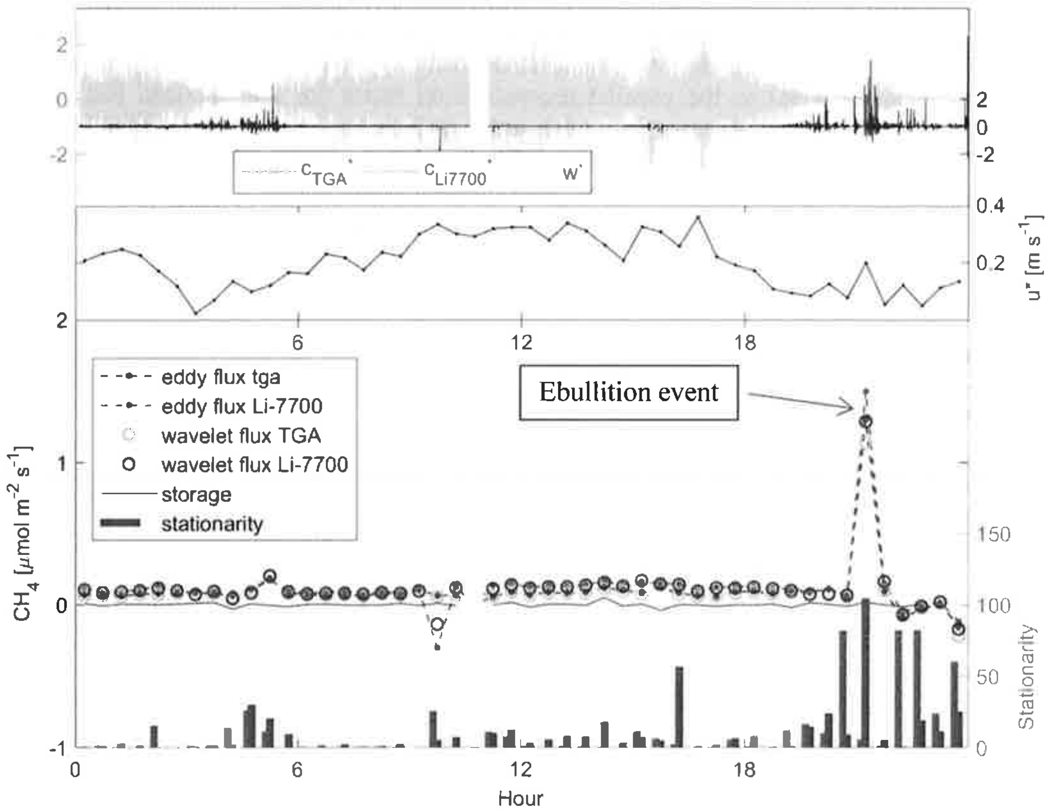

Figure 3. Example of using the continuous wavelet transform technique to identify ebullition events in high-frequency eddy covariance data at the Bog Lake Fen peatland in Minnesota, USA. Top panel: 10 Hz measurements of CH_4 mixing ratios and vertical wind velocities; Middle panel: friction velocity; Bottom panel: CH_4 flux estimated using the continuous wavelet transform and corresponding stationarity ratio.

