Ancient Climate Change Resilient but Understudied Enset agri-food system Diversity Mapping for Food Security and Sustainability (ACCRUED-MFSS)

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2.1 Specific Relevance to Program Element A.44 CSDA, ESD Agriculture & Climate Resilience programs

Ancient Climate Change Resilient but Understudied Enset agri-food system Diversity Mapping for Food Security and Sustainability (ACCRUED-MFSS) is a standalone project to leverage remote sensing assets of CSDA but will immediately contribute to the Earth Science Division (ESD) Applied Science Program (ASP) on Agriculture and the specific program priorities of Food Security and Protecting Livelihoods. The ESD ASP promotes measurable social benefit from NASA research and information products with the aim to improve decision making and related policy solution implementation. Understanding the role of agricultural diversity in addressing climate change resilience of the global agri-food system is a high priority research area. The greatest opportunity for major advances are in research areas relevant to food security and resilient livelihoods are often least studied. Neglected or 'orphan' crops still play a major role in food security for millions and may hold the genetic and cropping diversity that will underpin agri-food system resilience under climate change. Increasing, studies identify these types of traditional crops as 'future smart foods' that are nutritious and resilient to climate change (Adhikari et al., 2019). Our project team includes researchers from Kew Royal Botanical Gardens and the University of Addis Ababa that have collected meticulous farm level data that will provide more than >2500 ground truth sites to calibrate remote sensing of this unique staple crop.

Ethiopia has historically been the world's largest recipient of targeted food aid, yet little food-insecurity has been reported for the enset-growing southern Ethiopian highlands even during the devastating famines of the 1980s (Dessalegn, 1996). Today, the agricultural systems of the southern Ethiopian highlands successfully support one of the highest rural population densities in Africa and enset is the main staple for more than 20-million people (Borrel et al. 2020). Here, we propose to investigate the landscape scale dynamics, interactions and resilience of these agri-food systems leveraging CSDA data to map crop extent, management practices, and diversity. We will analyze how this may have changed due to threats from climate change-related drought, disease, and land use change whilst continuing to provide food security for a growing Ethiopian population – predicted to reach 172 million by 2050.

2.2 ACCRUED-MFSS Research Objectives

CSDA assets provide an unprecedented opportunity for research on crops that are understudied because they have complicated cropping patterns or grown in gardens that are difficult to distinguish with lower resolution remote sensing. A fundamental question in the evolution of domesticated plants is the extent to which genetic diversity and diversification is driven primarily by environment or culture over time. Vegetatively propagated crops in indigenous agri-food systems lend themselves to such evolutionary assessment as clonally propagated lineages are tightly coupled with cultural traditions and likely to acquire new diversity gradually (e.g. through somatic mutations and structural variation). Using enset, a clonal propagated Ethiopian crop, we will explore

questions of diversity and adaptation to local environmental factors and cultural preferences that are the foundations of food security and agri-food system resilience.

Figure 1:Co-Investigator Dr. Borrell pictured with stand of giant false banana enset plants

Three ACCRUED-MFSS Science Objectives (SOs) are SMART – Specific, Measurable, Attainable, Relevant, and Time-Bound – and call for specific tasks:

SO 1: Map where enset grows within identified study sites at farm relevant scales to inform species distribution models and improve reporting of national production that do not currently use extensive observational data. Using CSDA high resolution data together with ground truth data that we already have (>2500 points), demonstrate observation-based mapping at scale of enset to be tractable for the first time.

SO 2: Identify change and relation to diversity – Map how small and non-standard Enset fields have changed over the 5-year study period. These will be compared to *in situ* measures to investigate diversity, food security and livelihoods.

SO 3: Detect yellowing and other forms of stress – Indicators of enset drought-resistance are not currently based on remotely sensed observations and this research will seek to identify yellowing and other signs of drought stress by combining remote and in situ observations.

2.3 Expected contributions to enset agri-food system knowledge from synoptic analysis of integrated ground truth and high resolution remotely sensed observations

Enset agri-food systems have received little research attention. There are practical limitations such as difficulty in access to enset areas or the physical difficulty of destructive sampling of such large plants to measure biomass. Although there is great diversity in phenotypes and planting systems, observations are typically limited to those farms closest to exiting hard top roads. Therefore, production of enset is extrapolated from limited sampling and is a gross estimation for such a large and diverse crop.

The contributions of this research may progress basic questions of this ancient, important and potentially climate change resilient crop. ACCRUED-MFSS will:

- As a first contribution, have produced observation based estimates of the extent of enset and the extent of enset on farms.

- As a second contribution, have improved understanding of the prevalence of enset monoculture, mixed cropping, and diversity.

- As a third contribution, have explored the possibility of texture and timeseries data to detect enset age and transplanting rotation system.

- As a fourth contribution, have improved understanding of where enset farming or enset farming practices are undergoing change.

- As a fifth contribution, have assessed the ability to detect stress from drought or disease in enset stands using remote observation. If stress can be detected, then extent and range of enset stands under stress might inform urgent action and prioritize locations for further research or intervention.

There greater import of this work may be more generally in supporting research into orphan and traditional crops with the new capabilities of high resolution CSDA data. Diversity is the key to resilience, and CSDA research may provide new insights into these understudied but largely sustainable and notably resilient agri-food systems.

2.4 Enset farm data to ground truth and calibrate remotely sensed measurements

Kew Royal Botanical Gardens' team led by Co-Investigator Dr. Borrel and Ethiopian researchers led by Dr. Wendawek at Addis Ababa University have recorded enset characteristics at >2500 independent farms. Area and distribution of enset has been measured at >1200 of these farms. They have used the data for create a geobiome niche model of Enset distribution. This is possible because of the large amount of geolocated data of Enset plots associated with farms from across virtually the entire distribution of enset. A significant field campaign recorded Enset along elevational transects. Each of the eight replicated transects are between 20-40km long. These

transects encompasses a great deal of the climate and edaphic variation that will be advantageous to calibrating measurements retrieved by remote sensing.

Where enset is grown as a monoculture, altitude can be useful in discerning and separating out classification of banana stands. The mix of other crops with enset increases further out from the center of enset cultivation in Gurage and towards the south. Secondary data from agricultural surveys such as the Ethiopian Socio-economic survey can be used to support analysis of place specific mixed cropping patterns.

The enset knowledge and expertise working in enset regions accessible through the Co-Is and their institutions is unmatched. They have sequenced over 700 Enset landraces and have decades of experience working with enset farmers. Working with farmers, the have catalogued the signs of stress and shock to enset: yellowing for drought; brown for frost damage; and further yellowing for bacterial wilt. This knowledge can be put to work for the first time on a synoptic data set at the resolution necessary to begin quantifying these stresses and shocks across the enset growing region while at the same time assessing the capability for remote observation of these resilience threatening changes.

2.5 CSDA Earth observations for analysis and mapping

ACCRUED-MFSS' technical approach will leverage **CSDA Earth observations** to analyze and map enset extent, diversity and signs of stress. Furthermore, high-resolution measurement of diversity and change will reveal highly localized patterns that may be lost in current remote sensing. Previously approaches, that had lower spatial resolution cannot observe change in the relatively small enset plots. CSDA data at applicable scales to be integrated with *in situ* farm level measurements have not previously been processed and made available to botanists and agricultural scientists working on this understudied crop.

Drones are tightly regulated in Ethiopia. Receiving import permission of imaging drones has proven unsuccessful for several years. The licensing and permission to fly drones is still under policy discussion thus leaving researchers with a great deal of uncertainty and possibility of unintentional violation of local drone use norms. An alternative to drones is necessary to address the current lack of observational data on this significant staple crop.

Small and irregular agriculture plots are the norm in many traditional agri-food systems. These fields are not visible in sensors that may have daily return views but spatial resolutions of greater than 250 meters. Recognizing boundaries of irregular fields pose problems even for 30-meter resolution NDVI data from Landsat and Sentinel-2 data.

