PERENNIAL CLIMATE INC.

Response to Request for Proposals

RFP No. PLN2026-01

Humboldt Natural and Working Lands Carbon Stock and Management Study

Submitted to:
County of Humboldt
Department of Planning & Building
3015 H Street, Eureka, CA 95501

Submitted by:
Perennial Climate Inc.
Boulder, CO
www.perennial.earth

Authorized Contact:
JD Carluccio, VP of Commercial
jd@perennial.earth

Submission Date:
May 15, 2026

A. Cover Letter

May 15, 2026

Suzanne Lippre, Administrative Analyst

Planning & Building Department

County of Humboldt

3015 H Street, Eureka, CA 95501

Re: RFP No. PLN2026-01 — Humboldt Natural and Working Lands Carbon Stock and Management Study

Dear Ms. Lippre and Members of the Selection Committee,

Perennial Climate Inc. is pleased to submit this proposal in response to RFP No. PLN2026-01. We are a digital soil measurement company headquartered in Boulder, Colorado, and we specialize in precisely what this project requires: large-scale, scientifically rigorous quantification of carbon stocks across natural and working lands using remote sensing, digital soil mapping, and strategic field sampling.

Humboldt County presents an exceptional and meaningful opportunity. With 93 percent of its 2.3 million acres designated as natural and working lands — spanning old-growth redwood forests, timberlands, grasslands, agricultural lands, and wetlands — it is almost certainly a significant net carbon sink. Yet this has never been quantified. Perennial's mission is to make exactly this kind of measurement accessible, repeatable, and policy-actionable.

We bring three differentiating strengths to this engagement:

- Proven scale. We have delivered statewide soil organic carbon inventories for the State of North Dakota (in partnership with ADM and AGVISE Laboratories) and continental-scale SOC mapping across Australia, producing government-grade baseline inventories with change-over-time analysis.
- World-class scientific leadership. Our Chief Scientist, Dr. James Kellner, is a co-investigator on NASA's Global Ecosystem Dynamics Investigation (GEDI) — the leading spaceborne LiDAR mission for above-ground forest biomass mapping. This positions Perennial uniquely to integrate both soil carbon and above-ground biomass carbon into a single, unified countywide inventory.
- Technology efficiency. Our remote sensing and machine-learning platform dramatically reduces the cost of large-area inventories relative to traditional sampling-only approaches — comparable engagements of this scope and complexity typically exceed $500,000 through conventional consulting firms. Perennial's technology-driven methodology delivers superior rigor at a fraction of that cost.

We propose a fixed-fee engagement of $350,000 over three years. We are committed to delivering a high-quality, CEQA-defensible, CARB-compatible study that will serve the County and its RCAP partners for years to come.

We are excited by the alignment between this project and Perennial's core capabilities, and we welcome the opportunity to discuss our approach with County staff. Please do not hesitate to contact me with any questions.

Respectfully submitted,

JD Carluccio

VP of Commercial, Perennial Climate Inc.

jd@perennial.earth

www.perennial.earth

B. Authorized Signature (Attachment A)

The Signature Affidavit (Attachment A) is included as a separate document with this submission, executed by:

Name: JD Carluccio
Title: VP of Commercial
Company: Perennial Climate Inc.
Email: jd@perennial.earth
Date: May 15, 2026

Signature:

C. Company Experience

Perennial Climate Inc. is a remote sensing and digital soil health company focused on scaling and standardizing the measurement of carbon stocks in natural and agricultural landscapes. Our platform integrates machine learning, satellite and airborne remote sensing, and strategic field sampling to produce county- and regional-scale carbon inventories that are scientifically rigorous, cost-efficient, and repeatable.

We are Verra's chosen partner for soil organic carbon (SOC) measurements, and our methodology is peer-reviewed and compatible with IPCC Tier 2 approaches aligned with the California Air Resources Board Natural and Working Lands Carbon Inventory framework.

Relevant project experience

North Dakota Statewide Soil Organic Carbon Inventory (2022–2025)

In partnership with the North Dakota Agricultural Products Utilization Commission (APUC), ADM, and AGVISE Laboratories, Perennial delivered the first high-resolution statewide SOC baseline for North Dakota's agricultural lands — covering millions of acres of cropland and rangeland across diverse soil types and climate zones.

Scope	Statewide agricultural land carbon inventory; change-over-time analysis (2022 baseline → 2025 update)
Deliverables	High-resolution SOC % maps at 10m resolution; per-farm/rancher reports; policy brief supporting Governor's 2030 carbon neutrality goal
Technology	Remote sensing + ML + stratified field sampling (0–15 cm, 15–30 cm); AGVISE laboratory analysis
Outcome	North Dakota recognized as the most technologically advanced US state for agricultural carbon measurement; repeat sampling for change detection ongoing

Australia — Soil Organic Carbon Mapping (2021–2024)

Perennial developed and validated new SOC models for Australian soils across two New South Wales phases covering crop-pasture rotation and broadacre cropland systems. This work contributed to a $1.7M AUD government grant, in partnership with the Clean Energy Regulator, to scale soil carbon quantification across Australia's improved pasture land.

Scope	Continental-scale SOC mapping; regional and field-level accuracy validation across multiple soil classification zones and climate regimes
Deliverables	Multi-scale SOC maps (continental → 10m field level); validation reports; methodology for the SOC Innovation Challenge ($3/Ha target)
Technology	Remote sensing + DSM + calibration/validation sampling; 3x reduction in field MAE with 2 samples/strata vs. 0
Outcome	$1.7M AUD follow-on government grant; recognized model for scaling SOC measurement across international jurisdictions

Why this experience translates directly to Humboldt County

Both projects required: (1) building a carbon baseline across a large jurisdiction without farmer-by-farmer data collection; (2) producing GIS-compatible map deliverables at multiple spatial scales; (3) designing a repeatable

methodology so future updates can be run efficiently; and (4) communicating complex science to government stakeholders and landowners. These are precisely the core requirements of RFP PLN2026-01.

For the above-ground biomass component — critical given that roughly 80 percent of Humboldt County is forested — Perennial's Chief Scientist Dr. James Kellner is a co-investigator on NASA's Global Ecosystem Dynamics Investigation (GEDI), the world's leading spaceborne LiDAR mission for forest biomass mapping. Dr. Kellner will integrate publicly available above-ground carbon data products with Perennial's soil carbon platform to produce a unified countywide inventory.

D. References

Three professional references are provided below. A completed Reference Data Sheet (Attachment B) accompanies this submission.

Reference 1 — State of North Dakota / APUC

Organization	Agricultural Products Utilization Commission (APUC), State of North Dakota
Contact	Madison Bodine
Email	mbodine@nd.gov
Services rendered	Statewide soil organic carbon inventory and change-over-time analysis for North Dakota agricultural lands; remote sensing + field sampling; farmer/rancher SOC reports; policy support for Governor's carbon neutrality goal

Reference 2 — Clean Energy Regulator (Australia)

Organization	Clean Energy Regulator, Australian Government
Contact	Luke Signor
Email	Luke.Signor@cer.gov.au
Services rendered	Continental-scale SOC mapping and calibration/validation across Australian soil types and climate zones; support for $1.7M AUD government grant program to scale soil carbon quantification across Australia's improved pasture land

Reference 3 — CoolPath LLC

Organization	CoolPath LLC, California
Contact	Mike Powers
Email	mike@coolpath.com
Services rendered	MRV (Measurement, Reporting and Verification) services for a Verra VM0042 project regenerating California's rangeland through the utilization of compost to improve soil health

E. Staff Experience

The following key personnel will be assigned to this project. Full CVs are attached as supporting materials.

Dr. James R. Kellner | Chief Scientist Officer

Role on project: Technical Lead — Above-Ground Biomass & Remote Sensing

Dr. Kellner is an Associate Professor at Brown University and Chief Scientist of Perennial Climate Inc. He is a co-investigator on NASA's Global Ecosystem Dynamics Investigation (GEDI) and has developed and published the algorithm theoretical basis for GEDI's footprint aboveground biomass density product. He brings 20 years of remote sensing experience and has led field calibration campaigns across North America, South America, Africa, Hawaii, and Australia.

- NASA GEDI co-investigator; above-ground biomass density modeling for world's forests and woodlands
- Published: GEDI Algorithm Theoretical Basis Document (Earth and Space Science, 2022); GEDI biomass density models (Remote Sensing of Environment, 2022)
- GEDI biomass estimates across Sonoma County, California — directly analogous to Humboldt County's forest landscape (Remote Sensing of Environment, 2020)
- Co-author: Data-driven calculation of organic carbon stocks in North American agricultural land (Geoderma, submitted 2023)

Ph.D., Plant Biology, University of Georgia. ORCID: 0000-0002-9861-4857.

Christian D. Clanton | VP of Data Science

Role on project: Lead Data Scientist — SOC Modeling, ML Platform, GIS Deliverables

Christian leads Perennial's data science organization and is responsible for the development and deployment of all SOC and remote sensing ML models. Prior to Perennial, he was Sr. Director of Model Engineering at Orbital Insight, building geospatial AI models for satellite imagery at scale. He will oversee all modeling, GIS layer production, and digital deliverables.