3.3.1. Sun induced fluorescence analyses

Eddy covariance flux measurements will be ongoing over the duration of the project and will be supported with satellite-based sun induced fluorescence (SIF) observations and reflectance products to place QFR observations within the context of the larger PMRB region and to examine the seasonality and inter-annual variability of productivity in the PMRB, and compare with the larger Amazonian basin. Sun induced chlorophyll fluorescence is an optical signal that is mechanistically linked to photosynthesis [*Gu et al.*, 2018], that can be measured from towers [*Grossmann et al.*, 2018; *Gu et al.*, 2019], aircraft [*Frankenberg et al.*, 2018] and satellites [*Frankenberg et al.*, 2011; *Joiner et al.*, 2011; *Sun et al.*, 2018]. Satellite-based SIF has displayed strong linear scaling with GPP inferred from ground-based flux towers [*Guanter et al.*, 2014; *Sun et al.*, 2017; *Verma et al.*, 2017; *Wood et al.*, 2017]. We will use OCO-2 SIF in conjunction with MODIS bidirectional reflectance function-corrected narrow band reflectances and employ a neural network downscaling technique to generate high spatial resolution (0.05°) maps [*Yu et al.*, 2018] of the PMRB and larger Amazon basin. This downscaled SIF will be used to examine the dynamics of productivity at QFR in relation to the larger PMRB and Amazonian basin. In addition, GPP from QFR and other AmeriFlux sites in the Amazon will be related to the downscaled SIF to assess generality of the GPP-SIF scaling relationship. Finally, we will use these results to inform a regional scale assessment of GPP in the PMRB using high resolution SIF maps and GPP-SIF scaling relationships. Using these data and analyses we will test **Hypothesis 7**.

3.4. Sub-ecosystem-scale measurements and processes

Hypothesis 8: *Palms and non-palm tree species will differ in their mediation of methane efflux, via both soil and aboveground fluxes, because of the differences in vasculature and presence of pneumatophores.*

Hypothesis 9: *The CH_4 budget estimated from sub-ecosystem scale measurements will indicate smaller fluxes than would be expected based on EC tower measurements because of systematic biases associated with the under-sampling of hot spots and hot moments (i.e. ebullition events).*

To enable the scaling of fluxes beyond the study site, it will be essential to partition fluxes between different plant functional types (PFT: palm vs non-palm trees). To help constrain and partition the ecosystem CO_2 and CH_4 budgets and attribute to sources, we will measure fluxes of CH_4 and CO_2 from soils, trees, and dead woody debris, stratifying this sampling between palm (*Mauritia flexuosa, Mauretiella armata* dominated) and non-palm trees (*Tabebuia insignis*, *Symphonia globulifera* dominated) plots [*Roucoux et al.*, 2013]. Our measurements will be informed by the existing measurement scheme of co-I Hinsby Cadillo-Quiroz, who has been conducting CH_4/CO_2 flux measurements near (< 1 km) of the flux tower site (**Figure 2**) in the same peatland and under the same vegetation cover for several years. These data will be critical for ELM model optimization and will be used to examine **Hypothesis 8**.

For soil fluxes, as well as dissolved pore water CH_4 measurements at 30 cm depth, Dr. Cadillo-Quiroz has established two 0.5 ha plots where 7 mini-plots contain two replicated static chambers in each (total chambers:14 per plot, or 28 per 1 ha of the site). The static chambers have been monitored monthly using a gas chromatograph (2016), and a CH_4 ultraportable middle infrared laser-based gas analyzer (Aeris Inc.) in tandem with a LI-600 CO_2 detection system (2017-2019). Data acquisition has been maintained all year round and during flooded periods where floating chambers were used. Tree stem measurements were established in 2017, and have revealed significant CH_4 emissions in the first 50 cm along *Astrocaryum murumuru, Hura crepitans,* and *Mauritia flexuosa* stems where CH_4 fluxes up to 88 mg-C m^{-2} h^{-1} have been observed (*Cadillo-Quiroz, unpublished data presented at the American Geophysical Union December 2015*). A full tree taxonomic inventory within the new plots of the tower flux footprint will allow us to select representative tree classes (species and stem size) to better upscale tree stem measurements for the new proposed tree flux measurements.