Figure 2: Drone image of enset farm in Gurage Ethiopia

By exploiting the high spatial resolution of Maxar Worldview and the higher temporal return views of Planetscope, researchers successfully delineated boundaries of traditional farming plots that were less than one hectare in size (Cheng et al., 2020). After the period of peak senescence, potential plots were identified using a spatial segmentation approach on Worldview data. Planetscope-derived NDVI was then used in a temporal series to delineate plots growing different plants or under different agricultural rotations.

NDVI is expected to allow not only spatial delineation of the field boundaries, but to provide additional information about plant status and vegetation vigor. We have a high confidence that NDVI from PlanetScope data will be readily interpretable. Houborg and McCabe (2016) found that NDVI calculated from PlanetScope data was correlated at R^2 of 0.97 with simultaneous overpass of Landsat 8. Particularly for monitoring, we will seek index related approaches that give best results beginning with the Normalized Difference Vegetation Index (NDVI) to characterize vegetation dynamics and drought effects (Anyamba, Tucker & Eastman, 2001).

Using requested NASA High End Computing (HEC) resources, United States university-based researchers will lead acquisition and processing of the datasets into formats that can be used with high resolution field measurements. Table 1 lists CSDA remote sensing data inputs to be used. A time series of at least 5-years of cloud free images at key moments in the agricultural calendar will be used to identify patterns of change and diversity.

Table 1: Satellite data products employed in support of back-casting activities.

Source	Relevant spectral bands	Expected Distribution	Spatial	Temporal
Planet -- PlanetScope	**Primary for enset detection:** Near infrared, green panchromatic, yellow	16-bit Geo Tiff	3 meter	1-day
Maxar – Worldview (1-4)	**Primary for plot detection:** Near infrared1, Near infrared2, green, panchromatic	11-bit	0.31m panchromatic 1.24m spectral	Varies

Supervised classification approach to CSDA image processing is possible due to the abundance of ground truth data available in our enset farm survey. This is a unique opportunity to train a classifier on such a large set of irregular, complex, and small farm plots. ***Our methodology makes highly efficient use of resources because expensive filed work for collecting ground truth data is already available through collaborators.***

Analysis Step 1: create a training data set from >1200 geolocated farm sites with area estimates for enset**.** We propose to build on the approach to identification and segmentation of enset farm plots following on the methods of Cheng et al. (2020) to create a highly accurate enset map that can be used to train a subsequent supervised classification. This will require:

1. Identification of cloud free Maxar Worldview at the beginning and end of the growing season when field measurements were recorded. With >1200 measurements, we expect that we will have a sufficient number of sites to increase chances of cloud free views.
2. Edge detection segmentation for surveyed farms in cloud free views will proceed with automated detection and followed by on screen digitization of plots as necessary
3. Beginning with a set of monthly cloud free PlanetScope views, we will calculate changes in NDVI for each identified plot on the surveyed farms with identified field boundaries
4. Using the ground truth survey data, we will automate matching as possible but manually assign field characteristics for enset and mixed crops as necessary. We will then visualize and inspect matching of the phenological pattern evident in the time series of PlanetScope NDVI at plot level
5. This training data will be validated against the sub set of the >1200 farm surveys that were not sufficiently cloud free in Maxar but have PlanetScope views
6. Assessment of training set type 1 and type 2 errors will inform next steps for improving training data precision and accuracy

A process of on-screen digitization and supervised classification has been completed for selected enset growing communities using imagery taken by drones (see Figure 3). We seek to expand the scale to answer fundamental questions about enset distribution with the use of Maxar WorldView and PlanetScope data.

Figure 3: Multiple fields with plants of different ages on single farms demonstrate complex transplanting pattern of enset cultivation

Analysis Step 2: supervised classification of the >2500 farms geolocated and surveyed based on phenological signatures of the training data set**.**We propose to use supervised classification packages available in the open source software R. Our research team also has experience in custom coding in C and Python to handle any data management, data preparation or adjustments to classifier algorithms. We begin with tried and true Decision Tree classifiers following Friedl and Brodley (1997). PI Morrow co-authored a paper with Friedl in 1998 using a different modeling approach (see biosketches in section 4). Steps for supervised classification include:

- Select a set of training sites representative across image to be classified
- Extract pixels representing desired classes (eg pure mature enset, enset nursery, mixed cropping, …)
- Train classifier based on samples
- Classify the image
- Evaluate the classification. Possible sources of error may be introduced from numerous sources but special attention will be given to discrepancy between training and classified images due to angle viewing effects in PlanetScope data

Derived products including the classified images will now be shared with collaborators at Key Royal Botanical Gardens and University of Addis Ababa. They would proceed with calculating diversity measures and indexes. They will also interpreted the classifications with respect to their farm survey data sets and extrapolate estimations of enset diversity and quantity. Tulane University Export control officer will advise.

Analysis Step 3: assessment of change over time. Supervised classification will be completed for a sub-set of farms with cloud free images that allow for detection of change at two time periods 3-5 years apart. Detecting change for small and irregular plots is more complicated that identifying large scale change in broad landcover

classes. Therefore, the objectives of this analytical step are more modest and will cover a limited area of the study site. We will:

- Assess the ability to detect change in small and irregular plots from two classified images for ~50 farms.
- If change detection is unexpectedly successful with classified images, the team will proceed to map change throughout the study site
- If classified image change detection produces poor results, we will proceed with identifying plots in the training data using Worldview and PlanetScope data. Comparison between classified image change detection and chance detection following the training data set plot identification method will be analyzed and documented for reporting or publication

Analysis Step 4: stress and shock assessment to identify patterns of yellowing in enset stands. We will compare vegetation indexes to identify which index may be best at identifying stress from drought or disease in enset stands. We will compare results of indexes with available ground truth data for:

- Enhanced NDVI (ENDVI)
- Normalized Difference Red Edge
- Vegetation Condition Index
- Other index combinations using PlanetScope's eight bands including Yellow (610nm) and Red Edge (705nm)

Analysis Step 5: pilot test algorithms to identify individual enset 'trees'.We are inspired by the work, published recently in the journal Nature, by Tucker, Brandt and their team to estimate the number and carbon content of individual trees in semi-arid areas of Africa (Tucker et al., 2023). Time and resources permitting, we will pilot algorithms to identify individual enset 'trees'.

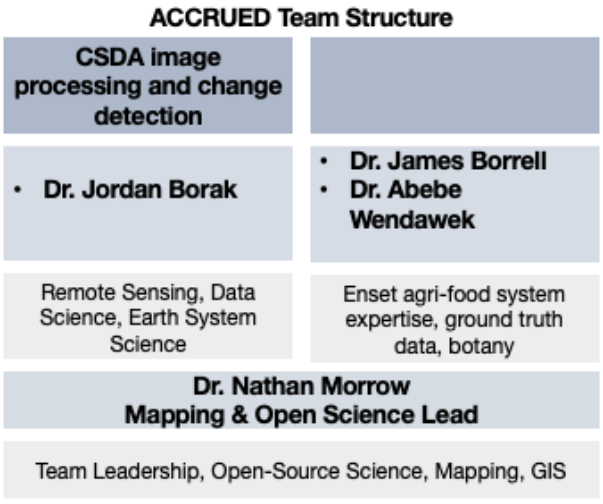
2.6 Open Source Software and Hardware

ACCRUED-MFSS is committed to every aspect of Open Source Science and will only use open source software. The open source code/data for image classification, change detection, and available from their GitHub site. ACCRUED-MFSS will also have a GitHub site and use the Zenodo folder 'Enset Research' for archiving and sharing research outputs. Modeling will primarily be conducted in R, Python and other open source languages will be used as necessary to manipulate data. All scripts will be posted. Jupyter notebooks will be piloted for potential future frontline researcher or community engagement. Computing hardware requirements are minimized as most data processing will be conducted through requested NASA HEC resources. University computing resources and available departmental IT support and equipment are sufficient for all other tasks.