- 10+ years building ML/DL models for satellite and geospatial data at scale
- Expert in time series modeling, change detection, and spatial interpolation — directly applicable to the 10-year change analysis required by this RFP
- Former NASA Postdoctoral Program Fellow (Ames Research Center)

Ph.D., Astronomy, The Ohio State University; B.S. Applied Physics, Caltech. ORCID: 0009-0003-8213-3164.

Kirk M. Demuth | VP of Operations

Role on project: Field Operations Lead — Sampling Campaign Design and Execution

Kirk oversees all operational logistics for Perennial, including airborne and ground field sampling campaigns. He has executed multi-state sampling campaigns generating thousands of soil samples under a wide range of conditions, including state-sponsored research in Colorado and North Dakota. He will manage all landowner coordination, field crew logistics, sample custody, and laboratory integration.

- Licensed professional pilot with extensive airborne survey experience in agricultural and natural landscapes
- Managed landowner relationships and sampling logistics across multiple US states
- Co-author: Data-driven calculation of organic carbon stocks in North American agricultural land; Mapping SOC in US croplands at 10m resolution (Geoderma, 2023)

B.S. Technology Management and A.S. Professional Pilot, Kansas State University.

JD Carluccio | VP of Commercial & Project Manager

Role on project: Project Manager & Client Relationship Lead

JD serves as VP of Commercial at Perennial (since January 2025) and will be the primary point of contact and project manager for the County. He will be responsible for scope management, timeline adherence, stakeholder coordination, and delivery of all client-facing materials including the final report and Board of Supervisors presentation support.

F. Rates and Proposed Budget

Budget rationale

Perennial proposes a fixed-fee contract of $350,000 for the full three-year scope. For context, comparable government contracts for multi-year regional carbon inventories of this complexity — spanning above-ground biomass, soil carbon, GIS deliverables, feasibility studies, and public process — typically exceed $500,000 through conventional environmental consulting firms. Perennial's remote sensing and machine-learning platform allows us to deliver a higher-resolution, more scientifically rigorous, and repeatable product at significantly lower cost.

By combining DSM-based modeling across the full county with targeted stratified field sampling, we eliminate the need for dense ground-truthing across 2.3 million acres — the primary cost driver in traditional approaches. Sampling volumes per campaign will be refined during Task 1 following review of the County's LiDAR data, existing Web GIS layers, and land cover analysis.

Three-year budget summary

Task / Line Item	Year 1 (2026–27)	Year 2 (2027–28)	Year 3 (2028–29)	Total
Task 1: Project planning & stakeholder engagement	$10,000	—	—	$10,000
Task 2: Carbon stock inventory (DSM + modeling)	$70,000	$50,000	$50,000	$170,000
Task 3: Field sampling campaigns	$15,000	$5,000	$5,000	$25,000
Task 3: Laboratory analysis	$15,000	$5,000	—	$20,000
Task 4: GIS deliverables	$10,000	—	$5,000	$15,000
Task 5: Feasibility study & best mgmt practices	—	$20,000	$15,000	$35,000
Task 5: Public review process & report finalization	—	$10,000	$10,000	$20,000
Task 5: Board of Supervisors presentation	—	—	$15,000	$15,000
Project management	$15,000	$10,000	—	$25,000
Contingency	$5,000	—	—	$5,000
TOTAL FIXED FEE	**$150,000**	**$100,000**	**$100,000**	**$350,000**

Note: Year 1 focuses on project setup, baseline carbon stock modeling, and the first field sampling campaign. Year 2 completes the carbon stock inventory and initiates the feasibility study. Year 3 delivers the final feasibility study, public review process, and Board of Supervisors presentation.

Hourly billing rates (for out-of-scope work)

Role	Hourly Rate
Chief Scientist	$275/hr
VP of Data Science	$225/hr

VP of Operations	$195/hr
Project Manager	$185/hr
Data Scientist / GIS Analyst	$165/hr
Field Technician	$95/hr

G. Timeline and Availability

Perennial is available to commence work immediately upon contract execution (upon Board approval, anticipated summer 2026). The proposed schedule below aligns with all milestones specified in the RFP, including the Kick-Off Meeting in mid-July 2026, the 30-day public review period, and the Board of Supervisors presentation in mid-late January 2029.

Milestone	Target Date	Key Activities
Contract execution	Upon Board approval (est. June–July 2026)	Contract signed; team mobilized; County data access requested (GIS, LiDAR, fire hazard layers)
Kick-Off Meeting	Mid-July 2026	In-person at County offices in Eureka or via Zoom/Teams; confirm key stakeholders, data sources, communication protocols, and deliverable formats per RFP Section II Task 1
Literature & data review complete	August 2026	CARB NWL 2025 inventory; 2017 North Coast Carbon Inventory; 2025 Humboldt RCAP; IPCC GHG Guidelines; Humboldt Web GIS and LiDAR data; AB 32, SB 32, AB 1757, AB 1279 — catalogued in Excel library per RFP requirements
Final project scope delivered	Within 30 days of Kick-Off (mid-August 2026)	Updated General Approach Table (Table 1) delivered in Word/Excel; guiding questions finalized with County staff; key assumptions confirmed
Stakeholder engagement / public meeting	September 2026	One public meeting with local landowners; existing land management practices documented to inform Task 5 Feasibility Study
Task 2: Methodology finalized	October 2026	Best methodology for carbon classification documented; CARB NWL land category alignment confirmed; CEQA defensibility reviewed
Sampling Campaign 1	Fall 2026 (Oct–Nov)	Stratified field sampling across priority land types (agricultural, grassland, wetland); soil cores at 0–15 cm and 15–30 cm collected and shipped to accredited laboratory
Task 2: Carbon stock modeling — Year 1	Winter 2026–27	SOC model calibration using Campaign 1 data; above-ground biomass integration from publicly available data products; preliminary GIS layers produced
Sampling Campaign 2	Spring 2027 (Apr–May)	Second stratified sampling campaign for model validation; focus on forest and timberland soil types; change detection baseline established
Task 2: Carbon stock modeling complete	Summer 2027	Full countywide SOC + above-ground biomass integration; GIS layers finalized for all land cover types; 10-year change analysis (2015–2025) completed
Draft Carbon Stock Inventory Report	September 2027	Draft report delivered to County for minimum 30-day review; includes maps, charts, and guiding question responses per Table 1; update instructions included
County review & feedback	October 2027	County provides written feedback; Perennial addresses comments
Final Carbon Stock Inventory Report	November 2027	Revised final report including full data documentation, QC records, and step-by-step update instructions for County staff
Sampling Campaign 3	Spring 2028 (Mar–Apr)	Third sampling campaign for temporal change detection; re-sampling of Year 1 locations to quantify SOC change over time; laboratory analysis completed
Draft Feasibility Study Report	May 2028	Best management practices and carbon sink scenarios delivered to County for review; responds to Guiding Question 6 (Table 1)
Draft Combined Study released for public review	June 2028	30-day public review period opens per RFP Task 3 requirements; County consolidates public comments

County provides consolidated public comments	July 2028	Perennial receives and reviews all public feedback
Final Humboldt NWL Carbon Stock & Mgmt Study	September 2028	All public comments addressed; final comprehensive report completed; submitted to County
Board of Supervisors presentation	Mid-late January 2029	Perennial attends and supports County-led presentation of final study; available to answer technical questions per RFP Task 3

H. Insurance Requirements

Perennial Climate Inc. will provide evidence of insurance meeting the requirements specified in Section 15 of the County of Humboldt Professional Services Agreement (Exhibit 1) prior to contract execution. We anticipate maintaining at minimum the following coverage:

Coverage type	Minimum limit	Status
Commercial General Liability	$1,000,000 per occurrence / $2,000,000 aggregate	**Carried**
Professional Liability (E&O)	$1,000,000 per claim	**Carried**
Commercial Automobile Liability	$1,000,000 combined single limit	**Carried**
Workers' Compensation	Statutory limits (California)	**Carried**
Employers' Liability	$1,000,000	**Carried**

Certificates of insurance naming the County of Humboldt as an additional insured will be provided prior to contract execution. Perennial will notify the County at least 30 days in advance of any material change in or cancellation of coverage.

Perennial has no objections to the terms and conditions of the Professional Services Agreement (Exhibit 1) as provided. Any requested exceptions will be communicated in writing prior to contract execution.

Technical Approach — Scope of Work

This section responds to the Scope of Work in Section II of the RFP and describes Perennial's proposed methodology for each task, directly addressing each of the six guiding questions in the General Approach Table (Table 1).

Task 1: Project Planning Framework

Perennial will organize a Kick-Off Meeting in mid-July 2026, within two weeks of contract execution, at County offices in Eureka or via Zoom/Teams. We will confirm project scope, data sources, stakeholder contacts, deliverable formats, and communication protocols. Within 30 days of the Kick-Off Meeting, we will deliver an updated General Approach Table and final Project Scope in Word/Excel format as specified in the RFP.

For stakeholder engagement, Perennial will support the County in organizing one public meeting with landowners and land managers, designed to surface information about existing management practices without requiring farmers or ranchers to share proprietary farm data.