Building on this past data, but focusing in the area under the flux footprint of the EC tower, we will add intensive automated- and extensive manual chamber measurements to assess sub-ecosystem scale fluxes of CH_4 and CO_2, with higher resolution that in the past. During the non-flooded season, automated chambers (LI-8100 CO_2 analyzer, LI-7810 $CH_4/CO_2/H_2O$ analyzer, and LI-8150 multiplexer linked to 8 automated chambers) will be stratified by PFT within the core tower flux footprint area to develop continuous soil flux estimates. Radius for the measurements around the tower will be 30 m, for a footprint of 2830 m^2. Throughout the year, extensive static chamber-based manual measurements of gas fluxes will be used to fill sampling gaps in the outer footprint, stratifying across PFTs, including soil and coarse woody debris derived fluxes (1each/plot/week) and stem fluxes (1 for each of two dominant tree species/plot at three heights/stem/month) using custom manual chambers at 20 plots (**Figure. 2**). Foliar fluxes from Amazonian floodplain trees are considered to be negligible compared with stem emissions [*Pangala et al.*, 2017], so will not be analyzed here. However, if the Lagrangian analyses indicate otherwise we will design further experiments to address this need.

During the wet season when groundwater is above the surface, we will use floating chambers (1/plot) for static measurements of diffusive fluxes [*Pangala et al.*, 2017], and gas traps (1/plot) to capture ebullition fluxes [*Stamp et al.*, 2013], with the latter analyzed on a gas chromatograph. Ebullition events captured in autochambers, gas traps, and detected by the EC tower will be modelled using statistical techniques (i.e. regression, machine learning) using relevant environmental parameters (i.e. changes in atmospheric pressure, friction velocity, water table fluctuations, etc). Further, the chamber measurements of CH_4 fluxes will be used to partition total ecosystem scale methane flux into soil, coarse woody debris, and live tree emissions as a function of PFT. Field parameters affecting CH_4 flux from these ecosystem components, including soil temperature, soil moisture, water table depth, and atmospheric pressure, will also be recorded. The component fluxes and ecosystem scale fluxes will be used to constrain the net ecosystem exchange, comparing chamber-based methods of soil and plant-mediated flux upscaled using forest inventory data, vs. Lagrangian estimates of fluxes at different heights in the canopy (**Hypothesis 9**). This comparison will play a critical role in evaluating the land surface scheme ELM and assessing biophysical feedback processes, especially for developing distinct palm and non-palm tree PFTs that are proposed for improving the model (**Hypothesis 8**).

3.5. Biogeochemical CH_4 cycling informed by isotope studies:

Hypothesis 10: *AOM consumes 30 to 40% of gross CH_4 production at the QFR site and scales (increases) with respect to peat layer depth below the surface and will increase with peat temperature.*

Hypothesis 11: *Absolute rates of AOM will have low variability in deep layers of QFR (>50 cm) and a seasonal response in the upper layers with lower activity depending on the intensity and length of the rainy season and flooding, with lower rates under flooded conditions.*

The main pool of CH_4 in peatlands is located in the wet soils or under the water table. In QFR, co-I Cadillo-Quiroz, has recorded values of dissolved CH_4 at 30 cm depth ranging from 20 to 150 μmol/L in monthly records from 2017 to 2019. The fate of soil CH_4 before reaching the atmosphere can be affected by diffusion, ebullition, plant-mediated transport, or consumption aerobically and anaerobically (i.e. AOM) depending on soil conditions. AOM has been detected and quantified as a significant, but is often ignored in peatlands [*Smemo and Yavitt*, 2011; *Gupta et al.*, 2013; *Miller et al.*, 2019]. Further, CH_4 can be consumed on plant surfaces where methylotrophic or methanotrophic bacteria can live consuming atmospheric levels of CH_4 [*Sato et al.*, 2012; *Larmola et al.*, 2014; *Yoshida et al.*, 2014], and this also has not been quantified in tropical peatlands. Therefore, we propose that the modelling of CH_4 flux should include the dynamics of the CH_4 pool in soils and air column close to soils or vegetation given that the pool is not only affected by geochemical and production controls but also by consumption. Aerobic CH_4 consumption is addressed in **section 3.4**.