2.7 Resilience and robustness of ACCRUED-MFSS

Potential pitfalls for ACCRUED-MFSS related to uncertainty and error are largely counterbalanced by a very experienced team of researchers supported by leading institutions. CSDA data has not been used in enset agri-farm systems and the unique shape and structure of enset stands may pose challenges due to viewing angle and bidirectional reflectance. Dr. Borak did his PhD. on these issues. The team as a whole has a broad and diverse toolkit for managing research challenges. For example, if the HEC request is not approved, the team has necessary skills for data processing with Google Earth Engine. The team has >100-years of combined data analysis and applied research experience. Travel restrictions due to health or security concerns may require meetings and research convenings to be held virtually and the PI recent experience in leading online teams. ***Special capabilities and facilities*** include the extensive botanical research into enset at Kew, agri-food systems applied research community led by Addis Ababa University, UMD's leading expertise in terrestrial remote sensing as well as Tulane's Export Control Officer and R-1 administrative support will ensure compliance that may be complicated for working with CSDA assets.

2.8 Management structure



The ACCRUED-MFSS management structure aims to encourage collaboration enabled by technology (Ramachandran, Bugbee & Murphy, 2021) with clear shared objectives, empowered leadership of sub-teams, and easy exchange through advanced digital tools for inclusive communication. Implementing an interdisciplinary project requires active and engaged project leadership with regular team communication and directed reflection. ACCRUED-MFSS brings together investigators that work at different time and spatial scales as well as with different disciplinary tools and methods. To balance interdisciplinary interaction with research efficiency, tasks and sub-tasks will be assigned to sub-teams led by a Co-Investigator with the PI participating in all of the teams' work planning and task result monitoring. Furthermore, the PI is responsible for promoting necessary cross-team interaction, monitoring dependencies, open science, and further interdisciplinary co-creation tasks and results. Quarterly virtual all team meetings, annual workplanning, and PI/Co-I business meeting focused on reporting project progress will provide necessary collaborative discourse. Dependencies, emerging challenges, co-created cross-learning and solutions from virtual/face-2-face team interaction will be used to monitor workplan and share with NASA.

In the third quarter of project year one, Dr. Morrow and Dr. Borak will travel for a research team meeting at Kew Royal Botanical Gardens outside London UK. The purpose of this meeting is to review the classified image derived products against Kew Researchers' ground truth data in an intensive workshop. This should result in a fully

validated product by Kew's team of enset experts. We will also prepare annual reports on research progress to date and conduct workplaning for project year 2. Travel to Kew Royal Botanical Gardens outside London UK in project year 2 will proceed with a Kew enset expert validation of the change and stress products. The team will also prepare for final reporting and publication and DMP plan completion. In the fourth quarter of project year 1, Dr. Morrow will travel to Addis Ababa to validate products with collaborator Dr. Wendawek and Ethiopian enset researchers. In these meetings, we will engage with enset researchers at institutions through out the country and seek meaningful opportunities for collaborating on publications, planning future research to build on derived ACCRUED-MFSS products, and engaging in policy processes. The travel in project year two has similar purposes with validation and encouraging use and impact of the change and stress products. Both engagements in Ethiopia will contribute to required reporting and promote use of the research products – leading to the greater contribution to applied science benefits for those living in enset growing areas.

2.9 Foreign participation and compliance with U.S. export laws and regulations

The majority of CSDA Planet and Maxar data will be processed within the NASA High End Computing (HEC) environment. As required, Dr. Borak or Dr. Morrow may produce a RGB, monochromatic or false color image from Maxar or Planet data to spot check classification results or resolve classification conflicts using a Geographic Information System overlay. This use of data would be only undertaken within the secure university computing environment or on their own secure personal computers. Only derived products would be shared with Co-Investigators Dr. Borrell or Dr. Wendewek. Only derived products would be presented during annual meetings of the research team in London and Addis Ababa. The Tulane University Export Control officer will be regularly consulted and included on communications to ensure compliance with regulations. Specifically, the roles and location for handling CSDA data will be:

- Dr. Borak – within HEC and UMD computing environments. He will ensure only derived products and no raw data is transported on any personal devices when he travels to team meetings in London.
- Dr. Morrow – may also engage with raw data within the HEC environment. He will occasionally create overlay images from raw CSDA data for use in improving supervised classifications within the Tulane University computing environment and a secure personal workstation. He will only share or present derived products with foreign collaborators. No raw data will be present on his personal computing devices during annual meetings in London or Addis Ababa.
- Dr. Borrel will only work with supervised classification results and related derived products. His collaboration does not require use of any raw data.
- Dr. Wendawek will only work with supervised classification results and related derived products. His collaboration does not require use of any raw data.

Dr. Morrow is responsible for full compliance with the EULA for Planet and Maxar data. He has already corresponded with the NASA CSDA team that assured him

> "Data access is restricted to US Government funded researchers (https://www.earthdata.nasa.gov/esds/csda/csda-faq). Derived products may be shared without restrictions however the raw data would not be accessible to them".

With regard to **Export Controls**, it is understood that this proposed research is subject to United States laws and regulations controlling the export of technical data, computer

software, laboratory prototypes and other commodities, articles, and information, including the Arms Export Control Act as amended in the Export Administration Act of 1979, and that the parties' obligations are contingent upon compliance with applicable United States export laws and regulations, including the International Traffic in Arms Regulations (ITAR; 22 CFR Parts 120-130) and the Export Administration Regulations (EAR; 15 CFR Parts 730-774). The transfer of certain technical data and commodities could require a license authorization from an agency of the United States Government and/or written assurances by Licensee that Licensee shall not export data or commodities to certain foreign individuals/countries without prior approval of such agency. Tulane represents neither that a license is not required nor that, if required, it can obtain approval.

2.10 Outcomes and primary tasks of task identified personnel

ACCRUED-MSFF will produce a series of novel data and mapping for the understudied enset with coordinated research activites over two project years (see Milestone Schedule in section 2.11). The primary output is novel classification product using CSDA data to demonstrate an approach to mapping enset extent, shape and size of fields. Data integration with a >2500 point *in situ* data set of enset botanical, farm system and farming household food security and resilience will inform both the classification and the interpretation of results. In the second year, these data will be interrogated to better understand the ability to detect diversity and change in enset stands. Analysis of the relation of diversity and change related to food security and resilience indicators will then be undertaken. Finally, likely drought stress indicators will be identified based on multispectral data and ins situ measurements.

Dr. Morrow as PI is accountable for grant implementation, compliance, risk management and reporting, quality and timeliness of all deliverables, implementation of the DMP, responsive communication, and reporting to NASA and all stakeholders. Dr. Morrow will manage collaboration, GitHub sites. Dr. Morrow will take the technical lead on all spatial analysis and mapping sub-tasks. Accountable for all milestones, he ensures inclusive and equitable contributions to collaborative deliverables including publications, open science and reports in following Milestone Schedule.

Dr. Borak's research responsibilities will focus on processing CSDA data and generating satellite-derived classifications and data products in the HEC environment. He will oversee and implement the training of the classifier, classify images, and conduct stress and change analysis. In addition to detailed documentation of all procedures and codes used and all datasets generated, overall summary of satellite data characteristics over the study area and a set of specific lessons learned will be posted following the DMP.

Dr. Borrel will contribute to data integration with 2500+ field observation of enset gardens and related livelihood, food security and agri-food system indicators. He will lead analysis and documentation of results related to enset botanical traits, environmental and cultural determinants of diversity. Together with the team, he will assess the quality and significance of deliverables for answering enset-related science questions about agri-food system resilience and sustainability.

Dr. Wendawek will convene and communicate with enset researchers in Ethiopia and around the world to multiply the impact of the research. He will contribute to validation and ground truthing of derived products. He will advise on publishing strategy and further articulation of research questions to ensure the highest levels of relevance.

