PANGEA Draft White Paper

[NASA Tropical Ecology Scoping Solicitation](https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=860588/solicitationId=%7BEB63A640-7CE0-70F6-BE80-C12541C56B5F%7D/viewSolicitationDocument=1/A.4%20Terrestrial%20Ecology%20Amend%2036.pdf)

ABoVE White Paper: [ABoVE Final Scoping Report 2010.pdf](https://drive.google.com/file/d/1r9vFP5H4r7QVy379OSeGuPAWdINTQuRj/view?usp=sharing)

***From Solicitation:***

The main deliverable will be a scoping report that lays out the scientific issues at stake, the logistical framework, and one or more paths forward toward implementation. Scoping studies will be required to address the following elements:

1. The science questions and issues
2. The current state-of-the-science
3. The potential for a major, significant scientific advancement
4. The central, critical role of NASA remote sensing
5. The essential scientific components of the study and why coordinated teamwork is required in their implementation
6. An overall study design identifying the required observational (e.g., spaceborne, airborne, and/or supporting in situ observations) and analytical (e.g., models, data, and information system) infrastructure
7. The feasibility of the proposed project, both technical and logistical
8. The engagement of the broader research community to seek feedback on the ideas, to assess interest, and to foster diversity and inclusion
9. The disciplinary skills needed to conduct the study and engage potential partners in their planning activities
10. Potential use of results for applications and decision support.

Scoping studies must produce a written report that **provides the scientific rationale and an initial study design concept** for a new field campaign or related team project. While this report need not be lengthy, it **must include a thorough presentation of science questions, goals, and objectives; the underlying rationale in terms of state-of-the-art, relevance, and expected advances; implementation concepts**; and other information to enable NASA to fully evaluate the project.

**[LOGO]**

**The PAN tropical investigation of bioGeochemistry and Ecological Adaptation (PANGEA): A Concise Plan for a NASA-Sponsored Field Campaign**

**Draft Report**

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**Foreword**

NASA’s Research Opportunities in Space and Earth Sciences released in 2022 called for proposals to conduct scoping studies to identify the scientific questions and develop the initial study design and implementation concept for a new NASA Terrestrial Ecology field campaign. In the spring of 2023, NASA selected two projects for funding, including a project entitled: “*A Scoping Study for the NASA Tropical Terrestrial Ecology Campaign”* (NASA Grant 80NSSC23K1019 to the University of California, Los Angeles). This report contains the recommendations from this scoping study, which presents the **PAN tropical investigation of bioGeochemistry and Ecological Adaptation (PANGEA).** NASA outlined ten expectations to be identified for each scoping study:

1. The science questions and issues.
2. The current state-of-the-science.
3. The potential for a major, significant scientific advancement.
4. The central, critical role of NASA remote sensing.
5. The essential scientific components of the study and why coordinated teamwork is required in their implementation.
6. An overall study design identifying the required observational (e.g., spaceborne, airborne, and/or supporting in situ observations) and analytical (e.g., models, data, and information system) infrastructure.
7. The feasibility of the proposed project, both technical and logistical.
8. The engagement of the broader research community to seek feedback on the ideas, to assess interest, and to foster diversity and inclusion.
9. The disciplinary skills needed to conduct the study and engage potential partners in their planning activities.
10. Potential use of results for applications and decision support.

In this white paper, we XXX.

**Acknowledgments**

**Biogeochemical Cycles & Carbon Dynamics:**

**Ecosystem Structure, Function & Biodiversity:**

**Social-Ecological Systems:**

**Climate Feedbacks & Interactions:**

**Community Engagement & Research Applications:**

**Table of Contents**

[**1. Introduction and Motivation 7**](#_k34ngprcwpga)

[1.1 Science Questions and Objectives/Issues 9](#_f43eyfjc03r4)

[1.2 PANGEA Science Themes 10](#_cyg5djpq2r2c)

[1.3 Role of Remote Sensing Observations 10](#_521zhe1ijge9)

[1.4 PANGEA Study Domain 11](#_szwuuhpl6jrs)

[**2. PANGEA Science Themes 12**](#_67ufwhve0n98)

[2.1 Biogeochemical Cycles and Carbon Dynamics 12](#_ykkfx91lnxr)

[2.2 Ecosystem Structure, Function, and Biodiversity 13](#_h53zsa9y2giw)

[2.3 Climate Interactions and Feedbacks 14](#_stmvw8hd42mo)

[2.4 Social-Ecological Systems 16](#_thgadem9pj58)

[2.5 Enabling Earth Science to Action 19](#_25c81bcwumhk)

[**3. Research Strategy and Study Design 20**](#_krtr9hnd65qf)

[3.1 Overall Design / Approach 20](#_a7rsc2zcb4s)

[3.2 Scaling Strategy 21](#_qeoxw1u7i7b0)

[3.3 Candidate Study Sites / Regions 21](#_rt2hahfr5phm)

[3.3 Satellite Remote Sensing Observations 23](#_8hvwu2pr0zwb)

[3.4 Airborne Remote Sensing Observations 23](#_tvm98o3pux72)

[3.5 Field Observations, Studies, Experiments 24](#_7locis78pd28)

[3.6 Modeling and Integrative Analyses 24](#_f11ajoxckysx)

[3.7 Technical and Logistical Feasibility/ Issues 24](#_1smg2g6mkz5h)

[**4. Organization and Management 26**](#_zcnistoad9yt)

[4.1 Scientific Leadership 26](#_qehjbydfrdgv)

[4.2 Project Organization 26](#_d22q1idfjrqr)

[4.3 Field Operations 26](#_86samrvtiytv)

[4.4 Data Management and Sharing 26](#_igdor1b4j3oc)

[4.5 Timetable 28](#_f0glc3cmn1d)

[**5. Community Engagement 28**](#_ew9ozfnr9qlx)

[5.1 Community Engagement Methods during the PANGEA Scoping Campaign 28](#_oxsrjdaxwwmp)

[5.2 Community Engagement during the PANGEA Program 29](#_36r59k3txf8h)

[5.2.1 Alignment with existing NASA efforts 30](#_7lqzpkrhhlc7)

[5.2.2 Indigenous Peoples and local communities 31](#_n8zienedm11e)

[5.2.3 Scientific Institutions 31](#_glsb0arf4prz)

[5.2.4 Government agencies 32](#_s9ee7zozhnl)

[5.2.5 Non-governmental organizations 32](#_41yg8zuo2zsk)

[5.2.6 Intergovernmental organizations 32](#_f6ec2jt44lrn)

[5.2.7 Private sector 32](#_us8jjwxp2vb)

[5.2.8 Women 34](#_kfrmrtpvs17c)

[5.2.9 Donor community 34](#_j5dmv8ifpvgl)

[5.3 PANGEA Partners 34](#_snp7kz6sl5x6)

[5.3 Capacity Building, Training, and Education 35](#_8t6ay0v9gizk)

[5.4 Limitations 35](#_n6p8ovtnhgkd)

[**6. Required Resources and Coordinated Teamwork 36**](#_holoc4bxi14m)

[6.1 Disciplinary skills needed 36](#_q05ndsu4lq59)

[6.2 Field Infrastructure 36](#_pua32mp6t3e7)

[6.3 Suborbital Platforms and Sensors 36](#_6c2uwkfc8y82)

[6.4 Satellite Data Availability, Access, and/or Purchase 36](#_qotvmdehk31u)

[6.5 International and Other Agreements 36](#_duixp9495bxf)

[6.5.1. NASA airborne campaign Indigenous agreements, permissions, and treaties (KEEP this section) 36](#_44zh5ia5coj2)

[6.6 Cost Estimates 36](#_p91su4asg6fq)

[**6. Issues to be Resolved 36**](#_snqbbghpa3qt)

[**7. References 36**](#_c36m01esiuds)

[**8. Figure and Photograph and Credits 36**](#_z4vei7kqp4a)

[**9. Glossary 36**](#_crm1yggb334o)

[**10. List of Acronyms 38**](#_pzrw4c5s7tpd)

[**11. Appendices 38**](#_rymy755ymrd5)

[A - Planned and Ongoing Research and Monitoring Activities 38](#_969urlcnvqlw)

[B - Summary of Level II and III Ecoregions in PANGEA Study Region 38](#_79hvy15uphw)

[C – Summary of Airborne and Spaceborne Remote Sensing Systems for PANGEA 38](#_6akhrmoqr5g7)

[D - Summary of PANGEA Participants 38](#_ud6tg3r5l8q3)

[E - Letters of Support 39](#_u0cqs6788e4p)

[**6. Stuff that’s beyond scope that could be developed in collaboration with PANGEA 40**](#_ffo9zvtu7fi)

## 

## 1. Introduction and Motivation

In response to a call from the NASA Terrestrial Ecology Program, we present the scope of a terrestrial ecology field campaign, *The PAN tropical investigation of bioGeochemistry and Ecological Adaptation* (PANGEA), that will focus on the tropical forest biomes. PANGEA will answer big science questions emphasizing comparison among the major tropical forest formations on our planet through effective interpretation and analysis of space-based measurements and through a combination of ground, airborne, and satellite-based science investigations. PANGEA will foster collaborations and build new relationships within the scientific community with a special emphasis on interactions among US scientists and scientists from tropical forest countries, and provide opportunities for training and educating the next generation of scientists including obligatorily scientists from countries where field research will be based. PANGEA will leave a legacy of open data, open science, and strengthened partnerships between the US and tropical institutions as the basis for future research.