To address **Hypotheses 10 and 11**, we will complete measurements of CH_4 consumption *in vitro* (potential consumption) and *in situ* thus reflecting idealized and natural conditions. Isotope labeling experiments will be conducted to assess the importance of AOM. Lab measurements of potential consumption rates will be done at three different times per year (before flooding, during and after flooding) by vertical soil sampling an area near the automated and static flux chambers. Anaerobically collected soils will be incubated in slurries using the Hungate technique, degassed, and incubated with ^{13}C-CH_4. Change in overall CH_4 concentration will be measured for 1-2 months with gas chromatography, while ^{13}C-CO_2 shifts will be measured with a Picarro ^{13}C-CO_2 ^{13}C-CH_4 Isotopic Analyzer available at Arizona State University (Cadillo-Quiroz Lab). For estimating *in situ* AOM rates we will perform field ^{13}C labeling directly to the soil column.

For AOM, i*n-situ* peat columns that have been isolated from horizontal advection by installation of a PVC pipe. We will conduct three isotope labeling experiments between year 1 and 2. The main experiment will involve using in the field passive porous silicone tubes as diffusion chambers for the delivery of labeled gas (i.e. $^{13}C\text{-}CH_4$, at appropriate concentration) belowground for the *in-situ* determination of the net CH_4 oxidation based on $^{13}C\text{-}CO_2$ excess [*Fan et al.*, 2019; *Dorodnikov* 2019]. Tubes will be tightly closed from both sides with septa and allow for needle injection of appropriate gas after their installation at different soil depth (proposed at above water table and a depth of 35, 100, 150, 200 cm). CO_2 as the product of oxidation will be collected from the same chambers after 24 hours and labeling will be repeated afterwards. Values of $\delta^{13}C\text{-}CO_2$ from background (before $^{13}C\text{-}CH_4$ injection) and after injection will be recorded and the amount of the dissolved CH_4-derived C in CO_2 will be calculated using an isotope mixing model. In addition, the soils surrounding the $^{13}C\text{-}CH_4$ diffusion tubing will be collected to complete a stable isotope probing (SIP) analysis of the microbial communities consuming injected CH_4. If incubation time in field conditions is too short to generate ^{13}C-labeled DNA to be use in 16S rRNA amplification, we also propose to extract and store DNA from *in vitro* slurry incubations that based on previous research and its extended time of incubation (up to 2 months) are amenable to labeling. The results of this cellular labelling will allow us to define the active microbial constituents involved in cycling dynamics, which can be used for kinetic estimations of the activity of AOM.

Previous observations of the vertical profile of $^{13}C\text{-}CH_4$ in QRF at one time point and the dynamics of the dissolved methane pool at 30 cm depth for July 2017 until Nov 2018 (measurements are still ongoing in 2019), shows the dynamics of the dissolved CH_4 pool, are not simple and can be affected by a few drivers including AOM. To test **Hypothesis 11** regarding the temporal stability and seasonal change of AOM, we will combine isotopic enrichment experiments with the monitoring of natural isotope abundance at 4 depths (5, 15, 30 and 50 cm depth) monthly for a one year cycle to capture the shift in CH_4 and CO_2 isotope abundance resulting from the strong kinetic fractionation effects associated with methanogenesis and CH_4 oxidation. Methane from acetoclastic and CO_2 reduction pathways is depleted in ^{13}C on the order of 20–35‰ and ≥55‰, respectively, with concomitant equal enrichment of $^{13}CO_2$. In contrast, CO_2 produced by methanotrophy is depleted in ^{13}C by ~10‰ relative to the source CH_4, while oxidative (heterotrophic) respiration of other substrates gives rise to CO_2 with a similar isotopic signature as the source material.

4. Team Management Plan, Research synergies, and capacity building: This project represents a major collaborative effort among 9 principal investigators or senior personnel and their respective research groups. All personnel are committed to sharing the data and resources in order to meet the overall objectives, research and outreach/education goals, and science questions outlined in the Project Narrative. Many of the principal investigators have collaborated on past projects and publications for over 15 years now. To ensure systematic and efficient coordination of the combined research and educational activities and to maximize the communications among the principal investigators and their associated research groups, Dr. Griffis will serve as the Project Director and Dr. Erik Lilleskov were serve as the Co-Project Director. Ecosystem modeling will be led by Ricciuto with close collaboration from the rest of the team in providing needed parameterization. Tower EC flux work will be led by Griffis, with support from Fachin, Kolka, and Roman. The inverse Lagrangian budget analyses will be led by Wood and Griffis. Sub-ecosystem flux work will be led by Lilleskov, Chimner, and Kolka, with input from Cadillo-Quiroz to coordinate with prior flux work. Biogeochemical/AOM analyses will be led by Cadillo-Quiroz. Site management and overall local coordination of Quistococha activities will be led by del Castillo with support from Fachin.