Our Literature and Data Review will include, at minimum: the 2025 CARB Natural and Working Lands Carbon Inventory; the 2017 Carbon Inventory Estimates for the North Coast Resource Partnership; the 2025 Humboldt RCAP; IPCC Guidelines for National GHG Inventories; Humboldt County Web GIS layers (fire hazard, natural resources, LiDAR); AB 32, SB 32, AB 1757, AB 1279; and relevant peer-reviewed literature on North Coast California carbon stocks.

Task 2: Countywide Carbon Stock Inventory

Methodology: Integrated SOC + Above-Ground Biomass

Perennial will employ a two-component integrated approach:

Component 1 — Soil Organic Carbon (SOC): Digital Soil Mapping (DSM) using Perennial's ML platform, calibrated and validated by stratified field sampling. Our approach is consistent with Verra VM0042/VT0014 and IPCC Tier 2 methodology, providing a CEQA-defensible, CARB-compatible baseline. Field sampling will target 0–15 cm and 15–30 cm depth increments across stratified soil types, land cover classes, and management regimes.

Component 2 — Above-Ground Biomass Carbon: Integration of publicly available above-ground carbon data products, led by Dr. James Kellner. Perennial will leverage existing open datasets and published scientific products covering above-ground biomass for California's forests and woodlands — including data available through public marketplaces and government data repositories — to produce above-ground carbon maps at countywide scale, validated against the County's existing LiDAR data.

Root carbon (below-ground non-SOC) will be estimated using published allometric relationships by land cover type, consistent with CARB NWL methodology.

Land classification

We will classify lands into CARB NWL-compatible categories: forests/timberlands, shrublands, grasslands, croplands, wetlands, developed, and Tribal lands. GIS layers will be produced for each category showing carbon stocks and sequestration rates, with breakdowns by public vs. private ownership and County-owned land.

Ten-year change analysis (Guiding Question 2)

Perennial's platform is specifically designed for change-over-time analysis. We will combine archival satellite imagery and existing CARB/USDA data sources to reconstruct the 2015 baseline, with annual sampling campaigns in Years 1, 2, and 3 for SOC change detection, and publicly available temporal biomass data products for above-ground change. The result will be a spatially explicit map of carbon stock change over the past decade, with ongoing temporal monitoring through the project period.

Carbon stock stability and wildfire risk (Guiding Question 5)

We will integrate the County's fire hazard data layers and historical fire perimeter data to assess the vulnerability of carbon stocks to wildfire and other disturbances. Scenario modeling will estimate carbon loss under different fire regimes, consistent with the County's Community Wildfire Protection Plan.

Task 3: Field Sampling

Perennial will conduct three targeted stratified field sampling campaigns across the project period to calibrate and validate the DSM models and support temporal change detection. Sampling locations will be determined following review of the County's LiDAR and GIS data at kickoff. All samples will be analyzed by an accredited laboratory for total organic carbon, bulk density, and particle size distribution at minimum. Chain of custody and quality control documentation will be maintained throughout.

Task 4: GIS Deliverables

All guiding questions will be addressed through a comprehensive set of GIS data layers, maps, charts, and data tables as specified in Table 1. Deliverables will be provided in formats compatible with Humboldt County Web GIS and will include clear documentation of data sources, methodologies, and uncertainty estimates. Map exhibits will highlight key findings suitable for County dashboards and public outreach.

Task 5: Feasibility Study, Public Review, and Final Report

Drawing on the Inventory results and stakeholder input from Task 1, Perennial will prepare a Feasibility Study identifying best management practices to maintain and enhance carbon sequestration in Humboldt County. We will respond to Guiding Question 6 by producing scenario-based analyses of carbon sequestration potential under different land management strategies — including forest management, agricultural practices (cover cropping, reduced tillage, compost application), wetland restoration, native grassland restoration, and reforestation — with feasibility considerations including cost and implementation barriers.

The Draft Combined Study will be released for a 30-day public review period. Perennial will address all public comments with the support of County staff and deliver the Final Humboldt Natural and Working Lands Carbon Stock and Management Study. Perennial will support the County in preparing for and presenting the final study to the Board of Supervisors in mid-late January 2029.

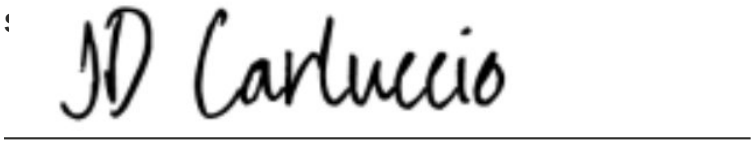
Repeatability and data documentation

Following completion of the Final Inventory Report, Perennial will deliver: (1) clear step-by-step instructions for County staff or a future consultant to update the inventory; (2) a complete list of required data inputs; (3) all underlying data, calculations, model parameters, uncertainty estimates, and quality control documentation. Our goal is to leave the County with a fully self-sufficient, repeatable carbon accounting system aligned with the 2030 RCAP update cycle.

ATTACHMENT A — SIGNATURE AFFIDAVIT

The undersigned hereby certifies that the information contained in this proposal is true and accurate, that the proposing firm has read and understands the requirements set forth in RFP No. PLN2026-01, and that the firm is authorized to submit this proposal and, if selected, to enter into a contract with the County of Humboldt for the services described herein.

Name of Authorized Representative:	JD Carluccio
Title:	VP of Commercial
Company:	Perennial Climate Inc.
Address:	Boulder, CO
Email:	jd@perennial.earth
Website:	www.perennial.earth
Date:	May 15, 2026



(Signature above)

JD Carluccio, VP of Commercial, Perennial Climate Inc.

Certification: I certify that I am duly authorized to legally bind the above-named firm. I certify that this proposal is made without prior understanding, agreement, or connection with any corporation, firm, or person submitting a proposal for the same services, and is in all respects fair and without collusion or fraud. I agree to abide by all conditions of this RFP.

Attachment B

REFERENCE DATA SHEET

Provide a minimum of three (3) current references with name, address, contact person, and telephone number whose scope of business or services is similar to those of Humboldt County, preferably in California. Previous business with the County does not qualify.

NAME OF FIRM:	Agricultural Products Utilization Commission (APUC), State of North Dakota		
STREET ADDRESS:	600 E Boulevard Ave, Dept 602		
CITY, STATE, ZIP	Bismarck, ND 58505		
CONTACT PERSON:	Madison Bodine	**EMAIL:**	mbodine@nd.gov
PHONE #:	N/A	**FAX #:**	N/A
Product(s) and/or Service(s) Used:	Statewide SOC inventory and change-over-time analysis for North Dakota agricultural lands; remote sensing, digital soil mapping, and field sampling; farmer/rancher SOC reports; policy support for carbon neutrality goals.		
NAME OF FIRM:	Clean Energy Regulator, Australian Government		
STREET ADDRESS:	2 King Street		
CITY, STATE, ZIP	Deakin, ACT 2600, Australia		
CONTACT PERSON:	Luke Signor	**EMAIL:**	Luke.Signor@cer.gov.au
PHONE #:	N/A	**FAX #:**	N/A
Product(s) and/or Service(s) Used:	Continental-scale SOC mapping and calibration/validation across Australian soil types and climate zones; support for $1.7M AUD government grant to scale soil carbon quantification across improved pasture land.		
NAME OF FIRM:	CoolPath LLC		
STREET ADDRESS:	California		
CITY, STATE, ZIP	California, USA		
CONTACT PERSON:	Mike Powers	**EMAIL:**	mike@coolpath.com
PHONE #:	N/A	**FAX #:**	N/A
Product(s) and/or Service(s) Used:	MRV (Measurement, Reporting and Verification) services for a Verra VM0042 project regenerating California's rangeland through the utilization of compost to improve soil health.		

North Dakota

Measuring Impact at Scale

Perennial

What were the objectives of the project?