Tropical forests represent 45% of the world’s forested area, of which less than 40% of the total extent is in Brazil, the Democratic Republic of the Congo and the mega-islands of the tropical East (Hartshorn, 2013). Tropical forests regulate climate locally, regionally, and globally and retain the greatest share of biodiversity of any terrestrial biome. Tropical forests store vast amounts of carbon [quantify] (REF) and provide the critical global service of removing carbon dioxide from the atmosphere rapidly, especially in young tropical forests (REF). In contrast, tropical deforestation and degradation account for X% of annual anthropogenic carbon dioxide emissions (REF). Control of tropical deforestation and forest degradation and regeneration of tropical forest carbon can be a cost-effective tool for mitigating climate change. Tropical forests maintain high levels of evaporation and transpiration throughout the year, transferring energy and water to distant latitudes and maintaining the high rates of regional precipitation through rainfall recycling (Salati et al. 1979; recent refs Amazon; Worden et al. 2021; Worden et al. 2024). Deforestation and forest degradation reduce evapotranspiration in the dry season (Sampaio et al. 2007; Longo et al. 2020; recycling models refs) potentially leading to forest mortality and a positive feedback loop resulting in forest ecosystem collapse that has been called a “tipping point” (Lovejoy and Nobre 2018).

Tropical forests are highly threatened by climate change and land use change. Forests in the hot equatorial regions will soon experience the highest known temperatures since

the Eocene which, combined with land-use change, will lead to increasing atmospheric dryness and water stress (Barkhordarian et al 2019). Tropical tree mortality rates are rising differentially across the tropics due to increases in drought duration and severity and storm intensity (Allen et al 2010, McDowell et al 2018, Choat et al 2012). Tropical forest canopy temperatures are more frequently dangerously close to the critical temperature (~47⁰ C), at which irreversible damage to the photosynthetic machinery occurs (Doughty et al. 2023). Unprecedented rates of anthropogenic land-use change in recent decades (DeFries et al 2004, Gibbs et al 2010a, Hosonuma et al 2012) have resulted in some tropical forests becoming net-sources of carbon to the atmosphere (Gatti et al 2021). Prolonged hot and dry conditions increase forest vulnerability to fires and already burned forests in turn become hotter and drier leading to a positive feedback that has been called a “gathering firestorm” (Brando et al. 2020).

[punchy first sentence - evidence] The biogeochemical response of tropical forests to changing climate forcing and climate extremes is not consistent across the globe. From 1985 through 2015, the carbon sink of intact African lowland tropical forests measured in forest inventory plots was effectively constant while the carbon sink in Amazonian lowland tropical forests declined by one-third from 2005 through 2015 compared to the 1990s (Hubau et al. 2020; Brienen at al. 2015). Under El Niño conditions during 2015-2016, tropical America, Africa, and East Asia, all had similar net released CO2 to the atmosphere (Liu et al. 2017). However, heterogeneous processes determined these net carbon losses (Figure 1). **We cannot explain with confidence why different tropical forest biomes are responding differently to similar climate forcing with our current understanding of tropical forest ecology and biogeochemistry.**

Future predictions of the role of the tropical carbon land flux in the Earth system also remain highly uncertain (REFS). The current uncertainty in terrestrial carbon flux predictions across Earth System Models (ESMs) is three times greater in the tropics than at any other latitude (Cavaleri et al 2015). [more here - reference Friedlingstein et al 2022 - CMIP5 to CMIP6 updates, but remaining uncertainties regarding processes - are we getting the right answers for the right reasons - and need for improved RS data model integration]

Critically, tropical forests are also the least investigated of all of the Earth’s major biomes. Few tropical forest countries maintain systematic repeated forest inventories because inventories are costly and require technical and management expertise. Collections of research plots provide valuable insights into forest dynamics, but their distribution is sparse and extrapolation from potentially biased plot locations may lead to significant uncertainties and biases (Saatchi et al., 2015). Perversely, latitudinal distribution of both forest inventory plots and eddy covariance flux towers is nearly inversely proportional to gross primary productivity (Baldocchi et al 2022, Schimel et al. 2015) (Figure X).

A hallmark of PANGEA is its commitment to community-engaged research. By engaging communities traditionally left behind in major and international projects from the beginning, PANGEA is poised to …

* state that this is feasible and necessary
  + the lack of cal-val data in the tropics, XXX
  + we HAVE to do this to understand XYZ
  + we need this global context that we can only get from remote sensing
* **Societal need** - lots of people depend on those forests
  + local, regionally, or globally
* **Urgency/Timeliness** - need to do this now - why this should be the next campaign; why we can’t wait another 5-10 years
  + tropical ecosystems, and in our data-rich era of new dimensionality effectively utilize current and forthcoming satellite missions to diagnose the current state of tropical forests
* we learned from LBA that by adding new components and integrating / interdisciplinarity results in the pie growing for everybody
* **Embed within Earth Science to Action Strategy** 
  + PANGEA is an opportunity to integrate!!!
  + CC&E umbrella logical place to start
  + but emphasize integration beyond CC&E
  + integrate across R&A and Applied
* equitable science and not extractive science

### 1.1 Science Questions and Objectives/Issues

As a result of climate change and land-use change, the globally important tropical carbon balance, heretofore mainly a sink, is now often reversing to become a source of carbon emissions to the atmosphere in response to extreme events and climate and land-use change feedbacks. Critically, the tropical forest landscapes appear to differ in their recent carbon sink trends, sensitivity to extreme events, and interactions with climate and land-use change. Understanding long-term tropical carbon flux trends and the resilience of the tropical carbon sink to extreme events has globally important implications and requires an improved understanding of patterns and processes. PANGEA aims to answer the following overarching research question:

**~~How vulnerable or resilient are tropical ecosystems and society to carbon cycle perturbations and environmental change in the tropics?~~**

**Over the past decades, the tropical forest carbon flux has represented a globally important sink of atmospheric carbon. As a result of climate change induced extreme events and land-use change feedbacks, this sink is now often reversing to become a source of carbon emissions to the atmosphere in response to extreme events and climate and land-use change. However, this reversal does not appear uniform, with tropical forest landscapes differing in their recent carbon sink trends, sensitivity to extreme events, and interactions with climate and land-use change. Understanding the controls on tropical forest carbon flux, the resilience of the sink to climate warming and drying trends, and the response of the carbon sink to extreme events has globally important implications and requires an improved understanding of patterns and processes in tropical forests.** [1-2 more paragraphs in the white paper after this about why this is uniquely suited to satellite remote sensing → the central, critical role of NASA remote sensing]

* Data-rich and model-rich moment
* We now have remote sensing capabilities that allow for more direct measurement of diversity (structural, functional, maybe taxonomic)
* We now have numerical models that represent processes that mediate forest diversity the interactions of structurally heterogeneous forests with climate, land use and biogeochemical cycles
* Also cloud computing / computational resources
* But we can’t use those satellite data effectively without coordinated cal/val measurements
* Cut and paste from ROSES solicitation, and reviewer comments, and slide that emphasizes things from solicitation
* Tropical forests have a major role on global climate and teleconnections with non-tropical climate

PANGEA will study the complex interactions of society and the carbon cycle in the tropics by addressing the following questions.

1. **How does ongoing and projected changing climate impact the resilience of the tropical carbon sink, and how does the weakening of the carbon sink feedback on climate-related events (e.g., drought, biomass burning)?**
2. **How does variation in biodiversity, ecosystem structure and function, land-use change, and human interactions within and among regions in the tropics contribute to geographic variation in tropical forest responses to climate change?**
3. **How will potential future changes to the tropical terrestrial carbon flux interact with geographical variation in ecosystem structure, function, biodiversity, and human interactions to influence climate feedbacks, biogeochemical cycles, and society?**

### 1.2 PANGEA Science Themes

### 1.3 Role of Remote Sensing Observations

* We cannot answer the big questions of PANGEA without pan-tropical satellite observations, integrative analyses, and models.
* Need to clearly state the rationale for why a campaign is needed
  + Why does this require going beyond the use of just satellite data or just ground data?
* point to satellite observations and drone and airborne capabilities for scaling
* Link science themes and questions to variables, measurements, and geographies
  + 'scoping' traceability matrix
* Emphasize data fusion
  + Carlos Silva (and Laura Duncanson?) [has CMS funded project](https://carlos-alberto-silva.github.io/silvalab/cms4d/cms4d_workshop.html) that emphasizes data fusion
    - Include as case study of data-model fusion and stakeholder engagement
    - iterative process
    - Carlos in Brazil - August and September, but otherwise can help with figures and text

RS related methods advances enabled by PANGEA

* Cal/Val and algorithm development
  + SBG, CHIME, ECOSTRESS, NISAR, BIOMASS, OCO-2/3, SMAP, GRACE,
* Model-[RS] data integration
  + Processes we need to get right in models
    - Dynamic vegetation (incl post-disturbance recovery and structural and functional diversity)
    - Plant water use efficiency
    - Drought stress response (incl. natural vs. managed lands)
    - Partitioning of ET
    - Hydraulic redistribution
    - Root-groundwater interactions
    - Surface water quality
    - Planetary boundary layer diurnal evolution, advection, and entrainment
    - Drivers of land-use change?
    - Feedbacks of climate change in tropics on people (e.g., ag production, water quantity and quality, fire & air quality)
* RS indicators of:
  + Vulnerability to tree mortality
  + Biodiversity – in most biodiverse region (what taxonomic/functional scales of diversity matter for carbon cycle dynamics?)
* Improved climate model predictions for the tropics (has global climate prediction implications)
  + ERA5 and CHIRPS discrepancies / lack of weather stations
  + Land-atmosphere interactions

### 1.4 PANGEA Study Domain

* Modeling and satellite RS at pan-tropical scale
  + Specify domain still - see FAO boundaries
  + Includes moist tropical forests, wetlands, peatlands, mangroves
  + include montane forests??
* Coordinated ground, tower, drone, and aircraft measurements will be collected in landscapes that capture variation in ….
  + See Section X for more detailed information

## 2. PANGEA Science Themes

### 2.1 Biogeochemical Cycles and Carbon Dynamics

In recent decades, tropical forest regions have been a strong and persistent carbon sink. As a result of climate change and land-use change, the tropical carbon sink is now fragile, at times reversing to become a source of carbon emissions to the atmosphere in response to extreme events. Critically, tropical forests appear to differ in their sensitivity to extreme events and future climate and land-use change feedbacks. We do not currently know how sensitive tropical forest regions are, how much that sensitivity differs across continents, or the mechanisms that account for those differences.