2.11 Tentative Schedule of Research and Deliverables

Project Year 1: Enset extent mapping and integration of in situ data			
Q	**Milestone deliverable**	**Open science output**	**Reporting**
Q1	• Literature review focus on measuring, and analyzing enset diversity and climate change resilience	• Open Access Annotated Bibliography GitHub site	• Submit Work and Costing plan • Submit PY1 Q1 report
Q2	• *in situ* ground truth data set created for study sites • *Enset study site CSDA data parameters extracted and organized for extent mapping*	• Register open science plan for reproducibility	• PY1 Q2 report with some discussion of data quality
Q3	• Run multiple classification models based on training data set • Team meeting in London	• Open science badges PI/CO-I	• PY1 Q3 Report
Q4	• Quality control and selection of optimal enset extent mapping classifier • Data integration of in situ data and CSDA classification • Research meeting in Addis Ababa	• GitHub updated • Annual inclusion/DMP tasks	• Draft peer review manuscript • PY1 Annual Report
Project Year 2: Change, diversity and stress analysis			
Q	**Milestone deliverable**	**Open science output**	**Reporting**
Q1	• Change analysis based on extent map	• CJ & EJ community Open Science badge contest	• Share PY2 workplan • Submit PY2 Q1 report
Q2	• Diversity analysis on integrated data	• Community GitHub event	• PY2 Q2 report w/ monitoring overview
Q3	• Seek indicators for drought/disease stress based on *in situ* and CSDA measures. • London team meeting	• presentation at AGU • GitHub update • All documents to Zenodo	• PY2 Q3 Report
Q4	• Final lessons learned workshop in Addis Ababa	• GitHub updated • Annual inclusion/DMP tasks • Closing and reporting on all Inclusion and DMP Plan activities	• Final Tech/Financial Report • Draft peer review manuscript

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4.0 Data management plan

Accountability for full implementation of the Data Management Plan (DMP) and ensuring full compliance to NASA DMP requirements lies with the Dr. Nathan Morrow as PI. He has extensive experience managing geographic and remotely sensed data for research and decision making. He has published peer reviewed articles on data for decision making (Mock, Morrow & Papendeick, 2012) has written and taught about data responsibility (Morrow, 2022), and recently was awarded a grant for increasing the use of Open Source Science for Environmental Justice.

End User License agreements for PlanetScope and Maxar Worldview describe how commercial data can be used by NASA researchers for Scientific Use research purposes as outlined in the research award agreement. Public Release or Commercial Use of the CSDA data is prohibited. Any raw imagery must be securely handled. Only derivative products with clearly defined research purposes are to be shared with the general public, used in publications or shared with our non-US based collaborators.

Every effort will be made to limit the access to original or raw PlanetScope and Maxar Worldview data. Dr. Borak works in a secure NASA affiliated research center with a nasa.gov email. The raw data will almost exclusively be processed in the HEC computing environment by Dr. Borak following the strict security protocols of his center. On occasions when Dr. Morrow is required to use imagery, it will be processed in HEC environment or on a secured workstation. No raw data will be present on laptops during travel. Tulane's Export Control officer is fully aware of this work and will set up standard protocols and secure approaches to communication and exchange of information and derivative products with our foreign collaborators.

ACCRUED-MFSS is committed to Open Source Science and identified personnel will complete NASA TOPS core curriculum to earn a minimum of 5 open science badges.

The ACCRUED-MFSSteam will pursue the development plan along the lines of the "Geosciences Paper of the Future" with the intention move towards improving the DMP "to make data, software, and methods openly accessible, citable, and well documented" (Gil et al., 2016) and the FAIR principles: Findable, Accessible, Interoperable, & Reusable (Wilkinson et al., 2016). As part of the advancement of CJ&EJ data for decision making methods and with the specific expertise in the ACCRUED-MFSSscience leadership in this research area, the team will leverage the DSCEJ Data Center and Tulane University's Data Hub along side GitHub, data.nasa.gov, and Zenodo to ensure data and information are shared in ways that maximize access, reuse and application to new problems, contexts, and research questions. Data will be made publically available with enough detail to allow for validation and metadata standards will conform to open science standards of the repository such as coding in XML.

The ACCRUED-MFSS data management plan ensures public access to publications and digital datasets arising from NASA research. All ACCRUED-MFSS data posting and archiving tasks will be **confirmed quarterly**. Open Science milestones are identified on the schedule and assigned responsibility to the postdoc and accountability to the PI. The preprints will be posted on Earth and Space Science Open Archive, associated with

the American Geophysical Union, pre-print server https://www.essoar.org/. Open access articles will be available as soon at final revisions are accepted, but expected to be within one year from project closure.

Data sets, meta data and other materials developed to support the proposed research will be archived at data.nasa.gov, as appropriate, and Zenodo (https://zenodo.org/) site associated with European Organization for Nuclear Research (CERN) and expected to maintain the open archive as long as CERN exists. ACCRUED-MFSS has created an Enset 'community' on Zenodo to encourage findability of the research and exchange with other enset researchers.

All derived products and documents produced by ACCRUED-MFSS encourage redistribution, reproduction and creation of derivatives with a Creative Commons Attribution 4.0 International license, and uploaded to Zenodo/DSCEJ Data Hub/Github including:

- 1 or more enset plot classification maps made available in geotiff and pdf formats
- Scripts and source code for training classifier and calssifying images including source code, guidance notes and results/validation
- Manuscripts and documentation of change and stress detection. These will be given a unique doi when uploaded and include source code, guidance notes and results/validation on GitHub site

Development of the project in year one will take place primarily on a dedicated GitHub site. During initial extraction of remote sensing measurements as discreet data sets will temporarily be stored in the NASA HEC environment. As derived products are finalized and model source code documented in a distributable version, these information assets will be open source licensed and uploaded to data.nasa.gov and Zenodo. Full documentation will be completed by project close out and will be transferred to the Tulane Data hub with links to the permanent archives.

The PI will maintain communication as necessary with the data repository and the NASA program manager to ensure that: DMP is updated as needed at time of award; appropriate attribution is included; data meet minimum quality standards; and data are appropriately evaluated for and secured to prevent disclosure of personally identifiable information and to protect proprietary interests, confidentiality, and intellectual property rights.

5.0 Biographical Sketches

PI: Dr. Nathan Morrow

1. Professional Preparation

Boston University, Geography, Bachelor of Arts with Honors 1997
Boston University, Geography, Master of Arts 1998
University of Maryland, Geography, Doctor of Philosophy (M. Hansen advisor) 2021

2. Professional Experience and Positions

Current Sponsored Research:

- PI, Assessment of the Gulf Coast Environmental Justice Landscape for Equity (AGEJL-4-Equity), NASA-funded, 10/22-4/23
- PI, Open Science Outlook for Environmental Justice and Resilience of the Louisiana Gulf Coast (OSO-LoGiC), NASA-EPSCoR-funded, 5/22-4/23

Appointments:

- Associate Research Professor, Tulane Public Health & Tropical Medicine, 2022-.
- Associate Research Professor, Tulane Law, 2014-2018, Adjunct 2007-2012
- Associate Clinical Professor, Tulane School of Social Work, 2012-2014
- Associate Clinical Professor, Tulane Public Health & Tropical Medicine, 2011-2014, Adjunct 2007-2022

3. Selected Bibliography

Morrow, N., Mock, N. B., Gatto, A., LeMense, J., & Hudson, M. (2022). Protective Pathways: Connecting Environmental and Human Security at Local and Landscape Level with NLP and Geospatial Analysis of a Novel Database of 1500 Project Evaluations. *Land*, *11*(1), 123. https://doi.org/10.3390/land11010123

Morrow, N. (2022). *People-centered design in Open Sourced Science for enhanced use of Earth observation in equitable engagement, empowerment for collective action, and meaningful measurable impact.* Open Sourced Science (OSS) for Earth System Observatory (ESO) Mission Science Data Processing Study. https://doi.org/10.5281/zenodo.5932699

Mock, N., **Morrow, N.**, & Papendieck, A. (2012). From complexity to food security decision-support: Novel methods of assessment and their role in enhancing the timeliness and relevance of food and nutrition security information. *Global Food Security*, *2*(1), 41–49. https://doi.org/10.1016/j.gfs.2012.11.007

Muchoney, D., Borak, J., Chi, H., Friedl, M., Gopal, S., Hodges, J., **Morrow, N.**, & Strahler, A. (2000). Application of the MODIS global supervised classification model to vegetation and land cover mapping of Central America. *International Journal of Remote Sensing*, *21*(6–7), 1115–1138. https://doi.org/10.1080/014311600210100

Morrow, N., & Prince, S. (1999). Use of potential and actual primary production models to map drought and degradation in semi-arid Southern Africa. *EOS Transactions, 80*(46), F403.