1. Measure Impact of the Agriculture Programs sponsored by the Department of Agriculture (without requiring data from farmers)

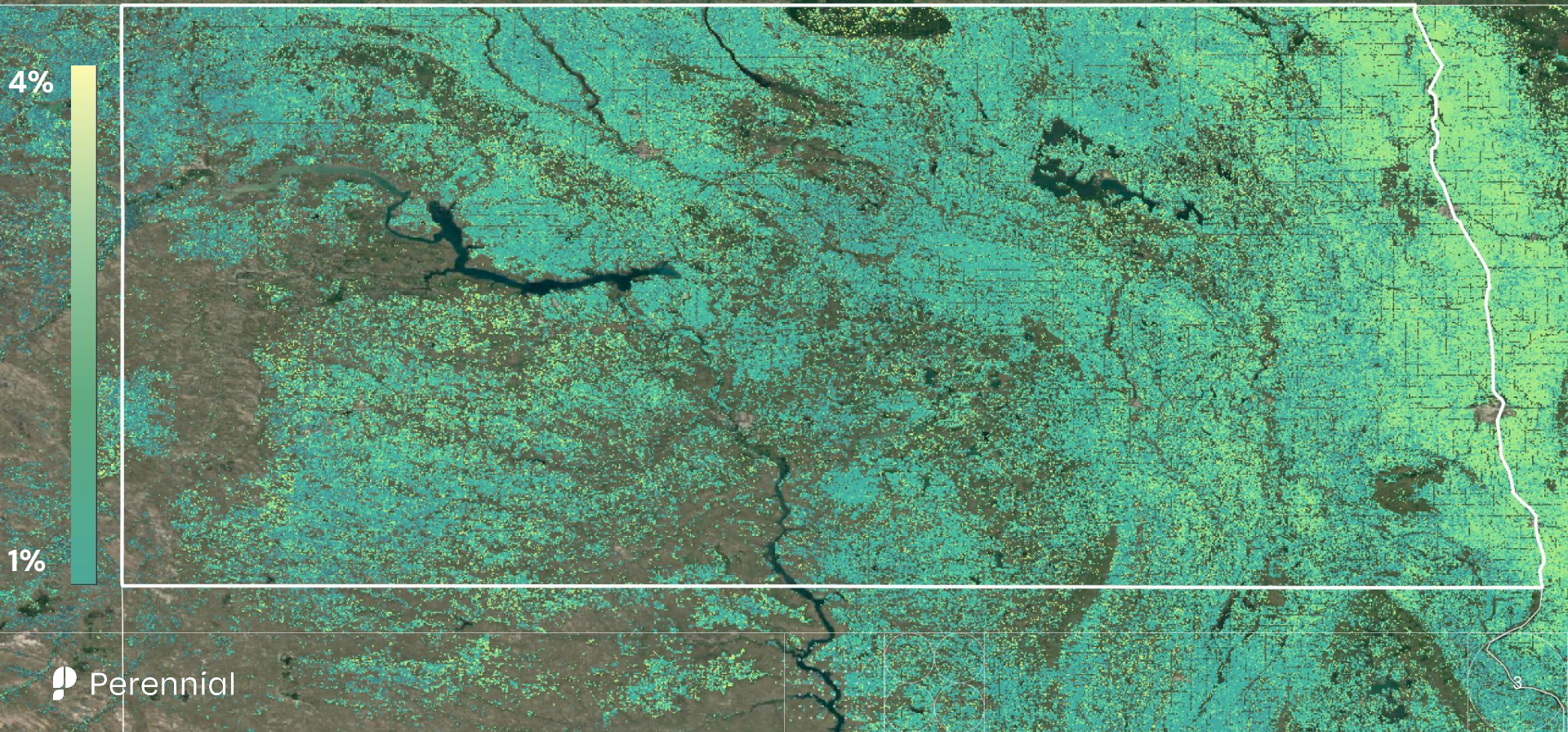
2. Provide Farmers/Ranchers with data on their farms so they can make better decisions regarding additional income opportunities

Partners:

ADM AGVISE LABORATORIES

North Dakota Soil Organic Carbon % Map

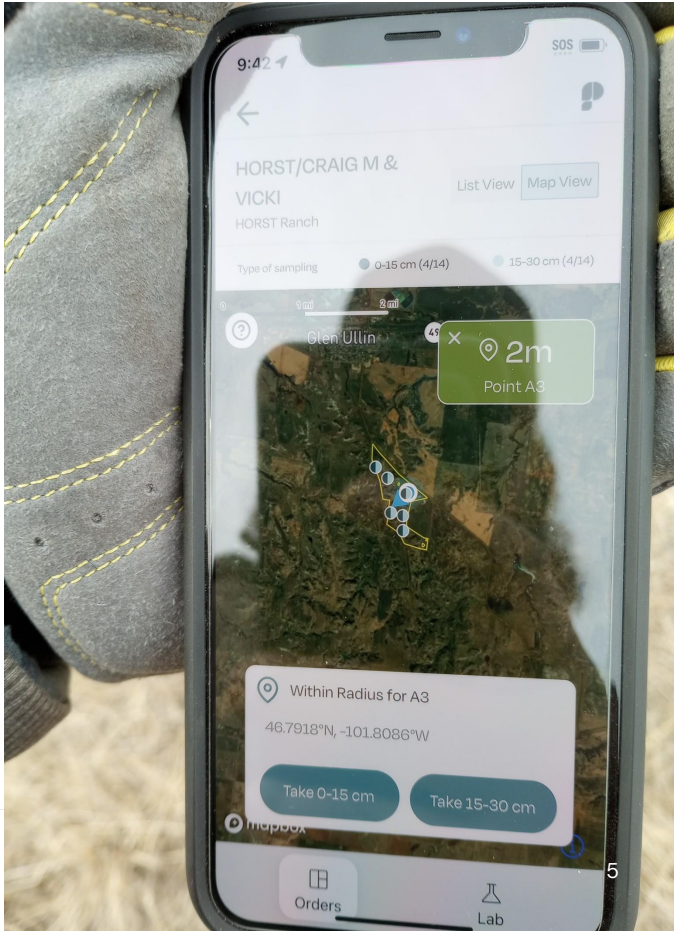
(Developed with support from APUC)



Perennial

North Dakota ‘22-’23 -’25 Project Sample Locations

Sampling Operations



What can be the results used for?

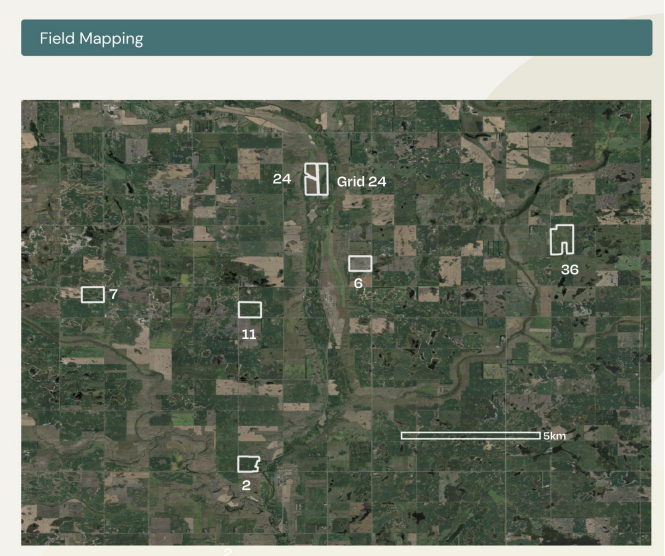
- Identify areas where landowners can profitably store carbon
- Improve access for farmers and ranchers to sustainability programs that generate revenue
- Help farmers and ranchers make decisions that steward soil

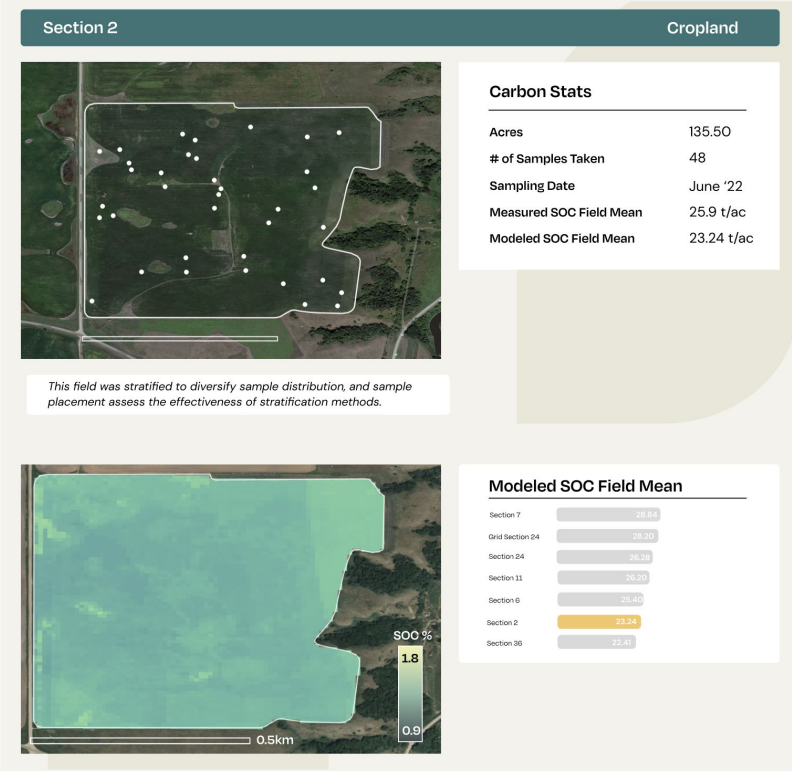
Guy Christiansen from ADM explained. “I know all the history of my growers fields and a lot of them are no-till, but that is becoming a problem for many, because the chemicals and pesticides being applied are lowering the pH to the point the the soil is becoming acidic and crops are dying. ADM will work again with Perennial for the betterment of their growers.”

- Help the State of North Dakota achieve Governor Burgum's goal for carbon neutrality by 2030

Farmer/Rancher Reports

In addition to completing the objectives proposed in the first grant, Perennial has built **customized SOC reports** for each individual farmer and rancher that have participated in this effort.





Thank you!