1. **How do geographic variations in species composition, land-use, climate regimes, aquatic water bodies, and edaphic properties contribute to differences in carbon cycling (CO2 and CH4)?**
   1. How do changing hydroperiods, river connectivity, and land-use affect carbon source/sink behavior of tropical flooded and wetland forests?
   2. What is the spatial distribution of soil carbon stocks across tropical forests, and how do climate and land-use change, edaphic controls, aboveground stocks, and biomass carbon residence time drive the variability in soil carbon stocks?
   3. How does variability in primary biological and physicochemical factors drive CH4 and CO2 fluxes from tropical inland waters, floodplains, and wetlands?
2. **How are current and historical trends and variability of carbon cycling linked to variation in soil nutrient availability and fluxes of nitrogen and phosphorus?**
   1. How do nitrogen and phosphorus limitations on tropical forest carbon stocks and fluxes vary across the tropics?
   2. Does variation in land-use and land cover change within and between tropical continents affect nutrient dynamics and limitation?
   3. How does broader variation in soil physical and chemical properties interact with N and P limitations to control tropical forest productivity and carbon storage?
   4. What is the relative role of climate change, elevated CO2, nutrient deposition, and land cover on the current and historical trends in vegetation and soil carbon stocks, as well as carbon fluxes (photosynthesis, respiration)?
3. **How do disturbances (e.g. droughts, biomass burning, storms, deforestation, and degradation caused by wildfires) impact tropical forest biogeochemical cycles and carbon dynamics?**
   1. How does forest resistance or resilience to disturbances vary across climate and disturbance history gradients within biomes and across continents?
   2. What are the post-disturbance recovery time scales of forest structure, composition, ecosystem functions (e.g., evapotranspiration, gross primary productivity), and carbon stocks?
   3. How do disturbance type and intensity influence post-disturbance recovery time scales?
   4. How have disturbances impacted the carbon use efficiency (CUE) and water use efficiency (WUE) of tropical forests?
   5. What are the spatial and temporal CO2 and CH4 flux differences associated with climate variability, wildland fires, and human modifications in tropical forests laden with inland waters and wetlands?

### 2.2 Ecosystem Structure, Function, and Biodiversity

1. **What are the roles of ecosystem structure, function, and biodiversity in driving spatial variation in tropical forest carbon stocks and fluxes?**
   1. How do forest structure, function, and biodiversity covary with each other and with abiotic variables that control tropical forest carbon stocks and fluxes within and among biogeographic regions in the tropics?
   2. How does variation in ecosystem structure and functional composition correspond to variation in woody productivity (GPP, CUE, and allocation to wood production) and woody residence time, and thus to spatial variation in tropical forest biomass?
2. **How are tropical forest phenology and mortality responding to temporal and spatial variability and systematic shifts in forcing processes, including climate, land-use, and disturbance regimes?** 
   1. How does temporal variation in tree mortality rates, especially of large trees, relate to temporal variation in climate, land-use, and disturbance regimes
      1. How do these relationships differ among tropical forests, and how do these temporal responses vary spatially in relation to environmental variables?
   2. What are the main causes of tropical tree mortality?
      1. How does this differ geographically across the tropics?
      2. How are the drivers of mortality-associated carbon fluxes changing in space and time?
   3. How does geographic and temporal variation in tropical forest phenology influence carbon stocks and fluxes?
   4. How is tropical forest phenology changing in response to climate and land-use change?
3. **How does functional composition influence ecosystem processes and tropical forest vulnerability and resilience to environmental change?**
   1. How do tropical forest plant functional traits vary vertically and across forest types and environmental gradients?
      1. How do species- and organismal-scale plant functional traits aggregate to ecosystem-scale functional composition (e.g., community-weighted means and variances of particular traits), and does this vary among tropical ecosystems?
      2. How do tropical forest functional traits relate to interspecific variation in responses to spatial and temporal environmental variation, and how do these traits contribute to forest function?
      3. What are the plant functional traits that confer resilience to environmental change, and how do they vary across different forest types and environmental gradients?
      4. To what degree are changes in tropical carbon cycle dynamics caused by shifts in [woody plant] functional composition?
4. **How does biodiversity, including plant-animal interactions, mediate the vulnerability or resilience of tropical forest carbon stocks and fluxes?**
   1. How well does variation in structural diversity, functional composition, and spectral diversity - mappable with remote sensing datasets - correspond to tropical plant, animal, and microbial taxonomic diversity?
   2. To what degree does biodiversity (including tree functional composition and diversity, liana abundance and composition, megafaunal abundance, abundance of seed-dispersing animals, microbial biodiversity, and diversity networks) contribute to explaining spatial variation in tropical forest carbon cycle dynamics?
   3. How vulnerable or resilient are species interactions underpinning tropical forest function to climate and land-use change?

Genetic adaption - too slow; Migration - too slow; Acclimation - large knowledge gaps. Need PANGEA to fill these knowledge gaps at landscape scales that capture the heterogeneity of responses

### 2.3 Climate Interactions and Feedbacks

[CFI WG white paper document draft](https://docs.google.com/document/d/1oH33TdJfn2YtZqanLNf9cWcuI1FNM-2k21iK0MkCUWo/edit?usp=sharing): Motivations/Background, Scientific Questions, PANGEA’s role of using satellite data to address these questions.

The global carbon cycle and tropical forest function are tightly linked to the water cycle (e.g., rainfall recycling), increasing temperatures and changes in seasonality/phenology, the biodiversity that underpins these systems, and feedbacks with the people that live in and depend on these landscapes. A coordinated multiscale campaign is required to advance our understanding of the sensitivity of these systems to future environmental change. A field campaign will simultaneously advance global-scale understanding of tropical ecosystem processes, accelerate progress in modeling

1. **How do tropical forests alter surface biophysical properties that influence the strength of land-atmosphere feedbacks and teleconnection?**
   1. How do changes in surface biophysical properties (e.g., evapotranspiration, albedo, roughness, land surface temperature, and humidity) resulting from ecosystem structure and function and land-use change affect local and regional weather and climate and disturbance risks (e.g. fire, drought, flooding)?
   2. How do land-use change, climate change, and extreme events govern the land-atmosphere feedback strength in the tropics?
   3. How will shifts in tropical forest structure and function affect the seasonality of land surface energy balance, water exchange, and carbon fluxes, and their feedbacks with the climate?
2. **How do climate change, land use, and disturbances interact with tropical forests to alter the terrestrial water balance via changes in precipitation, atmospheric moisture, and surface water components?**
   1. How do changes in precipitation patterns (e.g., caused by ITCZ displacement) affect tropical forests, and how do these forest dynamics feedback on seasonal rainfall timing and duration?
   2. How do different land-use practices, deforestation, forest regrowth and degradation alter rainfall recycling and the patterns, frequency, and intensity of precipitation, and what are the associated feedbacks?
      1. What are the feedback processes between land cover and land-use change and physical climate systems during specific climate variability events (e.g., ENSO, AMOC, MJO, IOD)?
   3. How do tropical forest disturbances (e.g., fire and associated aerosol loading from biomass burning) interact with clouds to influence continental precipitation?
3. **What are the direct and indirect hydroclimate controls on the resilience or vulnerability of the tropical forest carbon balance and how do they vary due to effects from extreme events, land cover and land-use change, and increases in atmospheric CO2?**
   1. Are there key hydrological thresholds, such as critical soil moisture levels, and/or elevated temperatures that limit forest photosynthesis and sustainability, varying within and between tropical continents?
   2. What are the differences in hydrological controls on the terrestrial carbon cycle between the Amazon and the Congo basins, and how do these controls vary during extreme events (droughts, flooding, etc)?
   3. How do forest regrowth, and LCLUC alter regional hydrological cycles, freshwater resources, and water quality in tropical regions?
4. **How do changes in the physical climate system and extreme events influence land cover and land-use in the tropics, including processes, associated services, and the resilience of tropical landscapes?**
   1. How do climate warming and trends in extreme events interact with land cover and land-use change to influence forest and agricultural productivity and their climate feedbacks within and between tropical continents?
   2. What are the impacts of climate warming, an increase of atmospheric CO2, and extreme events (e.g., droughts, flooding, extreme temperatures) on ecosystem resilience, nutrient availability, and soil-vegetation interactions within and across tropical forests?
   3. How will climate warming and increasing extreme events influence plant physiology, crop productivity, and water availability in the tropics?