Morrow, N., & Friedl, M. (1998). Modeling biophysical controls on land surface temperature and reflectance in grasslands. *Agricultural and Forest Meteorology*, *92*(3), 147–161. https://doi.org/10.1016/S0168-1923(98)00098-7

4. Research Experience: Scientific, Technical, Management

Dr. Morrow has a paper co-authored with Dr. Borrell on enset under minor revisions at the journal Food Policy. His research and publications are informed by 25 years of experience not only as a professor but also leading implementation, developing capacity and ensuring research-based evidence for interdisciplinary/multi-sectoral food security, humanitarian response, and child wellbeing policy implementation projects. He has served as Chief of Party for a multi-organizational consortium for multi-country developmental relief and humanitarian aid response valued at over 400 million USD responding to an El Niño drought food security crisis in southern Africa -- a precursor to now ubiquitous resilience policy-focused programming. As co-chair of the Emergency and Disaster Evaluation thematic group at the American Evaluation Association, Dr. Morrow has promoted inclusive engagement and more rigorous measurement models in resilience research and intervention planning. The Global Environment Facility (GEF-7) replenishment strategy was informed, in part, by a geospatial analysis of environmental security led by Dr. Morrow.

Dr. Morrow is PI for two projects that intend to strengthen capacity for open source science to address challenges in CJ & EJ research in collaboration with Gulf Coast EJ community networks and organizations. Strategic assessment and strategy processes to strengthen evidence-based decision support have been a feature of Dr. Morrow's research and consulting with a variety of organizations including work on USAID's resilience measurement operational research in the Horn of Africa, needs assessment capacity for the United Nation's World Food Programme, and the global redesign of World Vision International's system for reporting to the International Board and other stakeholders on impact for improved child wellbeing. Dr. Morrow was invited to conduct the first-ever technical review of an SDG target indicator; 2.1.2 -- Prevalence of severe or moderate food insecurity. He recently completed a global capacity development effort for evidence based policy and policy implementation for the UN Food and Agriculture Organization for >50 countries.

Dr. Morrow continues to actively use remote sensing and geospatial analysis in his applied research following on early contributions to the MODIS, NPOESS, and Land-Use and Land-Cover Change science mission. These technologies featured in Developmental Evaluations of the World Food Program's mVAM program for improved needs assessment and hazard monitoring. They also feature in his teaching that includes problem sets related to assessing flood damage or humanitarian logistics planning.

Co-I: Institutional PI: Dr. Jordan Borak

1. Professional Preparation

Graduate Certificate, Data Science: University of Maryland, College Park, 2019.
Ph.D. in Geography: Boston University, 2000.
Master of Arts in Geography: Boston University, 1996.
Bachelor of Science in Geography (Math minor): University of Illinois, Urbana-Champaign, 1992.

2. Professional Experience and Positions

Current Sponsored Research:

- PI, Enhanced Roughness Length Estimates from ICESat-2 Vegetation Products
- Co-I,National Climate Assessment Land Data Assimilation System
- Co-I, Shallow Water Bathymetry Products and Analysis for Near-shore

Appointments:

- Associate Research Scientist, Earth System Science Interdisciplinary Center, University of Maryland and Hydrological Sciences Laboratory, NASA/Goddard Space Flight Center (June 2011 – present).
- Senior Support Scientist, Science Systems and Applications, Inc., then Wyle Information Systems, LLC, and Hydrological Sciences Branch, NASA/GSFC (July 2002 – June 2011).
- Support Scientist, Science Systems and Applications, Inc., MODIS Land Data Operational Product Evaluation Facility, NASA/GSFC (November 2000 – June 2002).
- Research Associate, Department of Geography and Laboratory for Global Remote Sensing Studies, University of Maryland (July 1999 – November 2000).
- Research Fellow, Department of Geography and Center for Remote Sensing, Boston University (September 1993 – June 1999).

3. Selected Bibliography

Borak, J.S., M.F. Jasinski, and N. Tangdamrongsub, 2021: Fusing ICESat-2 and MODIS Vegetation Data Products to Enhance Momentum Aerodynamic Roughness Fields with Spatially-Explicit Scaling for Improved Land Surface Modeling [Poster presentation G15B-0350]. AGU 2021 Fall Meeting, 13-17 Dec.

Tangdamrongsub, N., C. Hwang, **J.S. Borak**, S. Prabnakorn, and J. Han, 2021: Optimizing GRACE/GRACE-FO data and *a priori* hydrological knowledge for improved global Terrestrial Water Storage component estimates. *J. Hydrol.*, **598**, 126463.

Borak, J.S., M.F. Jasinski, and N. Tangdamrongsub, 2020: Enhanced vegetation aerodynamic roughness for momentum with ICESat-2 data products: early results [Poster presentation H194-0005]. AGU 2020 Fall Meeting, 1-17 Dec.

Jasinski, M.F., **J.S. Borak**, S.V. Kumar, D.M. Mocko, C.D. Peters-Lidard, M. Rodell, H. Rui, H.K. Beaudoing, B.E. Vollmer, K.R. Aresenault, B. Li, J.D. Bolten, and N. Tangdamrongsub, 2019: NCA-LDAS: Overview and Analysis of Hydrologic Trends for the National Climate Assessment. *J. Hydrometeorol.*, **20**, 1595-1617.

Kumar, S.V., M. Jasinski, D. Mocko, M. Rodell, **J. Borak**, B. Li, H. Kato Beaudoing, and C. D. Peters-Lidard, 2019a: NCA-LDAS land analysis: Development and performance of a multisensor, multivariate land data assimilation system for the National Climate Assessment. *J. Hydrometeorol.*, **20**, 1571-1593.

Kumar, S.V., D.M. Mocko, S. Wang, C.D. Peters-Lidard, and **J. Borak**, 2019b: Assimilation of remotely sensed Leaf Area Index into the Noah-MP land surface model: Impacts on water and carbon fluxes and states over the Continental U.S. *J. Hydrometeorol.*, **20**, 1359-1377.

de Gonçalves, L.G.G., **J.S. Borak**, M.H. Costa, S.R. … 2013: Overview of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia Data Model Intercomparison Project (LBA-DMIP). *Agr.Forest Meteorol.,***182-183**,111-127.

Borak, J.S., and M.F. Jasinski, 2009: Effective interpolation of incomplete satellite-derived leaf-area index time series for the continental United States. *Agr. Forest Meteorol.,* **149**, 320-332.

Borak, J.S., M.F. Jasinski, and R.D. Crago, 2005: Time series vegetation aerodynamic roughness fields estimated from MODIS observations. *Agr. Forest Meteorol.,* **135**, 252-268.

4. Research Experience: Scientific, Technical, Management

Dr. Borak's research interests include Earth science data processing and analysis: particular focus on long-term time series data at regional and continental scales; inter-annual and seasonal variability of vegetation and water cycle components; land-cover characterization from satellite observations; quality assessment of remotely sensed data. He has 25+ years experience with C programming and shell scripting in Unix-type environments; 4+ years with Python and Java. He also is an expert in machine learning software: scikit-learn and Keras; statistics and visualization packages: R, Tableau, and SAS.