Dr. Griffis and Dr. Lilleskov will organize progress reports from the principal investigators into a comprehensive report for submission, as appropriate. Initial PI meeting after funding will delineate modeling needs and coordinate efforts to structure empirical work to support modeling. Subsequent regular meetings (monthly) among the principal investigators (*via* teleconference) will be held to plan the details of the field studies, discuss measurements, and integrate the results of our studies into the modeling effort. An internal web site (managed by Griffis) will be used to post project updates, share data, prepare manuscripts and presentations, etc. Drs. Griffis, Lilleskov, and Kolka will work closely with all members to ensure that all milestones are met and that results and data products are delivered on time as outlined below.

Our team includes collaborations among several institutions. Noteworthy is the strong ties our team has built with USAID and IIAP. This collaboration has helped to establish the Quistococha AmeriFlux site. Further, we have helped train students and staff at IIAP in micrometeorological and trace gas flux measurement techniques. As part of this project, US and Peruvian students (and postdocs) will be recruited to solidify the collaboration and capacity building among our groups. As Peru does not have educational infrastructure to support their training, their students will visit US Universities (i.e. University of Minnesota, Arizona State University, University of Missouri) to gain theoretical and practical training related to the research activities at QFR. They will also be directly involved with the production of scientific papers and practical carbon management recommendations for the local government as outcomes of their research. In addition, a critical element of the institutionalization capacity is that an IIAP permanent research scientist Lizardo Fachin will also be trained in all facets of micrometeorological and trace gas measurement methods, guaranteeing institutionalization of the research capacity. As part of US investigators traveling to the QFR research site, we will ensure training opportunities in the field and workshops at IIAP headquarters each year.

5. Timetable of activities and milestones

<u>Fall/Winter 2019</u>

- Establish intensive and extensive sampling networks for sub-ecosystem scale measurements
- Field sampling and *in vitro* AOM incubation (one per semester, starting Winter 2019 finishing winter 2020)
- Establish concentration profile system for eddy covariance storage calculations and Inverse Lagrangian budget analyses

<u>Spring/Summer 2020</u>

- Sample for sub-ecosystem fluxes
- Dissolved methane Isotopic monitoring Starting Summer 2020 finishing Fall 2021
- Monitoring of dissolved CH_4 starting summer 2020 ending Fall 2022
- Eddy flux processing and budget analyses related to energy, CO_2, and CH_4 fluxes
- QA/QC all data products and archive (**see data management plan**)
- Team workshop meeting at IIAP headquarters (Iquitos, Peru) for ecosystem flux/modeling tutorial

<u>Fall/Winter 2020</u>

- Sample for sub-ecosystem fluxes
- Submit all micrometeorological data to the AmeriFlux program (**see data management plan**)
- Conduct wavelet coherence analyses to study controls on CH_4 emissions
- Collect satellite SIF products for regional GPP analyses
- Begin ELM parameter optimization – **use model results to inform new field experiments**
- Present preliminary results at key society meetings (i.e. American Geophysical Union)

<u>Spring/Summer 2021</u>

- Sample for sub-ecosystem fluxes
- Team workshop meeting at IIAP headquarters (Iquitos, Peru) for ecosystem flux/modeling tutorial
- Conduct wavelet and eddy covariance analyses for ebullition detection