### 2.4 Social-Ecological Systems

ONE-SENTENCE SUMMARY OF WHAT THIS SCIENCE THEME DOES

[*this could be a modification of the 'overarching' question: “How do climate change, tropical forest heterogeneity, and human activities and governance interact to impact food, water, energy, and livelihood security?”*]  
The Global Biodiversity Framework reported four long-term goals for 2050 and 23 targets to be achieved by 2030 to be achieved by 2030 (CBD, 2022) of which two are directly related to the xxxPROJECTS???XXX. Goal A focuses on expanding the area of natural ecosystems by maintaining, enhancing, or restoring the ecosystems, through the prevention of species extinction, and preservation of genetic diversity. Goal B emphasizes the sustainable utilization and management of biodiversity and recognizes nature's contributions to people. The 23 global targets aim to reduce threats to biodiversity, meet people's needs through sustainable use and equitable benefit sharing, and develop tools for conservation implementation.

CONTEXT

**Paragraph 1:** Description / definition of social-ecological systems in the tropics, highlighting that humans are part of the ecological systems [Oliver Coomes not available]

* integrated system comprising ecosystems and human societies with complex and interdependent relationships
* recognizing that human activities impact ecological processes and, conversely, ecological changes affect human well-being
* Mention the term co-benefits and that interconnectedness and interdependencies exist from which multiple benefits to nature and societies emerge (see also [Levis et al, 2024, NatEcoEvo](https://www.nature.com/articles/s41559-024-02356-1))

Social-ecological systems are shaped by diverse actors, placing multiple functions and motives on land and differing in terms of their values, capacities, aspirations, and goals that shape their interaction with nature (Meyfroidt et al., 2018, 2022).

Despite providing benefits to local communities, particularly indigenous populations, environmental changes in tropical ecosystems are likely to disrupt plant growth rates, leading to changes in species composition, survivorship and productivity, affecting various provision products, including timber and non-timber forest products (Siyum, 2020).

Land-use change and forest degradation contribute to carbon emissions (Houghton and Castanho, 2022). Climate change and land-use change are closely related (Dale et al., 2001), as CC affects agricultural practices and yields, leading to agricultural expansion to compensate for the yield reductions (Mendoza-Ponce et al., 2021; North et al., 2023). Climate change and land-use change together induce changes in nature's contributions to people (Díaz et al., 2018).

**Paragraph 2:** Describe feedbacks and their importance [Maria Santos]

* Feedbacks between human and natural systems are critical for understanding the dynamics of SES, can be positive or negative and influence the resilience, stability, and sustainability of these systems
* Can be complex and occur across scales (e.g., (inter)national policy and local action)
* Examples for positive and negative feedbacks

The resulting decline in species richness can have far-reaching implications, potentially undermining ecosystem services (e.g. pollination, pest control, seed dispersal), affecting food security by disrupting the food-networks, and modifying the functional diversity of the ecosystem, impeding the ability of local population to adapt to global environmental changes.

**Paragraph 3:** Demonstrate the relevance of better understanding SES (for NASA, and in general)

There have been many calls for ecosystem management and conservation to better consider social-ecological context (Fischer et al. 2017), to recognize that most landscapes are human dominated (Sanderson et al. 2002, Ellis et al. 2021), and to pay closer attention to human agency and context specificity of human activities (Ramankutty and Rhemtulla 2013, Pratzer et al. 2024).

Analyzing processes through the lens of complex social-ecological systems puts a focus on systemic aspects, including interactions, feedback mechanisms and dynamics exhibiting path dependency and non-linear change (Dearing et al. 2010, Mueller et al. 2024), and reveals new and complex patterns and processes not evident when studied by social or natural scientists separately (Liu et al. 2007).

Weak consideration of the complexity of social-ecological systems can not only conceal threats but also lead to missed opportunities in forest conservation. For instance, positive effects of Indigenous land-based stewardship on forest conservation and ecosystem service provisioning have recently been identified by several scientific studies (Vasco et al 2018, Baragwanath and Bayi 2020, Pratzer et al. 2023), in addition to Indigenous knowledge holders who have long provided contextual evidence of the various ecological values of their territories (Cajete 2000, Salmón 2000, Umeek 2011). Indeed, Indigenous land-based stewardship is often compatible with, and frequently actively supports, forest conservation and restoration (Newton et al. 2016, Fernández-Llamazares et al. 2024). This recognition has spawned innovative ways to design multi-functional reserves, policy instruments and management programmes (Garnett et al 2018).

LITERATURE REVIEW

* To provide appropriate literature background for the context sections
* And to demonstrate that the questions we ask are relevant, and have not been answered before (i.e., showcasing the literature gaps)

1. **How do human activities and socio-economic conditions affect the provisioning of and access to social-ecological co-benefits?**
2. **How will climate and land-use change affect the geographic distribution and scalability of forest-friendly economic activities?**
3. **How do different land-uses and deforestation and degradation patterns interact with climate to impact fire regimes and ecosystem recovery?**
4. **How do varying tropical forest land-atmosphere interactions affect water availability and food security, human health, and cultural practices, including Indigenous Peoples and Local Communities?**

WHAT ARE THE ADVANTAGES / KNOWLEDGE / OUTPUTS OF ANSWERING THE QUESTIONS ABOVE

APPROACH/METHODS

Remote sensing [Maria Santos]

* Detection of LULCC
* Identification of crop types
* Identification of agroforestry systems

Field data

* Using qualitative methods like interviews and focus groups to complement remote sensing data ,
* Governance [MVE]
* Economics
* Perceptions & culture [Ale Echeverri Ochoa?]

Methods: network analysis, social capital, modeling (biophysical models)

### 2.5 Enabling Earth Science to Action

* Work with partners to make these data products as accessible as buying something on Amazon - e.g., Global Forest Watch
  + Include info on how scaling was done so users understand
  + Educational materials - summer schools, MOOCs,
  + Raise awareness across communities - about PANGEA, about needs, also about existing datasets
* Use an example pyramid of PANGEA -> ES2A
  + use ES2A language
  + Provide specific examples
  + Maybe one pyramid for each Carbon, Biodiversity, and Agriculture
* In ABOVE referred to as "applications and decision support"
* Use the information we gathered during the DC workshop session on flows of information → specifically call out we worked to engage potential end users from the beginning. This should make the applications suggestions more realistic
* Draw upon lessons learned from ABOVE (Debjani Singh, Libby Larson, Kimberly Minor). Divide all the user cases into different stakeholder group. These groups will have different needs and how we will address these needs. Maybe have 4-5.
* Sort potential partners into groups
* Visualization of partners and different types of uses
* what's the outcome we want at the end of all of this and how are going to measure it at the end?
* Be realistic about data expectations from airborne campaigns
  + not data that's going to be around beyond the campaign (for the most part)
  + more episodic than is necessarily needed
  + how do we feather into other ongoing services / satellite missions
    - E.g. SAR training / readiness for SERVIR
      * Engage in something simliar for hyperspectral w relevant mission leads
  + can use the airborne campaign as candy
  + training before, after, alongside
  + Focus on operational data - already in the DAAC, as opposed to simulated data
    - Not so much early adopters workshops (e.g., for NISAR)
    - Nancy tries to keep ARSET out of 'simulated data' space

Applications that have the potential to be advanced by PANGEA

* Carbon mapping
  + Standards, uncertainties, harmonization
  + Do trade agreements and market policies (ex. EU Deforestation Regulation, African Continental Free Trade Area Agreement) between Global North/South countries affect SES?
* Mapping of risks to carbon stocks in the tropics - important for carbon markets
* Biodiversity Conservation
  + IPBES and Convention on Biological Diversity
* Sustainable agriculture and deforestation-free supply chains
  + Yield and crop type mapping
  + Water use and supply
  + Precision ag
* Supply chain traceability and management / Supply chains / Value chains - EUDR
* Deforestation and degradation alerts - associated with drivers?
  + Mining, roads, urbanization, etc. to be used by local and Indigenous communities and/or jurisdictional governments
* Bioeconomy
  + Non-timber forest products
* Restoration
* Ecosystem service mapping
  + What ecosystem services are readily mappable via remote sensing and/or integration with ancillary data and information (LEK, TEK, IEK)?
  + What ecosystem service mapping capabilities could be advanced by PANGEA?
* Disaster Alerts & Response
  + Fires
  + Flooding
* Weather prediction
* Empowering and elevating Indigenous, local, and traditional communities
  + Integration of RS data with LEK, IEK, and TEK