Collaborator: Dr. James Borrell

1. Professional Preparation

University of Exeter, Biology, Bachelor of Science 2011
Queen Mary University of London, Botany, Doctor of Philosophy 2017

2. Professional Experience and Positions

Current Sponsored Research:

- Evolutionary dynamics of vegetative agriculture in the Ethiopian Highlands:
- Evaluating genetic bottlenecks in planted and naturally colonised young woodlands: Implications for resilience to pests, diseases and environmental
- Realising the potential of plant bioresources as nature-based solutions in African biodiversity hotspots
- Building an incentive mechanism for agrobiodiversity conservation

Appointments:

Future Leader Research Fellow, RBGKew. Developing an independent research programme in plant health and adaptation, food security and ecological modelling. Responsible for decision making, budgets, leading and managing teams and accountable for outputs.(2021-present)

3. Selected Bibliography

- Borrell, J.S., Gebremariam, Z. & Abebe, W.M. *Nature Biotechnology* 39, 1064–1065 (2021).
- Koch, O., Mengesha, W. A., Pironon, S., Pagella, T., Ondo, I., Rosa, I., ... & Borrell, J. S. (2021) Modelling potential range expansion of an underutilised food security crop in Sub-Saharan Africa. *Environmental Research Letters* , *17*(1), p.014022.
- Borrell, J. S., Zohren, J., Nichols, R. A., & Buggs, R. J. A. (2020). Genomic assessment of local adaptation in dwarf birch to inform assisted gene flow. *Evolutionary Applications*, 13, 161–175.
- Borrell, J. S., Goodwin, M., Blomme, G., Jacobsen, K., Wendawek, A. M., Gashu, D., … Wilkin, P. (2020). Enset based agri-systems in Ethiopia: A systematic review of production trends, agronomy, processing and the wider food security applications of a neglected banana relative. *Plants, People, Planet*. *00, 1-17.*

4. Research Experience: Scientific, Technical, Management

James Borrell is a Future Leader Research Fellow, combining a background in associating genome-wide markers with broad-scale environmental models, together with extensive field experience in sub-Saharan Africa. For the past 4 years JB has studied the diversity and distribution of enset and its agri-systems in Ethiopia, funded through three large GCRF grants (with Co-I Wilkin, totaling ~£1.8m). Borrell was lead author of the two largest and most recent reviewson enset diversity5 and agronomy6,7, and has established relationships with key regional stakeholders. JB also provides expertise in biogeography, genomics of adaptation, and demographic reconstruction.

Collaborator: Dr Wendawek Abebe Mengesha

1. Professional Preparation

Addis Ababa University, Biology, Bachelor of Science 2011
Addis Ababa University, Botany, Doctor of Philosophy 1994

2. Professional Experience and Positions

Selected Sponsored Research:

1. Yams of West and South West Ethiopia: conserving yam agrobiodiversity and associated indigenous knowledge for Ethiopia's future. Establishment of cultivated yam germplasm collections and capture and dissemination of associated biocultural information. Funded by the Ellis Goodman Family Foundation and The Christensen Fund
2. Modeling and genomics resources to enhance exploitation of the sustainable and diverse Ethiopian starch crop Enset and support livelihoods. Funded by the Biology and Biotechnology Research Council (BBSRC, BB/P02307X/1) under the GCRF Foundation Awards for Global Agricultural and Food Systems Research call.

Appointments:

2015 - Associate professor, Department of Biology Hawassa University.
2008-2015 Assistant Professor, Department of Biology Dilla University,

3. Selected Bibliography

- Wendawek Abebe, Sebsebe Demissew, Fay M.F., Smith R.J, Nordal, I. & Wilkin. P. 2012. Genetic Diversity and Population structure of Guinea yams and their wild relatives in South and South West Ethiopia as revealed by Microsatellite markers. Genetic Resources & Crop Evolution 60:529–541 (Online first 18/7/12). DOI 10.1007/s10722-012-9856-0
- Wendawek Abebe, Sebsebe Demissew, Fay M.F., Smith, R.J, Nordal. I. & Wilkin. P. 2012. Genetic diversity and species delimitation in the Cultivated and Wild Guinea Yams from Southwest Ethiopia as determined by AFLP (Amplified Fragment Length Polymorphism) Markers. Genetic Resources & Crop Evolution 60: 1365-1375 (Online first 10/12/12). DOI 10.1007/s10722-012-9925-4
- Wendawek Abebe ; Sebsebe Demissew ; Fay, M. F. ; Smith, R. J. ; Nordal, I. ; Wilkin, P. (2008). Morphological and molecular characterization of Guinea yam from south and south west Ethiopia. (A poster presented at the 4th International Conference on Comparative Biology of Monocots, 2008, Denmark, Copenhagen).

4. Research Experience: Scientific, Technical, Management

Beginning with a MSc thesis on tissue culture and genetics of *Brassica nigra*, Dr. Wendawek has been working research on diversity, conservation and genetics of plants. Now focusing on taxonomy and genetics of yams, one of the food security crops in south and south West Ethiopia. He is heavily involved in teaching and advising MSc students of Botanical Science and Genetics streams and supports a growing group of researchers.

6.0: Current and Pending Support

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.	
Investigator: Dr. Nathan Morrow	Other agencies (including NASA) to which this
Support: ☒ Current ☐ Pending Project/Proposal Title**:** Assessment of the Gulf Coast Environmental Justice Landscape for Equity (AGEJL-4-Equity) Source of Support: NASA A.49 Earth Science Applications: Equity and Environmental Justice Total Award Period Covered: 10/22-06/23 Person-Months Per Year Committed to the Project: 2.0	
Support: ☒ Current ☐ Pending Project/Proposal Title: Open Science Outlook for Environmental Justice and Resilience of the Louisiana Role: PI Source of Support: NASA EPSCoR Louisianna BoR RID Project Total Award Period Covered: 3/22-05/23 Person-Months Per Year Committed to the Project: 2.0	
Support: ☐ Current ☒ Pending Project/Proposal Title: High-resolution Extreme Event and Localized Temperature for Health Forecasting Role: PI Source of Support: NASA A.28 Interdisciplinary Science Total Award Period Covered: FY24-FY26 Person-Months Per Year Committed to the Project: 5.4	
Support: ☐ Current ☒ Pending Project/Proposal Title: EJ Core GC; Engaging diverse researchers and EJ communities in inclusive Role: PI Source of Support: NASA Science Mission Directorate –F.14- Transform to Open Science Training Total Award Period Covered: 07/23-06/25 Person-Months Per Year Committed to the Project: 3.6	
Support: ☐ Current ☒ Pending Project/Proposal Title: Analysis of Locally Flooded Areas with Environmental Justice Role: PI Source of Support: NASA Science Mission Directorate –A.44- COMMERCIAL SMALLSAT Total Award Period Covered: 09/23-08/25 Person-Months Per Year Committed to the Project: 1.8	
Support: ☐ Current ☒ Pending Project/Proposal Title: Application of Commercial Smallsat Data to Enhance Flood Resilience in Role: Co-PI Source of Support: NASA Science Mission Directorate –A.44- COMMERCIAL SMALLSAT Total Award Period Covered: 09/23-08/25 Person-Months Per Year Committed to the Project: 1.8	

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Dr. Jordan S. Borak	Other agencies (including NASA) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending
Project/Proposal Title: Enhanced Roughness Length Estimates from ICESat-2 Vegetation Products
Role: PI
Source of Support: NASA Cryospheric Program/Studies with ICESat-2
Total Award Period Covered: 05/20-04/23
Person-Months Per Year Committed to the Project: 3.0

Support: ☒ Current ☐ Pending
Project/Proposal Title: National Climate Assessment Land Data Assimilation System, NCA-LDAS
Role: Co-I
Source of Support: NASA National Climate Assessment Program
Total Award Period Covered: FY16-FY23
Person-Months Per Year Committed to the Project: 3.6