JD Carluccio
VP of Product
jd@perennial.earth

Perennial

Delivering Soil Organic Carbon for all Australia

Perennial 2024

Perennial is a digital soil health company focused on scaling and standardizing the measurement of resilience and adaptation of sustainability

01

Standardized

Across geography we utilize the same models and technology to measure consistent outcomes

02

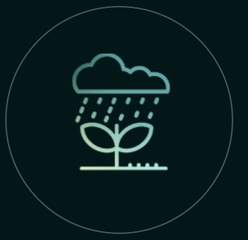
Scalable

Monitoring microbial activity, soil qualities like texture, pH, temperature, moisture, SOM, soil organic carbon, and more

03

Low Effort

Reduction in primary data without compromising on rigor



04

Scientifically Rigorous

Peer-reviewed; Industry supported: Perennial is Verra's chosen partner for SOC measurements

Project Summary (2021)

Phase 1:

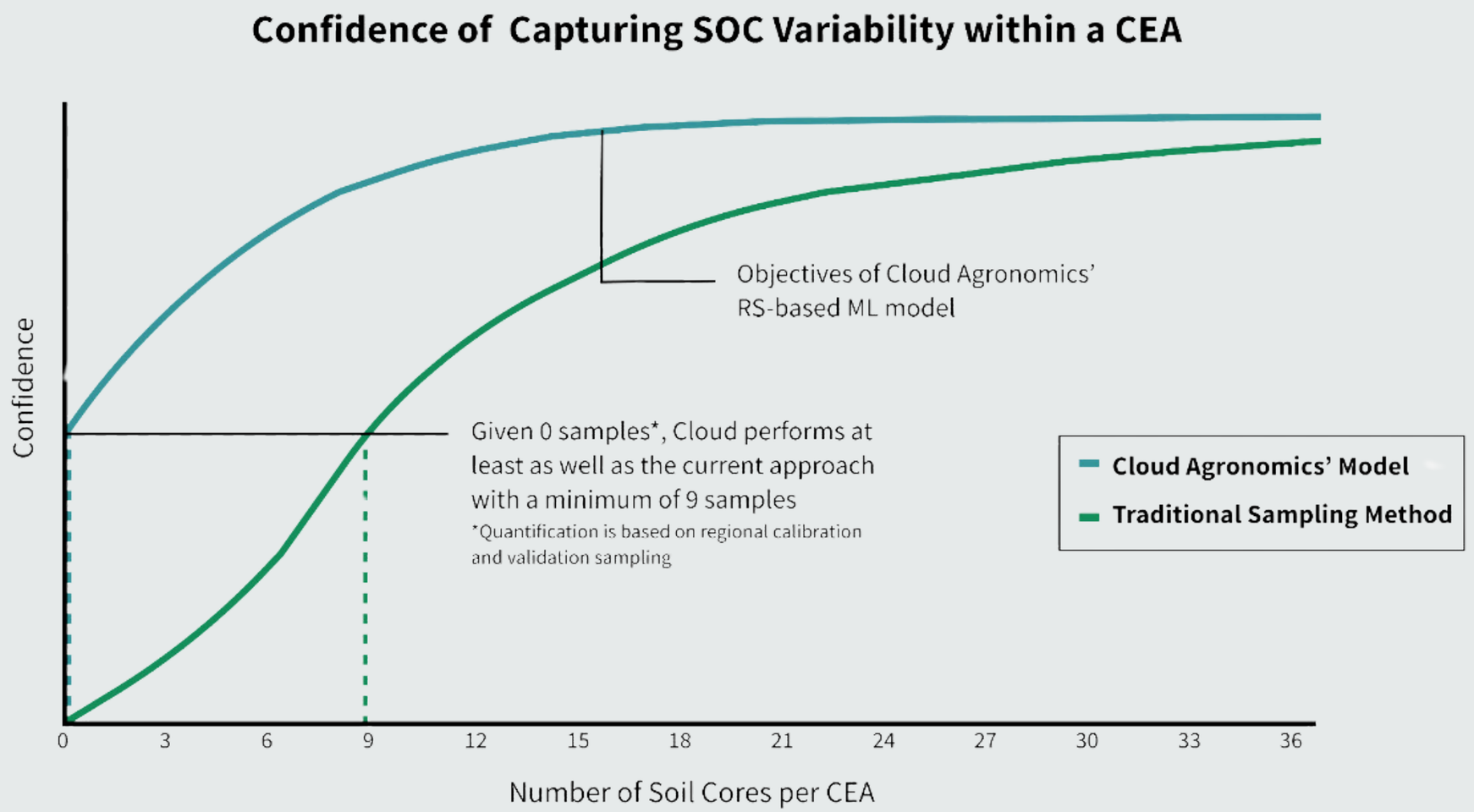
- NSW-based
- Crop-Pasture Rotation
- 2192.7 Ha Serviced
- 300 Total Samples

Phase 2:

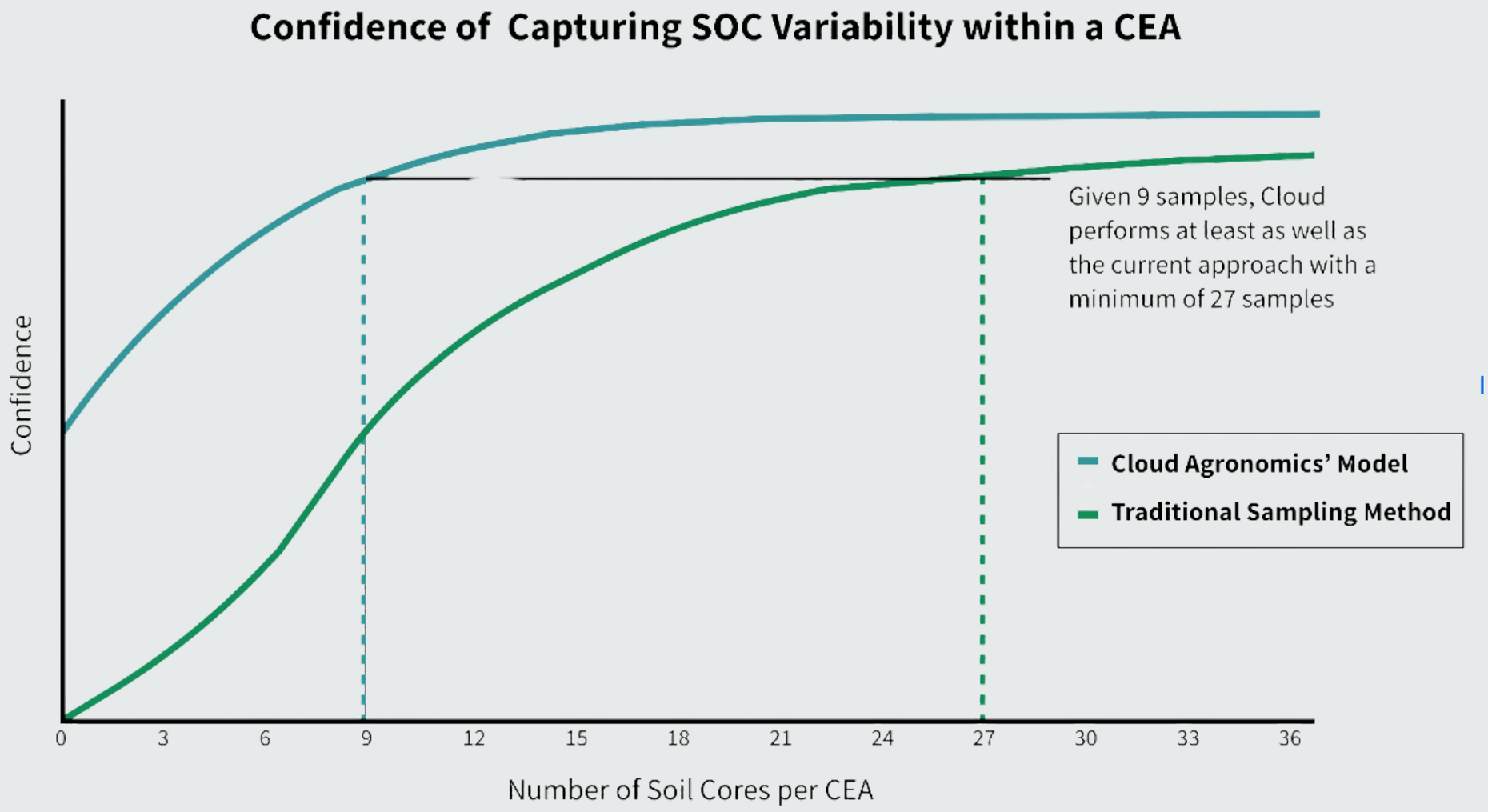
- NSW-based
- Broadacre Cropland
- 2023.5 Ha Serviced
- 468 Total Samples

Perennial developed new models for Australian soil. As such Phase 2 was an experiment in both performance and architecture. The quality of the model results will increase as we collect and incorporate more Australian data.