## 3. Research Strategy and Study Design

### 3.1 Overall Design / Approach

* Answering big scientific questions
* comparison among the major tropical forest formations on our planet
* effective interpretation and analysis of space-based measurements and through a combination of ground, airborne, and satellite-based science investigations.
* foster collaborations and build new relationships within the scientific community with a special emphasis on interactions among US scientists and scientists from tropical forest countries
* provide opportunities for training and educating the next generation of scientists including obligatorily scientists from countries where field research will be based.
* leave a legacy of open data, open science, and strengthened partnerships between the US and tropical institutions as the basis for future research.
* TIMELINE
  + show that there is a ramp up
  + peak in terms of data acquisition and field activity (years 2-4) - really consider that this could only be a 6 year campaign (6- to 9-year stated in solicitation – could be even less depending on budgets…)
  + analysis and synthesis -
  + gaining and final datasets to answer questions that arose during the campaign
  + real broad brush stroke
* emphasize collaborative data collection
  + protocols and standards for data collection
    - <https://ceos.org/ourwork/workinggroups/wgcv/>
    - <https://ceos.org/about-ceos/agencies/>
      * NEON / AVIRIS / EMIT / SBG
      * FluxNet/ICOS/AmeriFlux
      * Forest plots community
      * others??
  + plan for collating and archiving data from many people in many countries and many sources

### 3.2 Scaling Strategy

* **Scaling framework**: boots → plots → towers → drone → aircraft → diagram → satellite → modeling/integrative analyses
* sampling to scale
* Ground, tower, drone, aircraft,
  + Integrate into existing coordination efforts and gap-fill
    - Drone lidar standards - KC Cushman
      * would build something similar out for other sensors
      * Great collaborative example: https://arcticdrones.org/ - Welcome to the High-Latitude Drone Ecology Network (HiLDEN)

### 3.3 Candidate Study Sites / Regions

* Need to demonstrate the feasibility
* Clearly define what can be done within the NASA scope
  + what's the safe science we can commit to delivering just from NASA
  + baseline mission
  + expand on that with contributions from other agencies
    - ESA, USAID, NSF,
    - and donor community
* need to have a process for selecting and approving ground sites
  + locations for ground campaigns will be the hard part
  + Engage with existing efforts
  + Opportunities for training to expand existing data collection to fill in gaps
    - Drones
    - lab facilities
* There are many tropical forests - different tropical continents/forests are different - floristically, function, in terms of pressures faced
  + comparisons within and across continents is critical
* include statement about two continents - why tropical Americas (Amazon especially) and Africa (Congo Basin especially) are an important comparison
  + biggest extent; biggest impact on climate dynamics

Strawman Baseline/Threshold Mission Concept:

* Baseline A: extend to Amazon & Africa
  + - comparative - to include Africa - repeat AfriSAR with other sensors
* Brazil (and DRC / other risky countries)
  + Plan A - ARES first
  + Plan B - commercial aircraft and commercial sensor
* talk to Marc to see how he did it for Delta-X
* Emphasize gradients!
  + Climatic gradients
  + Elevation gradients
    - Peru, Rwanda,
* **Threshold:** Panama and French Guiana
  + Panama and French Guiana) are safe choice
  + Both are very well studied, lots of data available, NASA has flown, very different in important respects
  + Guiana with the exception of a coastal plain is very old continental shield.
  + Panama is an island arc terrain that is younger and more fertile.
    - Disadvantages to Guiana are twofold: (1) it is quite wet meaning that we do not get the window on climate change (hot drought) that we might like; (2) it is highly preserved and there is very little active land use.
* **Baseline A:** extent to Amazon
  + better if extend to Amazon

### 3.4 Satellite Remote Sensing Observations

* get specific about satellites and how they'd be used - **not just a list of sensors**
  + EMIT / CHIME / SBG / *Carbon-i*
  + NISAR / BIOMASS
  + GEDI / ICESat-2 / *EDGE*
  + ECOSTRESS
  + OCO
  + Geostationary
  + SMAP
  + GRACE
  + SWOT
* Synergies with partner agencies
  + ESA, JAXA, ISRO
  + Use of sensors from partner agencies:
  + BIOMASS

### 3.5 Airborne Remote Sensing Observations

* need to define what other aircraft assets could be deployed
  + commercial aircraft
  + why don't we just hire companies to hire data there
  + then don't have to worry about flight permissions for NASA aircraft
  + what about sensors
  + AVIRIS has flown a lot on a Dynamic Aviation aircraft
  + use ARES (Switzerland) - other assets?
* INDIA: shipping AVIRIS-3 over and installing on an Indian plane
  + is there a short write-up about Indian deployments
* **Will co-design the flight plans - recommendation from AfriSAR-2**
* **demonstrate precedent wherever possible**
* AfriSAR-2
* AVIRIS in India (ISRO putting up money on that)
* lidar in Brazil and DRC
* ARES?
* ESA?
* mention tech advancing so rapidly
  + describe current drone capabilities
  + are currently these instruments at this level of readiness
  + will have protocols in place to leverage rapidly evolving technologies

### 3.6 Field Observations, Studies, Experiments

### 3.7 Modeling and Integrative Analyses

* Emphasize model intercomparison efforts and ensemble modeling approaches
* NASA [Global Modeling and Assimilation Office](https://gmao.gsfc.nasa.gov/)
* Also DOE models, and NSF models
* ILAMB, TRENDY, Rubisco
* Integration of observations and models
  + Emphasize on RS data - model integration
* Advancing process-based understanding - specify a couple of key processes that PANGEA can advance
* Need to work on constraining uncertainty and getting the right answers for the right reason(s)

1. How can we quantify the long-term effects of CO2 fertilization by integrating data from previous/current long-term experiments?
2. What are the major dimensions or axes of tropical plant life strategies (e.g., physiological traits, drought tolerance strategies, structural allocation) functional trait variation that need to be captured in models to understand spatial variation in plant functional composition today and compositional shifts under global change?
   1. What are the functional properties (trait distributions) of forests on different continents, and how do differences in these trait distributions and trade-offs between traits affect forest responses to extreme events, climate change, and land use change on different continents?
   2. How sensitive are land model projections to different parameterizations of plant functional diversity (e.g., pantropical vs. continent-specific diversity parameterizations)?
3. To what extent can the impact of human land management on subsurface-surface-atmosphere coupling of water-energy-carbon cycle processes in the tropics be measured and modeled, and does it represent a significant source of subseasonal to seasonal hydroclimate predictability?
   1. What are the minimum levels of change in forest structure and composition caused by forest degradation that cause detectable shifts in the magnitude and seasonality of energy, water, and carbon fluxes relative to intact forests? How do these minimum levels of degradation vary across precipitation gradients and across continents?
   2. What are the typical time scales in which the energy, water and carbon fluxes of degraded forests become indistinguishable from non-degraded forests? How does the time scale vary as a function of degradation type (e.g., fires, logging, fragmentation) and climate?
   3. At which spatial scales the impact of forest degradation on energy, water, and carbon cycles is sufficiently strong to impact the dynamics of the planetary boundary layer and convective development, and thus impacting climate?
4. How can weather forecast duration and reliability be improved in the tropics?
5. How can predictions of climate variability and change be improved in the tropics?

### 3.8 Technical and Logistical Feasibility/ Issues

* Start with a statement showing that we are following on well learned precedents
  + ABLE 2a and 2b
  + SAFARI
  + LBA
  + AfriSAR 1 a 2
  + BioSCape
  + Multiple airborne campaigns in Central and South America using AVIRIS on a variety of platforms
* Will will go through NASA OIIR
  + We will build relationships with in-country partners and establish contacts to develop signed agreements
* not requiring NASA assets (NASA aircraft) to be deployed in Brazil or DRC
* NASA or other (ARES, commercial) can be used
* Interest from / alignment with partner agencies ESA, ISRO, Canadian Space Agency
* Emphasize that PANGEA will take advantage of what's happening locally
* Notes based on recent conversations with Ryan about scope
  + need to turn grand ambition into modular / scalable campaign
    - a few million / 10 million/ 30 million / 50 million -
  + depends on second PM though (an offer was made, date TBD, will likely start this summer)
  + could be bolstered by contributions from Biodiversity and/or Hydrology (also LCLUC, X, and X?)
  + possibly also Earth Action (Tom, Nancy, Keith)
* Provide threshold and baseline(s)
  + 5 years - $30 million
    - emphasize that we've already put in a PANGEA EVS
* 6 years - $50 million
* 8 years - $100 million
* 10 years - $150 million
* need proof that we've had discussions with partners who can allocate additional resources - actual funding or in-kind through existing activities (e.g., USAID, European Space Agency, NERC, donor community) - letters!
* **Synergies**
  + ride AfriSAR-2 - on budget, on schedule, for the most part no major glitches (describe successes and lessons learned)
  + LVIS flight(s) in SE Asia - talk to GEDI team
  + Amazon 2026 - Jack committed to trying to make NASA aspect equal to or exceed ESA component - talk to Clement Albergel & Dirk
  + talk to Barry Lefer about possibly sharing costs with Africa air quality campaign (not guaranteed, just being explored)
    - Building on Asia-AQ - Phillipines, Malaysia, Thailand, South Korea
  + possibility for synergies with Laura Lorenzoni's interest in lateral fluxes in rivers - especially in Amazon
  + India - AVIRIS-3 - in 2024 - other plans?
* **Cost** - Leveraging additional funding sources
  + Related relevant NASA funding opportunities
    - Topical Workshops, Symposiums, and Conferences (TWSC) in Space and Earth Sciences and Technology
    - ARSET, ….
  + Existing opportunities to solicit complementary funding
    - NSF RCN, AccelNet
    - NSF RISE
    - NSF EArly-concept Grants for Exploratory Research ([EAGER](https://new.nsf.gov/policies/pappg/24-1/ch-2-proposal-preparation#ch2F3)) Proposal
    - NSF DEB & BIO calls (alignment with NEON)
    - USAID CARPE
    - USAID SPARK (in prep)
    - USAID - other…
    - Belmont Forum
    - DOE calls?
  + In-kind support
    - AmeriFlux, ICOS
  + Seeking additional funding from new sources
    - Donor community