Support: ☒ Current ☐ Pending
Project/Proposal Title: Shallow Water Bathymetry Products and Analysis for Near-Shore Coastal and Inland Waters
Role: Co-I
Source of Support: NASA The Science of Terra, Aqua, and Suomi-NPP
Total Award Period Covered:
Person-Months Per Year Committed to the Project:3.0

Support: ☒ Current ☐ Pending
Project/Proposal Title: Remote Sensing of Vegetation in Puerto Rico for NIST's Hurricane Maria Infrastructure Project
Role: PREP Research Associate
Source of Support: NIST Community Resilience Program
Total Award Period Covered: 07/22-06/23
Person-Months Per Year Committed to the Project: 3.0

Support: ☐ Current ☒ Pending
Project/Proposal Title: Improving Our Understanding of Gulf Coast Wetland Dynamics with Spaceborne Lidar
Role: Co-I
Source of Support: NASA Cryospheric Program/Studies with ICESat-2
Total Award Period Covered: 05/23-04/26
Person-Months Per Year Committed to the Project: 3.0

Support: ☐ Current ☒ Pending
Project/Proposal Title: Spatio-Temporal Connections of Integrated Energy, Water and Biogeochemical Processes Across Alaska's Land and Ocean Ecosystems
Role: Co-I
Source of Support: NASA Interdisciplinary Research in Earth Science
Total Award Period Covered: 6/23-05/26
Person-Months Per Year Committed to the Project: 1.2

Support: ☐ Current ☒ Pending Project/Proposal Title: High-resolution Extreme Event and Localized Temperature for Health Forecasting in Under-served Lowlands of the Gulf Coast (HEELTHFUL-GC) Source of Support: NASA Interdisciplinary Research in Earth Science Total Award Period Covered: 07/23-06/26 Person-Months Per Year Committed to the Project: 3.6/2.4/1.8
Support: ☐ Current ☒ Pending Project/Proposal Title: Ancient Climate Change Resilient but Understudied Enset agrifood system Diversity Mapping for Food Security and Sustainability (ACCRUED-MFSS) Role: Co-I Source of Support: NASA Commercial Smallsat Data Scientific Analysis Total Award Period Covered: 09/23-08/25 Person-Months Per Year Committed to the Project: 3.6
Support: ☐ Current ☒ Pending Project/Proposal Title: Application of Commercial Smallsat Data to Enhance Flood Resilience in Support of Under-served Communities in Puerto Rico Role: PI Source of Support: NASA Commercial Smallsat Data Scientific Analysis Total Award Period Covered: 10/23-09/25 Person-Months Per Year Committed to the Project: 2.4

7.0: Statements of Commitment and Letters of Support

UNIVERSITY OF MARYLAND
EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER
Office of the Director

5825 University Research Court, Suite 4001
M Square Building
University of Maryland
College Park, Maryland 20740
TEL (301) 405-0050 FAX (301) 405-8468

Letter of commitment

Date: March 14, 2023

To: Dr. Nathan Morrow, Tulane University
From: University of Maryland, ESSIC
Subject: Statement of Commitment from Department

Dear Dr. Morrow

I acknowledge that Dr. Jordan Borak is identified by name as a Collaborator to the research proposal entitled: "Ancient Climate Change Resilient but Understudied Enset agrifood system Diversity Mapping for Food Security and Sustainability (ACCRUED-MFSS)" that is submitted by Tulane University to NASA in response to the NASA Roses Commercial Smallsat Data Scientific Analysis NNH22ZDA001N-CSDSA. Dr. Borak intends to carry out all responsibilities identified by Tulane University in this proposal.

Sincerely,

Dr. Ellen Williams,
Director, Earth System Science Interdisciplinary Center (ESSIC)

Royal Botanic Gardens, Kew, Richmond TW9 3AE
020 8332 5000 | kew.org | info@kew.org

Dr. Nathan Morrow
Tulane University
1440 Canal Street, New Orleans, USA

Date March 22nd, 2023

Dear Dr. Morrow,

I wish to write in support of this proposal, which I believe will significantly advance research in this field, as well as making an important contribution to food security and sustainable development in Ethiopia.

I acknowledge that I am identified by name as Collaborator to the investigation, entitled Ancient Climate Change Resilient but Understudied Enset agri-food system Diversity Mapping for Food Security and Sustainability (ACCRUED-MFSS), that is submitted by Dr. Morrow to the NASA funding announcement NNH22ZDA001N-CSDSA, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation, as stated in this proposal, will be considered during peer review in determining in part the merits of this proposal. I have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation." To conduct work for this investigation, my participating organization is Royal Botanic Gardens Kew, based in the UK.

In support of this application, I highlight that I will make available extensive previously acquired datasets. This includes >3000 ground truthed enset observations, species compositions of over 1200 farms and contemporary species distribution modelling wild and domesticated enset. The opportunity to use this data in a high resolution remote sensing context is significant, and will lead to high impact research.

Thank you for your consideration,
Kind regards,

James Borrell, PhD
Research Leader, Kew RBG

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ADDIS ABABA UNIVERSITY
DEPARTMENT OF MICROBIAL CELLULAR AND MOLECULAR BIOLOGY

Date: March 23, 2023
Ref. No: SF/MCMBl.35:5')15/2023

Dear assessment committee.

I wish to write in support of this proposal, which I believe will support our progress towards the sustainable development goals and food security in Ethiopia, as well as fostering productive international collaborations.

I acknowledge that I am identified by name as Collaborator to the investigation,entitled Ancient Climate Change Resilient but Understudied Ensel agri-food system Diversity Mapping for Food Security and Sustainability (ACCRUED-MFSS), that is submitted by Dr. Morrow to the NASA funding announcement NN1-122ZDA001N-CSDSA, and that I intend to carry out all responsibilities identified for me (us) in this proposal. I understand that the extent and justification of my participation, as stated in this proposal, will be considered during peer review in determining in part the merits of this proposal. I have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation." To conduct work for this investigation, my participating organization is Addis Ababa University, based in Ethiopia.

In support of this application, I highlight that I will make all relevant ground observation data available and support collection of additional contextual information as required. I have extensive experience of researching these agri-systems throughout my career, and so feel I am ideally placed to provide support for this important work.

Thank you for your consideration,

Kind regards,

Addis Ababa University
Department Of Microbial Cellular Molecular Biology
College Of Natural Sciences

Associate Professor Wendawek Abebe
Department of Microbial, Cellular and Molecular Biology
Addis Ababa University
Ethiopia

P.O.Box 1176
Addis Ababa
Tele: 251-8-95 92 16
mmc_biol_cns@;aau.edu.et

8.0 Budget
8a. Budget Narrative:

Key Personnel:

Tulane personnel will be leading the project from start to finish over the proposed period of 24 months.

Nathan Morrow, The Principal Investigator will contribute a level of effort (LOE)

Dr. Nathan Morrow as PI will provide 0.25 FTE. Dr. Morrow as PI is accountable for grant implementation, compliance, risk management and reporting, quality and timeliness of all deliverables, implementation of the DMP, responsive communication, and reporting to NASA and all stakeholders. Dr. Morrow will manage collaboration, GitHub sites. Dr. Morrow will take the technical lead on all spatial analysis and mapping sub-tasks. Accountable for all milestones, he ensures inclusive and equitable contributions to collaborative deliverables including publications, open science and reports in following Milestone Schedule.

Fringe Benefits
Tulane's fringe rates include health insurance, FICA, unemployment, workers' compensation, retirement, terminal leave payout and employee assistance. Amounts for the sponsor's contribution to employee fringe benefits are calculated using Tulane's U.S. Department of Health and Human Services (DHHS) approved Fringe Benefit Rates effective August 30, 2022. The approved rates are as follows: XX % for Faculty.

Travel
In the third quarter of project year one, Dr. Morrow and Dr. Borak will travel for a research team meeting at Kew Royal Botanical Gardens outside London UK. The purpose of this meeting is to review the classified image derived products against Kew Researchers' ground truth data in an intensive workshop. This should result in a fully validated product by Kew's team of enset experts. We will also prepare annual reports on research progress to date and conduct workplaning for project year 2. Travel to Kew Royal Botanical Gardens outside London UK in project year 2 will proceed with a Kew enset expert validation of the change and stress products. The team will also prepare for final reporting and publication and DMP plan completion.