Fall/Winter 2021

- Sample for sub-ecosystem fluxes
- Field sampling and *in situ* AOM experiments (open per term, starting Fall 2020; finishing summer
- Microbial sequencing and analysis of SIP DNA (starts Fall, ends summer 2022)
- Begin inverse Lagrangian budget analyses
- Finalize ELM parameter optimizations
- Present preliminary results at key society meetings (i.e. American Geophysical Union)

Spring/Summer 2022

- Sample for sub-ecosystem fluxes
- Team workshop meeting at IIAP headquarters (Iquitos, Peru) for ecosystem flux/modeling tutorial
- Begin ELM biophysical feedback analyses and long-term CH_4 emission estimates based on climate change scenarios
- Compare scaling of ecosystem components with eddy covariance and Lagrangian budgets

Fall 2022

- Analyze subecosystem fluxes, integrate with tower, and develop palm/non-palm PFTs for models
- Estimate net ecosystem CO_2 exchange and GPP for tower site
- Assess inter-annual variability in CO_2 and CH_4 budgets
- Assess SIF-GPP relations and examine how representative the research site is within the region
- Finalize ELM climate change budget analyses over period 2020 to 2080
- Present preliminary results at key society meetings (i.e. American Geophysical Union)

Manuscript Development

We envision eight primary manuscripts related to this research effort with others likely to evolve from ongoing field experiments, data and model analyses, and synergistic activities.

- The importance of recently fixed CO_2 and its influence on CH_4 production
- Partitioning CH_4 oxidation into it aerobic and anaerobic components
- The anaerobic oxidation of CH_4 (AOM) sink strength in tropical peatlands
- Use of stable isotope probing to measure microbial contribution to methane flux (methanogenesis and methane consumption) in tropical peatlands
- Measurement constraints on CH_4 emissions from diffusive, ebullition, and plant-mediated transport based on bottom-up (chambers) and top-down (flux tower) methods
- Modeling CH_4 production and consumption in a tropical peatlands
- Evaluating the sensitivity of CH_4 emissions to environmental controls within the ELM
- How will tropical peatland CH_4 emissions respond to climate change over the period 2020 to 2080?

22 March 2019

Tim Griffis, Professor of Biometeorology
Dept. Soil, Water, & Climate
University of Minnesota - Twin Cities
1991 Upper Buford Circle
St. Paul, MN, 55108

Dear Prof. Griffis:

Thank you for including us in the proposal to the US Department of Energy entitled "Biophysical processes and feedback mechanisms controlling the methane budget of an Amazonian peatland." We are excited to advance this research program at our Quistococha Reserve. We understand that if funded we will have a subaward budget from the University of Minnesota of $88,330 that will be managed by co-principal investigator Dennis del Castillo Torres. We also understand this work is proposed to occur between 1 September 2019 and 31 August 2022. The Instituto de Investigaciones de la Amazonia Peruana (IIAP) is committed to this effort and will carry out our portion of the work if funded.

Sincerely,

PRESIDENCIA

Mónica Muñoz Nájar Gonzales
Presidente Instituto de Investigaciones de la Amazonía Peruana

RESEARCH & RELATED BUDGET - Budget Period 1

OMB Number: 4040-0001
Expiration Date: 10/31/2019

ORGANIZATIONAL DUNS: 9347257630000 **Enter name of Organization:** Instituto de Investigaciones de la Amazonia Peruana

Budget Type: ☐ Project ☒ Subaward/Consortium **Budget Period: 1** **Start Date:** 09/01/2019 **End Date:** 08/31/2020

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Dr.	Dennis		del Castillo Torres		28,800.00	1.00			2,400.00	0.00	2,400.00
Project Role: PD/PI											
Mr.	Lizardo	Manuel	Fachin Malaverri		18,000.00	4.00			6,000.00	0.00	6,000.00
Project Role: Senior/key person											

Additional Senior Key Persons: Add Attachment | Delete Attachment | View Attachment

Total Funds requested for all Senior Key Persons in the attached file:

Total Senior/Key Person: 8,400.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	Field technician	10.00			10,500.00	1,500.00	12,000.00
1	**Total Number Other Personnel**					**Total Other Personnel**	12,000.00