## 4. Organization and Management

### 4.1 Scientific Leadership

* Guided by ATBC codes of conduct and etiquette, already thinking about differences regionally, culturally, etc
* Speak to measures of accountability embedded in PANGEA design - How to ensure our walk follows our talk - what’s the accountability for PANGEA and projects to ensure follow through on commitments (in terms of science, co-production, engagement, training, etc.)?
  + Organizational structure
    - Science Definition Team - diverse representation
    - Early Career Group established from the outset

### 4.2 Project Organization

* As soon as selected - [re-]initiate partnership conversations at the outset
  + call a PANGEA meeting with all PMs - but also have Earth Action there from the beginning
  + Engage international partners at the outset
  + PANGEA leadership team start relationship building with partner govts on Day 1 (or 2) to start developing MOUs for PANGEA campaign
    - Point to lessons learned from LBA and AfriSAR-2
* Coordinating with existing efforts - mechanisms and responsibility - link to existing mechanisms for coordination including CBSI, LBA, etc.
  + FluxNet (especially ICOS & AmeriFlux)
  + GEO-TREES
  + One Forest Vision
  + [GEO](https://earthobservations.org/)
  + [USGCRP LACI](https://www.globalchange.gov/our-work/laci)
  + Indigenous and Local Community Partners: GATC, RRI, SILK

### 4.3 Field Operations

### 4.4 Data Management and Sharing

* Explain how data management considerations will be addressed during the campaign.
  + NASA Terrestrial Ecology field campaigns must be committed to NASA’s Earth Data and Information Policy, NASA Open Science Philosophy, and NASA’s Open Data, Services, and Software Policy.
  + See ABoVE data management strategy - CCE
  + work with CCE and DAACS to ensure meet XYZ policies
  + Community input on data management plan
  + Refer to new NASA open science policy
* New data collection, but also collate and rely on existing data sources
  + How to ensure we do this collaboratively and ethically - respecting rights and ownership of data already collected
* Different data support for different data products linked to via central PANGEA Data Portal
  + DAACs for airborne data
    - Coordinated VSWIR data cleaning by (SBG/EMIT/AVIRIS/NEON coordinated team)
    - Coordinated …
  + AmeriFlux & ICOS for flux tower data
    - Including commitment to support resuscitation of LBA Phase 1 flux tower data??
  + Forest Inventory plot networks…
  + LBA
  + [KADI](https://kadi-project.eu/)
* DAACS, tropical DAACs, data sovereignty, cloud computing - access for partners (Centers for Excellence & trainings)
  + Also though, DAACs are a pain - make things available on apps - GEE - for upload and download
* highlight working with existing training programs (specify)
  + if they don't exist - describe and explain how PANGEA could implement
* How could PANGEA advance goal of democratizing data?
* Opportunity to harmonize protocols across research communities to support scaling
  + Point to work Dana is already doing w NEON, SBG, EMIT, other groups
  + Feedback from workshop: valuable to have standardized protocols - but not too rigid recognizing varying access to resources/capabilities
* Data accessibility
  + Need user-friendly data platform!!!!
    - Appears.earthdata - mentioned as useful by graduate student researchers from the tropics at various workshops
  + How to make data more accessible to non scientists? - think about applications side of things - partner with existing efforts like Global Forest Watch, Land and Caron Lab, GIS efforts via Rights & Resources Initiative

### 4.5 Timetable

## 5. Community Engagement

### 5.1 Community Engagement Methods during the PANGEA Scoping Campaign

The Community Engagement and Research Applications Working Group engaged with over 500 individuals from X number of countries across five continents during the PANGEA Scoping Campaign through (A) an international working group, (B) short information sharing events, (C) multi-day consultative workshops, and (D) bilateral meetings with potential partners.

(A) The Community Engagement and Research Applications (CERA) working group (1) was comprised primarily of students, researchers and professors from academic institutions, practitioners from non-governmental and intergovernmental organizations, and some private sector representatives. Similar to the other PANGEA working groups, CERA membership was open and advertised online, at PANGEA events, and within “word of mouth.” In total, approximately 100 individuals signed up to the CERA working group and participated in one or more of the 12 CERA meetings conducted online and/or contributed to the team’s collaborative documents. Many members also participated in CERA-relevant sessions at the PANGEA multi-day workshops in Cameroon, US, Brazil and Peru.

(B) The PANGEA Leadership Team engaged with X NUMBER OF PEOPLE through twelve information sharing events conducted on five continents. These events include 1-2 hour presentation and discussion sessions at international academic conferences (e.g. American Geophysical Union Town Hall, USA, December 2023; Ecological Society of America webinar, March 2024; European Geosciences Union presentation, Austria, April 2024), regional events (e.g. Smithsonian Tropical Research Institute, Barro Colorado Island 100th Anniversary Symposium presentation, Panama, June 2024; Congo Basin Forest Partnership 20th Meeting of the Parties presentation, June, 2024), and special meetings organized by the PANGEA community (e.g. Africa women’s session, April 2024; Meeting with Indigenous Communities in Panama, April 2024).

(C) The PANGEA Leadership Team organized four, multi-day regional scoping workshops that included sessions focused on community engagement best practices and regional demand and preferences for research applications. PANGEA Scoping workshops include a 3-day event in Yaoundé, Cameroon in February 2024; a 3-day event in Washington, DC in April 2024; a 3-day workshop in Manaus, Brazil in May 2024; and a 2-day workshop in Lima, Peru. All events were organized in close collaboration with local PANGEA partners representing the academic community, government agencies, and non-governmental organizations.

(D) The PANGEA Leadership Team and CERA working group members conducted bilateral meetings with 33 potential PANGEA partners, including. Many (ADD EXACT NUMBER HERE) have shared letters of support to confirm their interest in collaborating on the PANGEA program (if funded).

### 5.2 Community Engagement during the PANGEA Program

* General principals (CARE & FAIR, FPIC, Stephanie Caroll)
* PANGEA Engagement goals
  + How would PANGEA engage with existing efforts?
* Overall strategy
* Description of PANGEA-relevant communities and specific engagement considerations.
* Mention that the list below is non-exhaustive, but the overall strategy will provide a framework for also all engaging other under-represented communities

**Knowledge Exchange Opportunities:**

1. Are SES connections, cycles, and feedback perceived similarly between IPLCs and Western-trained scientists? How are these documented and/or mapped similarly or differently?
2. How can the knowledge/training on remote sensing and its capabilities enable (indigenous/traditional) communities to protect forests? What are the educational needs to support PANGEA? How can ILPC need and knowledge guide PANGEA funded research?
3. What are the most important sustainable alternative sources of income for ILPC?
4. What is the role of research and a science-based economy in this process?
5. How can PANGEA support or begin to establish a science-based economy and long-term research collaborations with IPLC across the tropics?
6. How can Indigenous Peoples & Local Communities be empowered to use remote-sensing data to conserve and restore their landscapes?