In the fourth quarter of project year 1, Dr. Morrow will travel to Addis Ababa to validate products with collaborator Dr. Wendawek and Ethiopian enset researchers. In these meetings, we will engage with enset researchers at institutions throughout the country and seek meaningful opportunities for collaborating on publications, planning future research to build on derived ACCRUED-MFSS products, and engaging in policy processes. The travel in project year two has similar purposes with validation and encouraging use and impact of the change and stress products. Both engagements in Ethiopia will contribute to required reporting and promote use of the research products – leading to the greater contribution to applied science benefits for those living in enset growing areas.

Total travel: $17,260.

Total Direct Costs
Direct costs are XX in Year 1, and XX in Y2. Total direct costs: XX.

Subawards

University Of Maryland:

Personnel Dr. Borak's research responsibilities will focus on acquiring data and generating satellite-derived classifications and data products. He will manage data processing in the HEC environment. Oversee and implement the training of the classifier, classify images, and conduct stress and change analysis. In addition to detailed documentation of all procedures and codes used and all datasets generated, overall summary of satellite data characteristics over the study area and a set of specific lessons learned will be posted following the DMP. salaries and benefits are requested for the UMD personnel who will be performing this research as described in the proposal narrative. The Senior/Key Personnel are as follows: Dr. Jordan Borak, Associate Research Scientist (FTE of .20 person-months per year).The base salaries applied to this budget reflect the actual salaries set forth by our institution and include a 3% anticipated escalation per year.

Fringe benefits include health insurance, FICA, unemployment, workers' compensation, retirement, terminal leave payout and employee assistance. Amounts for the sponsor's contribution to employee fringe benefits are calculated using UMD's U.S. Department of Health and Human Services (DHHS) approved Fringe Benefit Rates effective July 1, 2022. The approved rates are as follows: XX % for Faculty, XX % for Staff, XX % for Graduate Assistant and XX % for Contractual Faculty/Staff, hourly students, and most Faculty/Staff additional pays. Tuition Remission is a UMD fringe benefit but is not included in the fringe calculation and is budgeted separately as applicable. Additional information about fringe benefits can be found at: https://ora.umd.edu/resources/benefits-stipends. The Fringe Benefit Rate Agreement can be found at: https://ora.umd.edu/resources/fa. Fringe rates may be renegotiated and adjusted in future years.

Travel
In the third quarter of project year one Dr. Borak will travel for a research team meeting at Kew Royal Botanical Gardens outside London UK. The purpose of this meeting is to review the classified image derived products against Kew Researchers' ground truth data in an intensive workshop. This should result in a fully validated product by Kew's team of enset experts. We will also prepare annual reports on research progress to date and conduct workplaning for project year 2. Travel to Kew Royal Botanical Gardens outside London UK in project year 2 will proceed with a Kew enset expert validation of the change and stress products. The team will also prepare for final reporting and publication and DMP plan completion.

Total travel: $10,000

Indirect Costs
The University of Maryland's established indirect cost rate for research conducted off-campus is 27.5% of Modified Total Direct Costs (MTDC). The MTDC base excludes tuition remission, equipment over $5,000, rental costs of off-campus facilities, and the portion of individual subcontracts over $25,000. This rate has been approved by the cognizant government agency, Department of Health, and Human Services. This rate was approved on June 23, 2022 and is effective until amended. Any questions should be referred to the Office of Research Administration (301) 405-6269 or oraa@umd.edu.

Total Subaward: $ XX

Indirect Costs

The Negotiated Indirect Cost Rate Agreement for Tulane University is 53%. Indirect costs are $XX in Y1, and $XX in Y2. Total indirect costs: $XX.

Total Direct and Indirect Costs

The total budget for 2 years is $XX.

8b. Budget details

*As per ROSES guidance, all cost for people including salary, benefits, overhead or totals have been removed.

ACCRUED-MFSS - Budget
Ancient Climate Change Resilient but Understudied Enset agrifood system Diversity Mapping for Food Security and Sustainability

Tulane		**Year 1**	**Year 2**	**Total**
	Personnel			
	Faculty - Morrow - (.25)	X	X	X
	Fringe Benefits			
	Faculty (17.1)	X	X	X
	Subtotal Personnel	X	X	X
	Travel - London UK (2 days); Addis Ababa (8 days)			
	Airfare	4,500.00	4,500.00	9,000.00
	Hotel	2,700.00	2,700.00	5,400.00
	Ground and meals	1,430.00	1,430.00	2,860.00
Total Direct Costs - Tulane		X	X	X
F&A (indirect) Tulane (53%)		X	X	X
Subawards				
UMD				
	Personnel			
	Faculty - Borak (.3)	X	X	X
	Fringe Benefits (29.9%)	X	X	X
	Subtotal Personnel	X	X	X
	Travel - London UK 4 days			
	Airfare	2,500.00	2,500.00	5,000.00
	Hotel	1,200.00	1,200.00	2,400.00
	Ground and meals	1,300.00	1,300.00	2,600.00
	Total Direct	X	X	X
	F&A (Indirect) UMD (27.5)	X	X	X
	Subtotal	X	X	X
	F&A (Indirect) Tulane 53% (<=25k)	X	X	X
	Subaward Total	X	X	X
	Total Direct	X	X	X
	Total Indirect	X	X	X
Total Project Cost		X	X	X

Section 9. Table of Work Effort

Name	Role	Commitment (months per year)								
		Year 1			***Year 2***			***Sum***		
		This Project		*Other Funded Projects*	*This Project*		*Other Funded Projects*	*This Project*		*Other Funded Projects*
		NASA Support	*Total*		*NASA Support*	*Total*		*NASA Support*	*Total*	
Nathan Morrow	PI	1.8	1.8	0	1.8	1.8	0	3.6	3.6	0
Jordan Borak	Co-I	3.6	3.6	3.0	3.6	3.6	3.0	7.2	7.2	0
Sum of work effort:		**5.4**	**5.4**	**3.0**	**5.4**	**5.4**	**3.0**	**10.8**	**10.8**	**6.0**
Comments: Collaborators Dr. Borrell and Dr. Wendewek have contributed many months of work collecting the farm level data we will use in this research. During the project their actual time commitment will vary based on their interest but is not necessary to complete research objectives.										

Section 10. Facilities and Equipment:

Tulane University will provide facilities for workshops and meetings at no direct cost to the project. Facilities include the state-of-the-art research, education and outreach amenities of the River and Coastal Center offered by the ByWater Institute at Tulane. The TRCC opened in 2016 and features laboratories, offices, and a public meeting space with views of the Mississippi River. The building is managed by the ByWater Institute, but scholars can use the meeting space for programming relevant to the TRCC mission. The Tulane River and Coastal Center is available for exhibitions, classes, demonstrations, shows, receptions, meetings, and/or conferences that relate to the mission of the ByWater Institute. The Forum is 1400 square feet with flexible seating and views of the Mississippi River. The Selley Foundation Room is 200 square feet with fixed conference seating and views of the river

The Royal Botanic Gardens, Kew offers world-class research expertise in plant taxonomy allied to specialist knowledge and research being undertaken on some of the world's most important crop wild relatives. This research is underpinned by collections including an extensive living collection, 7 million herbarium specimens, 1.8 million fungarium specimens and 2 billion seeds. Kew currently has ~15 research projects in biodiverse LMIC/LDC countries in Africa including three Darwin grants and one Belmont grant addressing food security. The Jodrell Laboratory provides world-class plant genomic facilities and infrastructure, together with accompanying staff expertise and extensive experience in biodiversity informatics and spatial analyses. Kew has collaborated with Addis Ababa University for three decades, currently through projects on enset, coffee, yams, lupin and *Aloe*.