Total Salary, Wages and Fringe Benefits (A+B): 20,400.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment item	Funds Requested ($)

Additional Equipment: Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file	
Total Equipment	

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2. Foreign Travel Costs	
Total Travel Cost	

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	1,636.00
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	3,000.00
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. Accident Insurance	700.00
9.	
10.	
Total Other Direct Costs	5,336.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	25,736.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
de minimus rate of 10% MTDC	10.00	24,236.00	2,424.00
		Total Indirect Costs	2,424.00

Cognizant Federal Agency (Agency Name, POC Name, and POC Phone Number):

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	28,160.00

J. Fee

	Funds Requested ($)

K. Total Costs and Fee

	Funds Requested ($)
Total Costs and Fee (I + J)	28,160.00

L. Budget Justification

(Only attach one file.) BUDGET JUSTIFICATION IIAP.pdf

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Budget Period 2

OMB Number: 4040-0001
Expiration Date: 10/31/2019

ORGANIZATIONAL DUNS: 9347257630000

Enter name of Organization: Instituto de Investigaciones de la Amazonia Peruana

Budget Type: ☐ Project ☒ Subaward/Consortium

Budget Period: 2 **Start Date:** 09/01/2020 **End Date:** 08/31/2021

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Dr.	Dennis		del Castillo Torres		28,800.00	1.00			2,400.00	0.00	2,400.00
Project Role: PD/PI											
Mr.	Lizardo	Manuel	Fachin Malaverri		18,000.00	4.00			6,000.00	0.00	6,000.00
Project Role: Senior/key person											

Additional Senior Key Persons: [ ] Add Attachment | Delete Attachment | View Attachment

Total Funds requested for all Senior Key Persons in the attached file:

Total Senior/Key Person: 8,400.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	Field technician	10.00			10,500.00	1,500.00	12,000.00
1	**Total Number Other Personnel**						

Total Other Personnel: 12,000.00

Total Salary, Wages and Fringe Benefits (A+B): 20,400.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment item	Funds Requested ($)

Additional Equipment: Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file	
Total Equipment	

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2. Foreign Travel Costs	
Total Travel Cost	

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	636.00
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	7,500.00
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. Accident Insurance	700.00
9.	
10.	
Total Other Direct Costs	8,836.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	29,236.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
de minimus rate of 10% MTDC	10.00	27,736.00	2,774.00
		Total Indirect Costs	2,774.00

Cognizant Federal Agency
(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	32,010.00

J. Fee

	Funds Requested ($)

K. Total Costs and Fee

	Funds Requested ($)
Total Costs and Fee (I + J)	32,010.00

L. Budget Justification

(Only attach one file.) BUDGET JUSTIFICATION IIAP.pdf

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Budget Period 3

OMB Number: 4040-0001
Expiration Date: 10/31/2019

ORGANIZATIONAL DUNS: 9347257630000

Enter name of Organization: Instituto de Investigaciones de la Amazonia Peruana

Budget Type: ☐ Project ☒ Subaward/Consortium

Budget Period: 3 **Start Date:** 09/01/2021 **End Date:** 08/31/2022

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Dr.	Dennis		del Castillo Torres		28,800.00	1.00			2,400.00	0.00	2,400.00
Project Role: PD/PI											
Mr.	Lizardo	Manuel	Fachin Malaverri		18,000.00	4.00			6,000.00	0.00	6,000.00
Project Role: Senior/key person											

Additional Senior Key Persons: [Add Attachment] [Delete Attachment] [View Attachment]

Total Funds requested for all Senior Key Persons in the attached file:

Total Senior/Key Person: 8,400.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	Field technician	10.00			10,500.00	0.00	10,500.00
1	**Total Number Other Personnel**						

Total Other Personnel: 10,500.00

Total Salary, Wages and Fringe Benefits (A+B): 18,900.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment item	Funds Requested ($)

Additional Equipment: [ ] Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file	
Total Equipment	

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2. Foreign Travel Costs	2,500.00
Total Travel Cost	2,500.00