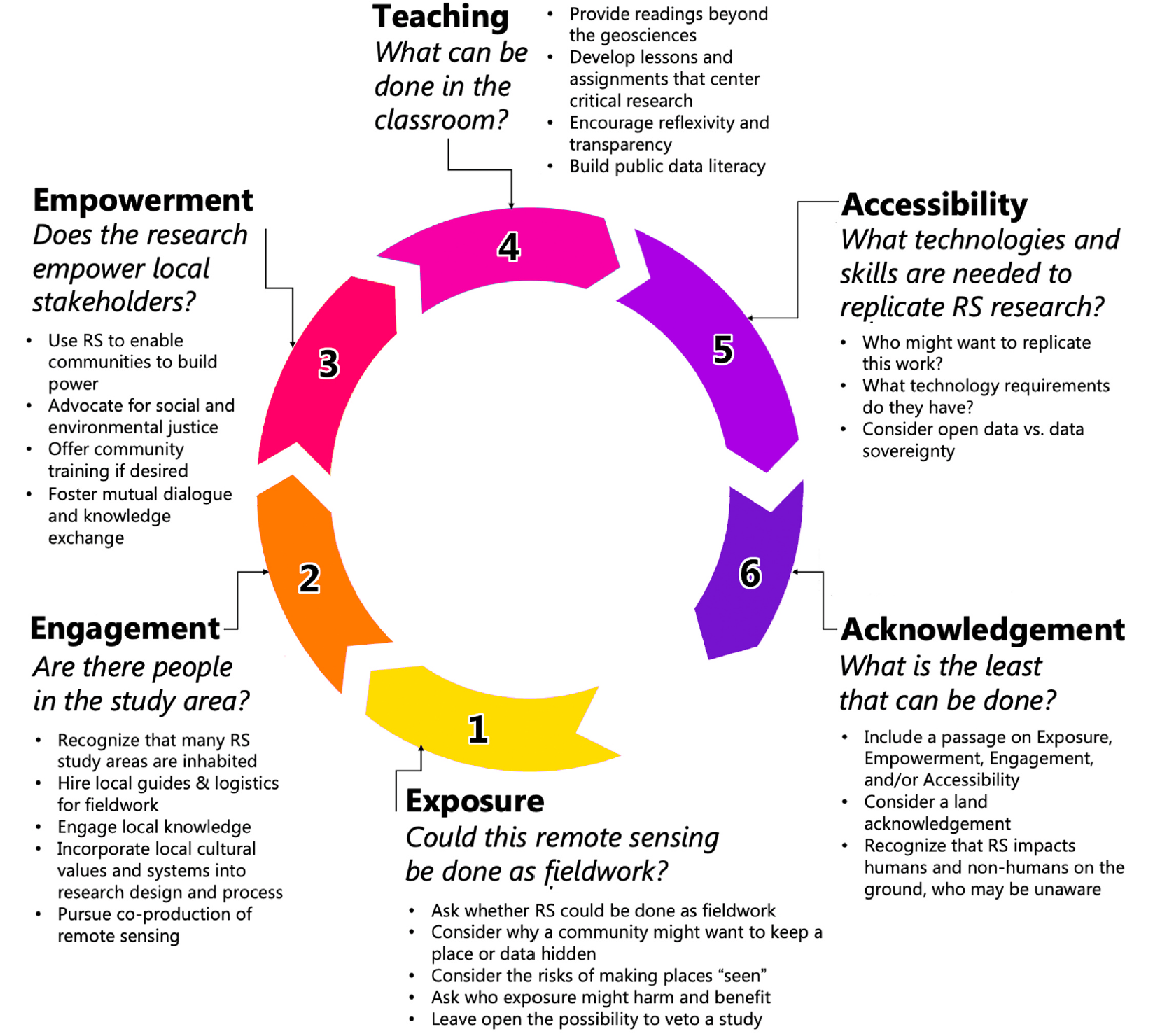


Figure X.   
The six-step framework centered on Exposure, Engagement, Empowerment, Teaching, Accessibility, and Acknowledgement, with key questions for remote sensing scientists to consider in their methods and practices.

Source: Bennett, Mia M., Colin J. Gleason, Beth Tellman, Luis F. Alvarez Leon, Hannah K. Friedrich, Ufuoma Ovienmhada, and Adam J. Mathews. "Bringing satellites down to Earth: Six steps to more ethical remote sensing." Global Environmental Change Advances 2 (2024): 100003. <https://doi.org/10.1016/j.gecadv.2023.100003>

#### 5.2.1 Alignment with existing NASA efforts

* Earth Science to Action - Est. 2024 decadal goal to co-develop with partners and users across sectors nationally and internationally to create a more resilient world
* Committee on Earth Observation Satellites WGCapD
  + Working group on Capacity Building and Data Democracy with outreach to over 164 countries
* ARSET Earth Observations - ARSET offers online and in-person trainings for beginners and advanced practitioners alike - **targeting decisions and actions,** not science
  + can't use NASA money to fund international science, but if it's a training, can use ARSET money
  + Not for training scientists - for training decision-makers how to use RS data / data products, not scientific workforce - training for next gen grad students different than a working professional
    - Emphasize ARSET for training working professions in PANGEA
  + Takes at least a year to spin something up
* NASA-USAID Joint Global SERVIR Initiative - Sustainable development through capacity building and incorporating perspectives from women, Indigenous Peoples and their communities
  + it's USAID $ that allows for SERVIR activities to be conducted internationally
  + New USAID SPARK solicitation - mention this!
  + include letters that speak to alignment with / support from USAID - country missions, SERVIR hubs, etc., CARPE in Central Africa
* NASA DEVELOP
  + DEVELOP - 10 week programs; can last up to 3 week terms
  + fellows pitch those
  + tool out there in the toolbox
  + DEVELOP has done projects with airborne data/campaigns
    - usually focused on integrating airborne & satellite data
  + **one of the most flexible mechanisms** 
    - can turn around a DEVELOP project/initiative fairly quickly - 6 months
    - Only a 1/4 or less of budget from DEVELOP for international, but little bites can be really helpful
* Indigenous Peoples Initiative - Est. 2017 for engagement with Indigenous geospatial community in US and globally

#### 5.2.2 Indigenous Peoples and local communities

* [Draft being co-written (in multiple languages) can be found here](https://drive.google.com/drive/u/1/folders/1Gw5jlwLzT7Z_KHRGMwto6nnl4nSpxRIX)

#### 5.2.3 Scientific Institutions

For the purpose of this proposal, we use the term scientific institutions primarily for universities, colleges, national labs, and research institutes that through their leaders, faculty, and students are fundamental partners of PANGEA.

PANGEA seeks to partner with scientific institutions located or with research expertise related to any part of the pan tropical forest region to collaborate and carry out its proposed research programs. This partnership will establish a world leading network of research experts and scientific institutions collaborating in responding to the grand environmental challenges in the Pan Tropical Forest region. A particular interest of this partnership is to facilitate knowledge and tech transfer to generate capacity and capability building in the local and regional institutions to train the next generation of scientists. This partnership seeks to focus on:

* Co-development of the research, analysis, and potential applications of the proposed programs by PANGEA.
* Identify field sites, research infrastructure, and capabilities that are critical to the PANGEA proposed research.
* Co-production, sharing, and management of data, development of data infrastructure, equipment, and management expertise at local and regional institutions.
* Seek to strengthen/expand state-of-the-art research infrastructure and instrumentation for the local and regional scientific institutions to be able to develop and carry out long-term critical research plans
* Capacity building for faculty and early career researchers at local and regional universities and research institutes to train and guide the new generation of scientists at local and regional institutions (for instance, co-lead technical workshops training junior research faculty and students, visiting scholars program in participating US-based scientific institutions).

Based on these ongoing efforts, engage national governments and relevant government agency leaders to showcase benefits and expected impacts to generate financial and policy support for PANGEA related programs in their jurisdictions.

#### 5.2.4 Government agencies

* Policymakers
* Administrators
* At national and sub-national levels

#### 5.2.5 Non-governmental organizations

* International
* Local

#### 5.2.6 Intergovernmental organizations

#### 5.2.7 Private sector

We use the term Private Sector to refer to for-profit entities of all sizes that are privately owned and managed. Private sector entities relevant to PANGEA include, but are not limited to; legally-registered (a) agribusiness which cultivate and/or wil harvest agricultural, timber and forest non-timber products; (b) extractive industries which alter land cover and/or below-ground ecosystems in search and extraction of oil, minerals, metals and other products from the ground; (c) energy companies that alter ecosystems by installing equipment on or below the surface of the ground; (d) big data companies that develop software or hardware that facilitates the collection and/or analysis of ecosystem data (e.g. forest carbon, biodiversity, etc.); (e) conglomerates and financing institutions that invest in, buy, and/or sell any of the aforementioned types of companies; and (f) companies involved in ecotourism. Although the scope of companies deemed relevant may be vast, the profile of companies present in each landscape where PANGEA is implemented will vary ranging from corporates to SMEs, coops and associations. This section describes a basic engagement strategy that can be adapted in each context.

Private value chain actors are under increasing legal pressure to comply with social, economic, and environmental standards and regulations. On the other end of the corporate responsibility spectrum, a growing number of companies strive to surpass minimum standards, potentially to improve competitiveness and sustainability in production areas, to report positive socio-economic changes to customers and clients, plan more efficient allocation of resources for future projects and improve accountability. This has fueled an increasing demand amongst private sector entities for Earth observation and ground-based data related to ecosystem extent, structure, function, and condition, as well as the social, economic, tenure, and governance systems that may impact ecosystems and communities. More specifically, many private sector entities seek data addressing (1) soil health and fertility, (2) land use (including forest) and land use change, (3) fire risk and occurrence, (4) ecosystem carbon stocks and greenhouse gas emissions, (5) fresh water availability and consumption, and (6) biodiversity conservation and enrichment.

Governance and market mechanisms that drive this demand include national and regional legislation (e.g. US Lacey Act, FLEGT, EU DR), international agreements (e.g. UNFCCC Kyoto Protocol, Paris Agreement, New York Declaration on Forests, UN CBD Aichi Targets, Bonn Challenge, etc.), carbon markets (e.g. voluntary, Clean Development Mechanism), certification schemes (e.g. FSC, Fair Trade), and industry-led associations (e.g. Roundtable for Sustainable Palm Oil / Biofuels / Cocoa, etc.). Evidence-based data, applied scientific research, capacity building and technical assistance is needed for private sector to move beyond commitments to action PANGEA’s engagement with the private sector has five objectives:

* Strengthen the use of Earth observation data to understand the impacts of companies on ecosystems and monitoring their degradation, mitigation and/or ecosystem enhancement efforts
* Develop standardized methodology/protocols for land use change, forest cover, fire alerts)
* Engage the private sector in a collaborative network, based on best practices and lessons learned and geared toward improving the collection, analysis, and sharing of ground-based data related to ecosystem extent, structure, function, and condition, as well as the social, economic, land tenure, and governance systems that may impact ecosystems and livelihoods..
* Capacity building and technical assistance…
* Targeted research dissemination via business briefs…

Corporates and value chain actors can be major contributors to GHG emissions and biodiversity loss. However, without those actors it will be all but impossible to put the agriculture sector on track towards net zero and sustainability. Engaging private sector in information and data sharing, fostering a business-friendly collaborative learning environment and providing ad-hoc (practical, operational?) capacity building and technical assistance could enhance the long-term impact of PANGEA (beyond the duration of the program’s funding) on people and nature in areas of operation.