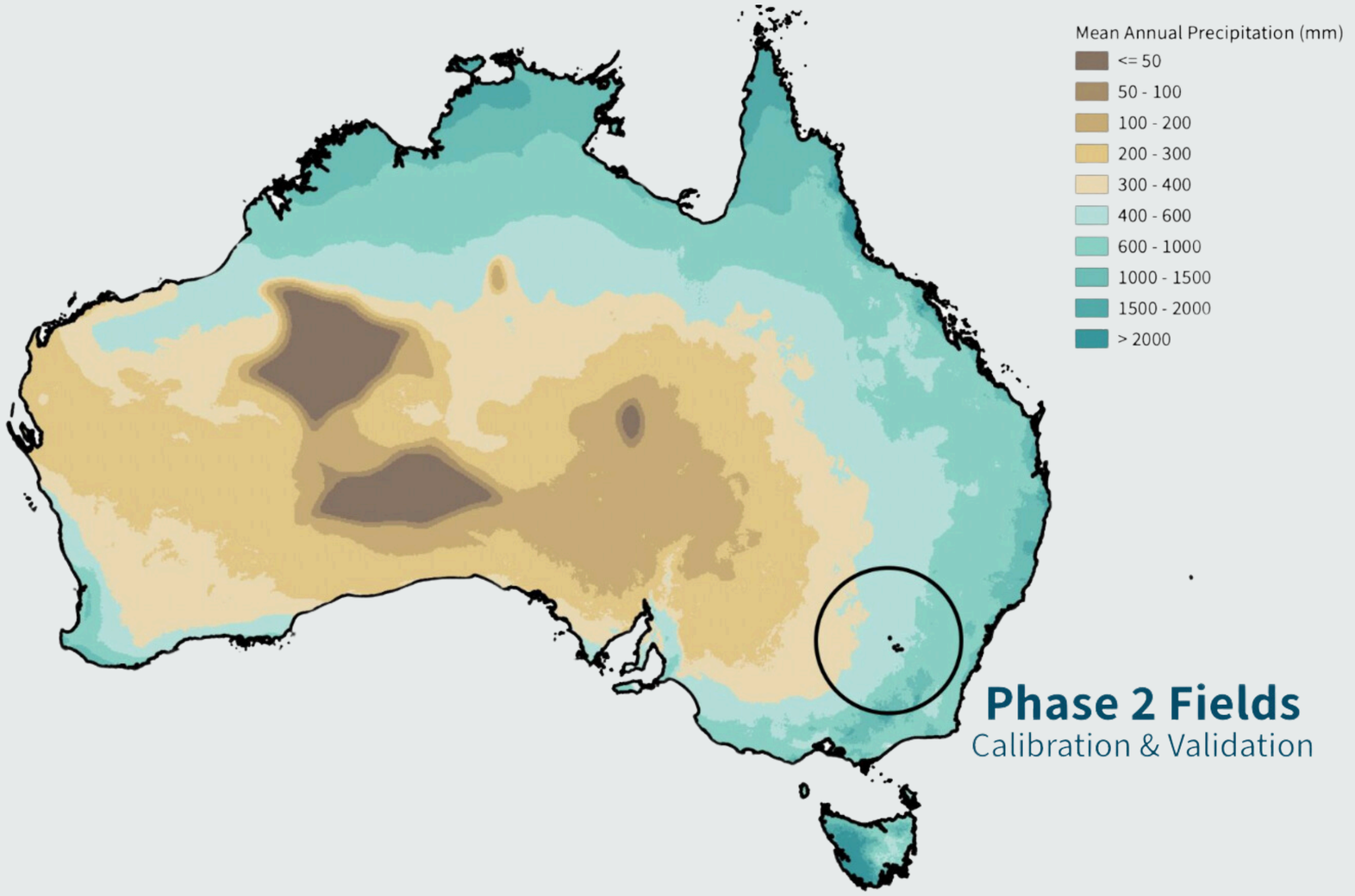
Development Objectives



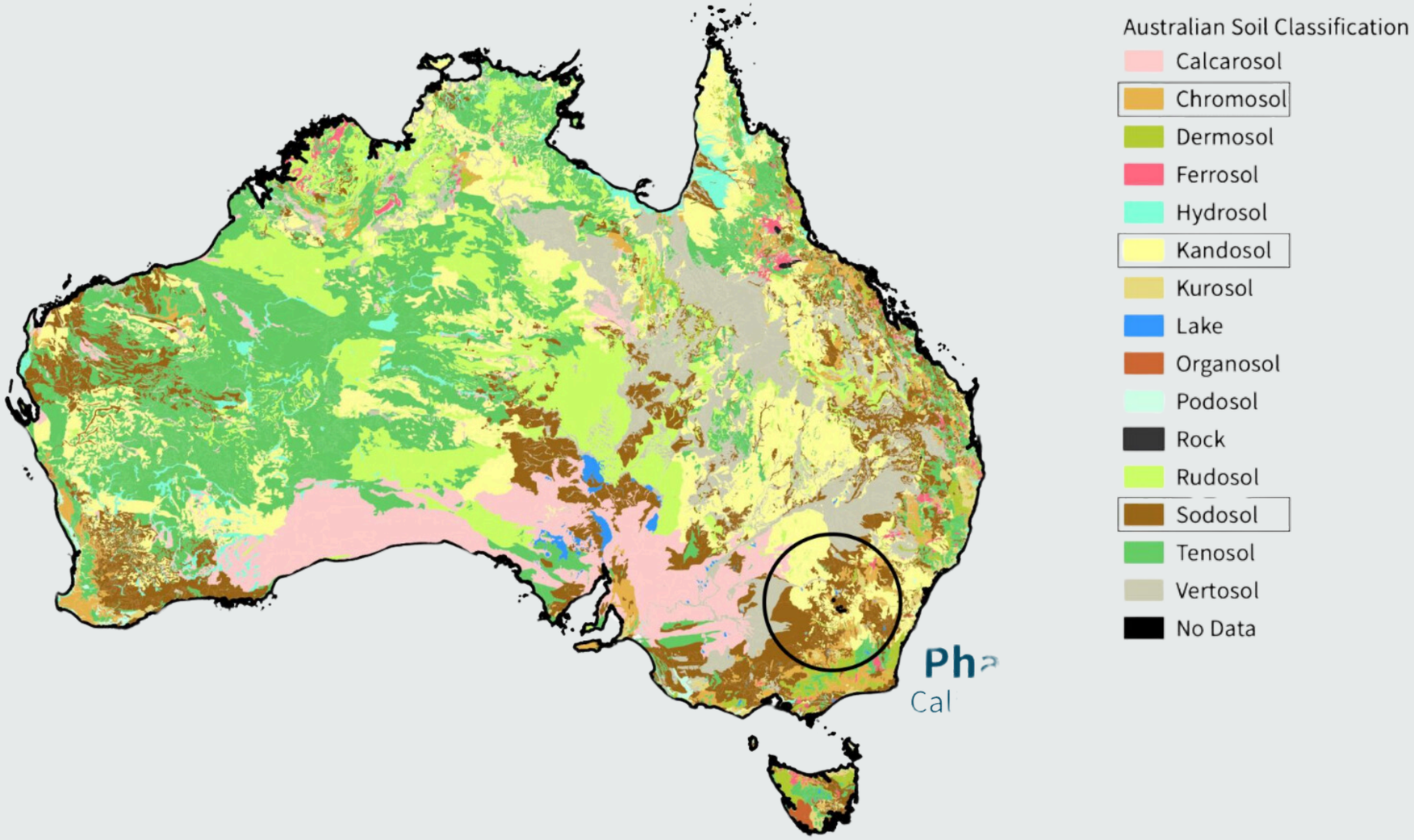
Development Objectives



Model Calibration – Climate Zones



Model Calibration – Soil Classification



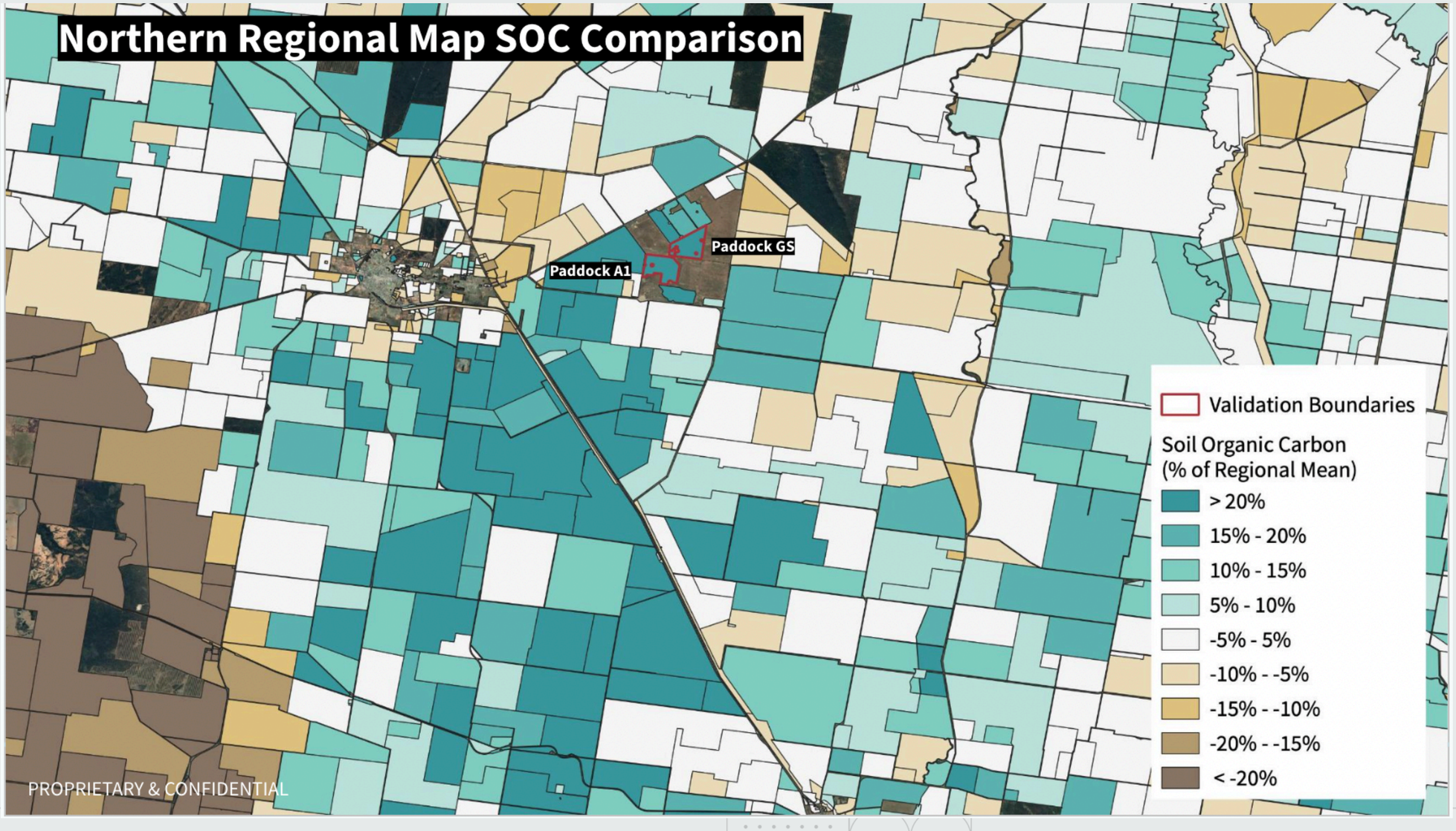
Results

Paddock Name	Sampled Field Mean Stock (metric ton / hectare)	Localised-to-Region Stock (metric ton / hectare)	Localised-to-Field Stock (metric ton / hectare)
HI	40.7	30.2	38.1
BE5	37.5	29.1	41.6