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
[ ] **Number of Participants/Trainees** — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	500.00
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	3,000.00
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. Accident Insurance	700.00
9.	
10.	
Total Other Direct Costs	4,200.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	25,600.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
de minimus rate of 10% MTDC	10.00	25,600.00	2,560.00
		Total Indirect Costs	2,560.00

Cognizant Federal Agency
(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	28,160.00

J. Fee

	Funds Requested ($)

K. Total Costs and Fee

	Funds Requested ($)
Total Costs and Fee (I + J)	28,160.00

L. Budget Justification

(Only attach one file.) BUDGET JUSTIFICATION IIAP.pdf | Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Cumulative Budget

		Totals ($)
Section A, Senior/Key Person		25,200.00
Section B, Other Personnel		34,500.00
Total Number Other Personnel	3	
Total Salary, Wages and Fringe Benefits (A+B)		59,700.00
Section C, Equipment		
Section D, Travel		2,500.00
1. Domestic		
2. Foreign	2,500.00	
Section E, Participant/Trainee Support Costs		
1. Tuition/Fees/Health Insurance		
2. Stipends		
3. Travel		
4. Subsistence		
5. Other		
6. Number of Participants/Trainees		
Section F, Other Direct Costs		18,372.00
1. Materials and Supplies	2,772.00	
2. Publication Costs		
3. Consultant Services		
4. ADP/Computer Services		
5. Subawards/Consortium/Contractual Costs	13,500.00	
6. Equipment or Facility Rental/User Fees		
7. Alterations and Renovations		
8. Other 1	2,100.00	
9. Other 2		
10. Other 3		
Section G, Direct Costs (A thru F)		80,572.00
Section H, Indirect Costs		7,758.00
Section I, Total Direct and Indirect Costs (G + H)		88,330.00
Section J, Fee		
Section K, Total Costs and Fee (I + J)		88,330.00

BUDGET JUSTIFICATION

Indirect Costs

De minimus rate of 10% modified total direct cost (MTDC)

Senior/Key personnel.

PI Dennis del Castillo: One month of salary at $2,400/month for three years to oversee the IIAP contributions to the project, coordinate with other collaborators. $2,400/month x 3 yr = $7,200/yr total

Senior personnel Lizardo Fachin Malaverri: Four months of salary at $1,500/month for three years to be the IIAP technical lead on the flux tower, overseeing day to day tower maintenance and contribute to data processing and analysis. $1500/month x 4 = $6000/yr x 3 yr = $18,000 total

Total senior personnel = $7,200 + $18,000 = $25,200 total. Note there is fringe benefits at IIAP.

Other personnel

Technician ten months of salary at $1,050/month to carry out day to day work on the tower and to carry out ground-based flux measurements. $1,050 x 10 = 10,500/yr x 3 yr = 31,500 total

Two years of support for MS tuition at a local Peruvian university for the technician on the project at $1500/yr x 2yr = $3000 total

Foreign Travel

$2500 in year three to partially cover travel to an international meeting such as AGU. Total = $2,500

Other Direct

Materials and Supplies

Supplies in support of tower climbing and maintenance activities, including helmets, harnesses, rope, calibration gases, multimeters, tubing, etc. $1636 yr 1 + $636 yr 2 + $500 yr 3 = $2,772 total.

Contracts

$7,500 in year two for a maintenance contract for the flux tower, including replacement of tower guy wires, repairs to tower structure, painting of tower components. $7,500 total

$3,000 in years 1 and 2 to pay a contractor to maintain the boardwalk access to the tower. This boardwalk is in need of continual maintenance because of the warm wet conditions that are continually degrading the boardwalk. $3,000/yr x 2 yr = $6,000.

Total contracts = $7,500 + $6,000 = $13,500 total

Accident Insurance

Accident insurance is critical for IIAP personnel working in the field and on the tower, who are otherwise uninsured by their employers.

It costs $350/yr per person x 2 field personnel x 3 years = $2,100 total