#### 5.2.8 Women

* Address gender balance overall. Highlight specific efforts PANGEA could take to address this and key performance indicators we’ll track over time.
* Gender-responsive vs gender transformative (is 9 years enough to transform a system?) acknowledge that we may not transform the system in 6-9 years, but describe the type of impact PANGEA would like to achieve

### 5.3 PANGEA Partners

* *Categorize potential PANGEA partners according to specific user groups*
* *Map geographically and thematically potential partners*

1. AndesFlux (research initiative conducted by institutions in the US, Canada, Germany, and Peru)
2. ASCEND
3. Australia
4. BELOW
5. Congo Basin Initiative
6. CBSI
7. CIAT - Alliance Bioversity International (International Center for Tropical Agriculture + Bioversity)
8. European Space Agency (ESA)
9. ESDT
10. Food and Agriculture Organization of the United Nations
11. FLUXNET
12. Global Alliance of Territorial Communities (GATC)
13. GeoTrees
14. IITA
15. IREES
16. MapBiomas
17. NASA ARID
18. NASA Biodiversity and Ecological Conservation (BDEC)
19. NASA Earth Science to Action (ES2A)
20. NASA Harvest
21. NASA Hydrology
22. NASA Jet Propulsion Lab / AfriSAR
23. NASA Land Cover Land Use Change (LCLUC)
24. NASA Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA)
25. NASA SERVIR
26. NASA Soil Moisture Active Passive (SMAP)
27. Observatoire National sur les Changements Climatiques (ONACC)
28. Penn State University
29. Poverty Action Lab at MIT
30. SilvaLab
31. Smithsonian
32. Sylvera
33. US Agency for International Development (USAID)
34. US Department of Energy (US DOE)
35. University of California Santa Cruz
36. United Nations Framework Convention on Climate Change
37. Woodwell
38. World Resources Institute

### 5.3 Limitations

* *Proactively discuss limitations in our engagement methods.*
* *Identify the gaps and explain why certain groups were under-represented groups in our consultative process (e.g. private sector, government esp in Africa, IPLC logistical challenge + ethical concerns). Explain how the funded PANGEA program could address these gaps.*

## 6. Capacity Building, Training, and Education

* Address capacity building
* Training that goes beyond data collection - learn to collaborate, plan, write papers, write grants, do analysis
* Workforce development, particularly, in the areas of emerging technologies such as machine learning and artificial intelligence (in addition to RS)
  + Emphasize that PANGEA will count on the participation of researchers from EPSCoR states as a part of NSF’s Broadening Participation portfolio.
  + Work with NASA ARSET and [NSF RISE](https://www.nsf.gov/div/index.jsp?div=RISE) programs
* GLOBE: <https://www.globe.gov/>
  + Support schools and teachers in landscapes to participate in GLOBE
  + Engage and connect elementary school students across the globe
* NSF Geoscience Opportunities for Leadership in Diversity ([GOLD-EN](https://new.nsf.gov/funding/opportunities/geoscience-opportunities-leadership-diversity-gold)) - Supports creating a network of professionals to implement evidence-based best practices and resources that improve diversity, equity and inclusion within the geosciences

## 7. Required Resources and Coordinated Teamwork

### 7.1 Disciplinary skills needed

### 7.2 Field Infrastructure

### 7.3 Suborbital Platforms and Sensors

### 7.4 Satellite Data Availability, Access, and/or Purchase

### 7.5 International and Other Agreements

#### 7.5.1. NASA airborne campaign Indigenous agreements, permissions, and treaties (KEEP this section)

* Indigenous land and sovereign territories.
* [Draft being co-written (in multiple languages) can be found here](https://drive.google.com/drive/u/1/folders/1Gw5jlwLzT7Z_KHRGMwto6nnl4nSpxRIX)

### 7.6 Cost Estimates

## 8. Issues to be Resolved

## 9. References

## 10. Figure and Photograph and Credits

## 11. Glossary

***Biodiversity***= tree functional composition, tree functional diversity, liana abundance, liana functional composition, microbial composition, megafaunal abundance, abundance of seed-dispersing animals, abundance and composition of flora and fauna more generally / Functional, phylogenetic, and taxonomic (think trait and spectral diversity and phylogenetic diversity likely at the genus and family levels), faunal and floral diversity

* More generally: Functional, phylogenetic, and taxonomic (think trait and spectral diversity and phylogenetic diversity likely at the genus and family levels), faunal and floral diversity

***Co-benefits*** = Joint positive contributions of biodiversity and cultural diversity for humans and other species. These contributions are associated with the concepts of nature’s contributions to people and people’s contributions to nature. → From: Levis et al, 2024, “Contributions of human cultures to biodiversity and ecosystem conservation”, Nature Ecology & Evolution, <https://doi.org/10.1038/s41559-024-02356-1>

***Degradation*** = selective logging, mining, defaunation, human-ignited fire

***Ecosystem*** = natural ecosystem, agro-ecosystem, social-ecological system

***Environmental variables***= current and past climate (amount and seasonality of rainfall, temperature, solar radiation, and more), geology, soils, topography (including elevation), current and past disturbance regimes (storms, flooding, drought, fire, etc.), current and past land use, and their interactions.

***Forest carbon stocks and fluxes*** = biomass stocks, woody productivity and woody mortality

***Forest-friendly activities*** = economic activities that utilize forest resources in a way that preserves the forest's ecological integrity and supports the sustainable livelihoods of local communities → From: IUCN. (2021). *"Forest Conservation and Sustainable Use"*

***Forest function*** = GPP, NPP, woody productivity, ecosystem respiration, tree mortality, woody residence time, evapotranspiration, sensible heat flux, net radiation, water-use efficiency, carbon-use efficiency, nutrient-use efficiency, and nutrient cycling

***Forest resistance*** = Forest resistance to a certain disturbance type = the relationship between forest stand mortality rates and disturbance intensity - define more clearly

***Forest structure***= Biomass, canopy height, stem density, vertical height heterogeneity, and vertical plant area density distributions

***Human activities =*** formal, informal, and illegal economic, subsistence, and development practices by humans that lead to the exploitation, alteration, and degradation of forest ecosystems, including logging, construction of infrastructure, agriculture, livestock rearing, fire, mining, hunting and wildlife exploitation, charcoal production

***Land-use change*** = deforestation, degradation, fragmentation, restoration, and regeneration

***Vulnerable communities*** = communities that are most likely to experience the adverse effects of climate change and environmental degradation, including indigenous peoples, low-income communities, and those reliant on natural resources for their livelihoods. → From: United Nations Framework Convention on Climate Change (UNFCCC). (2020). *"Vulnerable communities"*.

***Vulnerability*** = the propensity of social and ecological systems and their practices to be adversely affected by changes, encompassing their sensitivity to such changes and their ability to adapt. → Adapted From: FAO. (2013). *"Community-Based Forest Management and Vulnerability to Climate Change"*

## 12. List of Acronyms

## 13. Appendices

### A - Planned and Ongoing Research and Monitoring Activities

### B - Summary of Level II and III Ecoregions in PANGEA Study Region

### C – Summary of Airborne and Spaceborne Remote Sensing Systems for PANGEA

### D - Summary of PANGEA Participants

Detailed overview of PANGEA Community Engagement Activities

1. Community Engagement and Research Applications working group meetings online
   * February 13th
   * March 14th
   * March 21st
   * March 28th
   * April 3rd
   * May 15th
   * June 7th
   * June 27th
   * July 11th
   * July 25th
   * August 8th
   * August 22nd
2. Short (1-2 hour) information sharing meetings
   * Kick-off webinar, November 2023
   * American Geophysical Union (AGU) Town Hall, San Francisco, California, December 2023
   * Ecological Society of America (ESA) webinar, March, 2024
   * Information sharing (hybrid) meeting with Indigenous Communities in Panama, April 2024
   * Africa regional women’s session, online, April 2024
   * European Geosciences Union (EGU) presentation, Vienna, Austria, April 2024
   * Smithsonian Tropical Research Institute, Barro Colorado Island 100th Anniversary Symposium presentation, Panama, June 2024
   * Congo Basin Forest Partnership (CBFP) 20th Meeting of the Parties presentation, June, 2024
   * Congo Basin Institute, presentation, July, 2024
   * Ecological Society of America (ESA) update webinar, August, 2024
   * NASA Biological Diversity and Ecological Conservation meeting in Maryland, May, 2024
   * Association for Tropical Biology and Conservation (ATBC), Kigali, Rwanda, July 2024
3. Multi-day workshops
   * Africa Regional Consultation 3-day workshop, Yaoundé, Cameroon, February 2024
   * PANGEA Scoping 3-day workshop, Washington, DC, April 2024
   * Amazon Climate 4-day workshop, Manaus, Brazil, May 2024
   * PANGEA/Governors' Climate & Forests Task Force (GCFTF) Americans regional 2-day workshop in Lima, Peru, June 2024
   * Asia Regional Consultation X # of days? workshop, LOCATION?, July, 2024
4. Bilateral meetings with potential partners

### E - Letters of Support

1. National University of Piura, PERU  
   Agronomy Department  
   <https://www.gob.pe/unp>
2. PennState University, USA  
   Department of Meteorology and Atmospheric Science  
   <https://www.met.psu.edu/>
3. Université Catholique de Louvain

## 6. Stuff that’s beyond scope that could be developed in collaboration with PANGEA

* Ideas from PANGEA scopes that have been deemed beyond scope buy relevant
* List of complementary funding