GS	33.2	47.1	38.4
A1	40.6	45.0	44.2
Average absolute error (all fields)	–	25.2%	10.5%

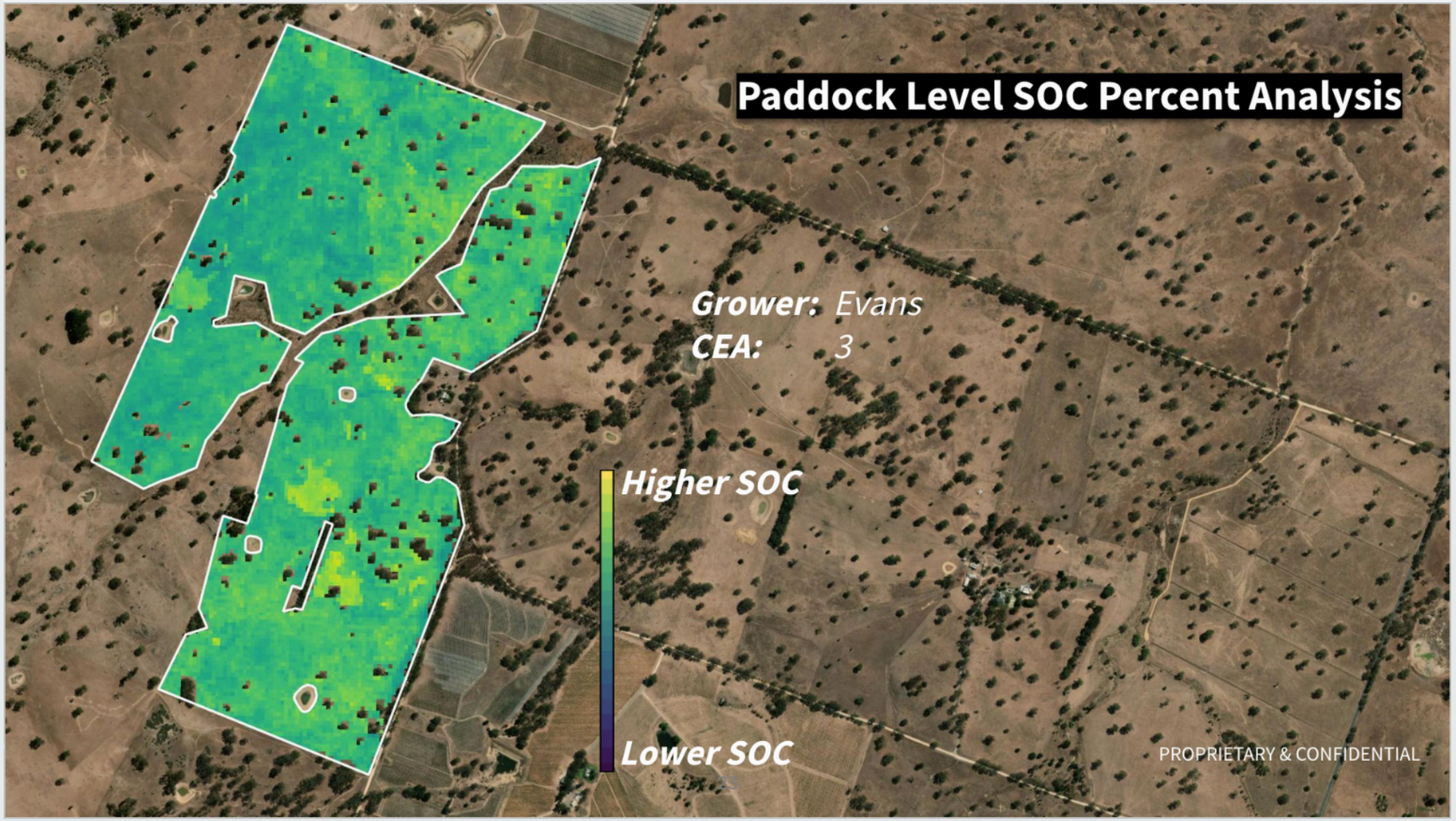
We can measure at continental level, regional level and per field level. Uncertainties drop considerable when adding more sample coverage.

Model results are from 2021, they have improved considerably as of today (2024).

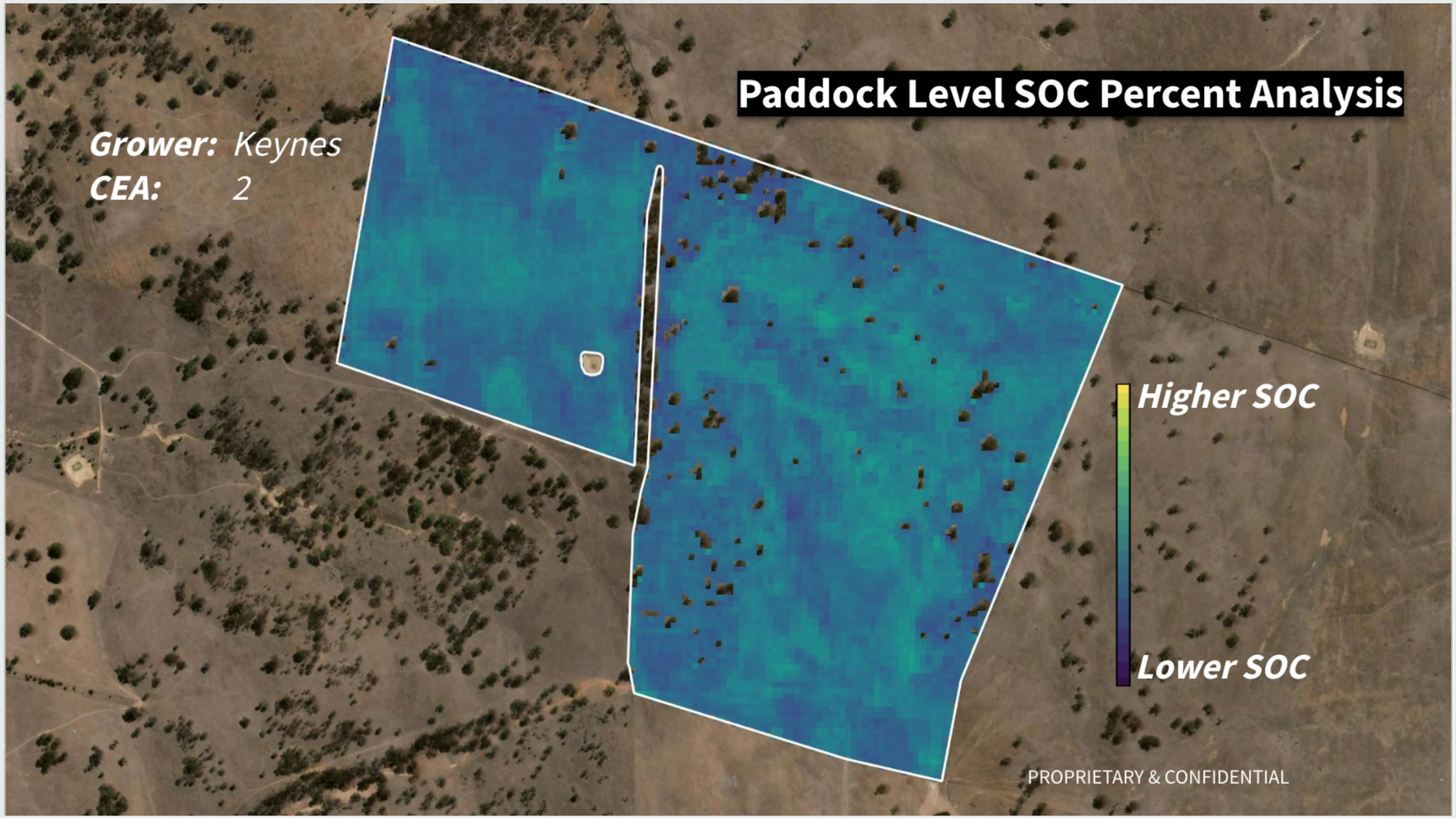
Mapping field per field – from large scale to field level



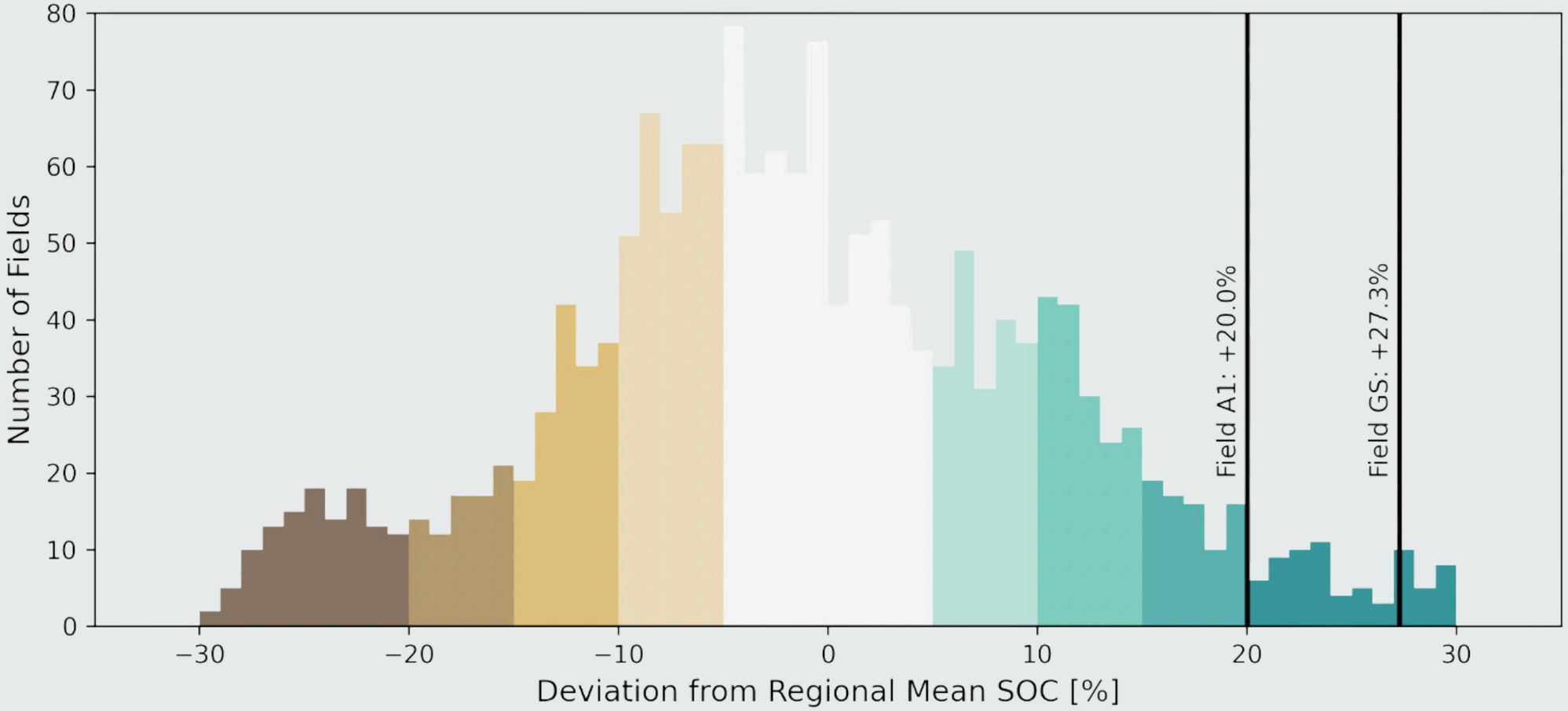
Mapping at 10m resolution, carbon variation inside the field



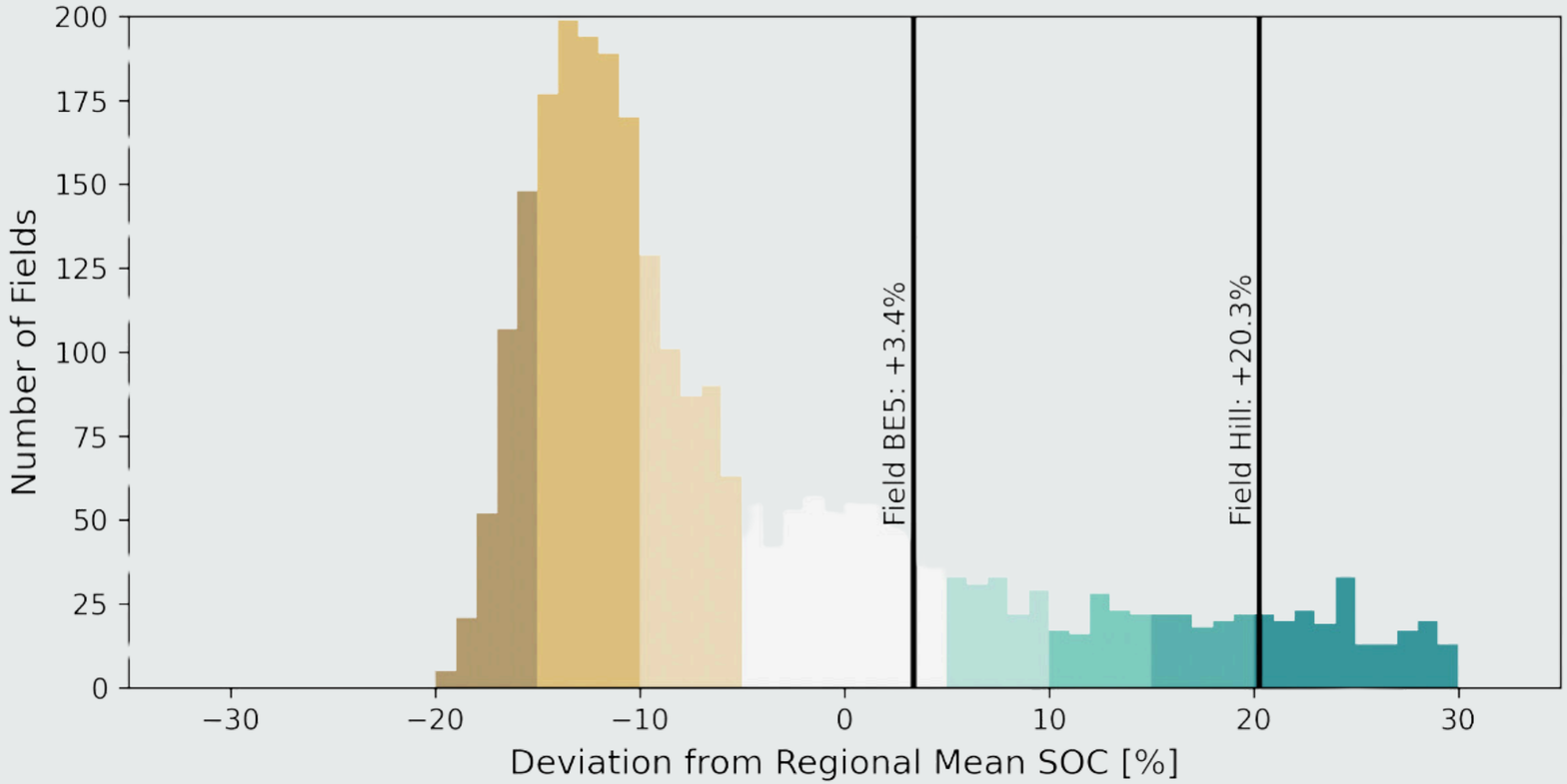
Mapping at 10m resolution, carbon variation inside the field



Validation Northern Region



Validation Souther Region

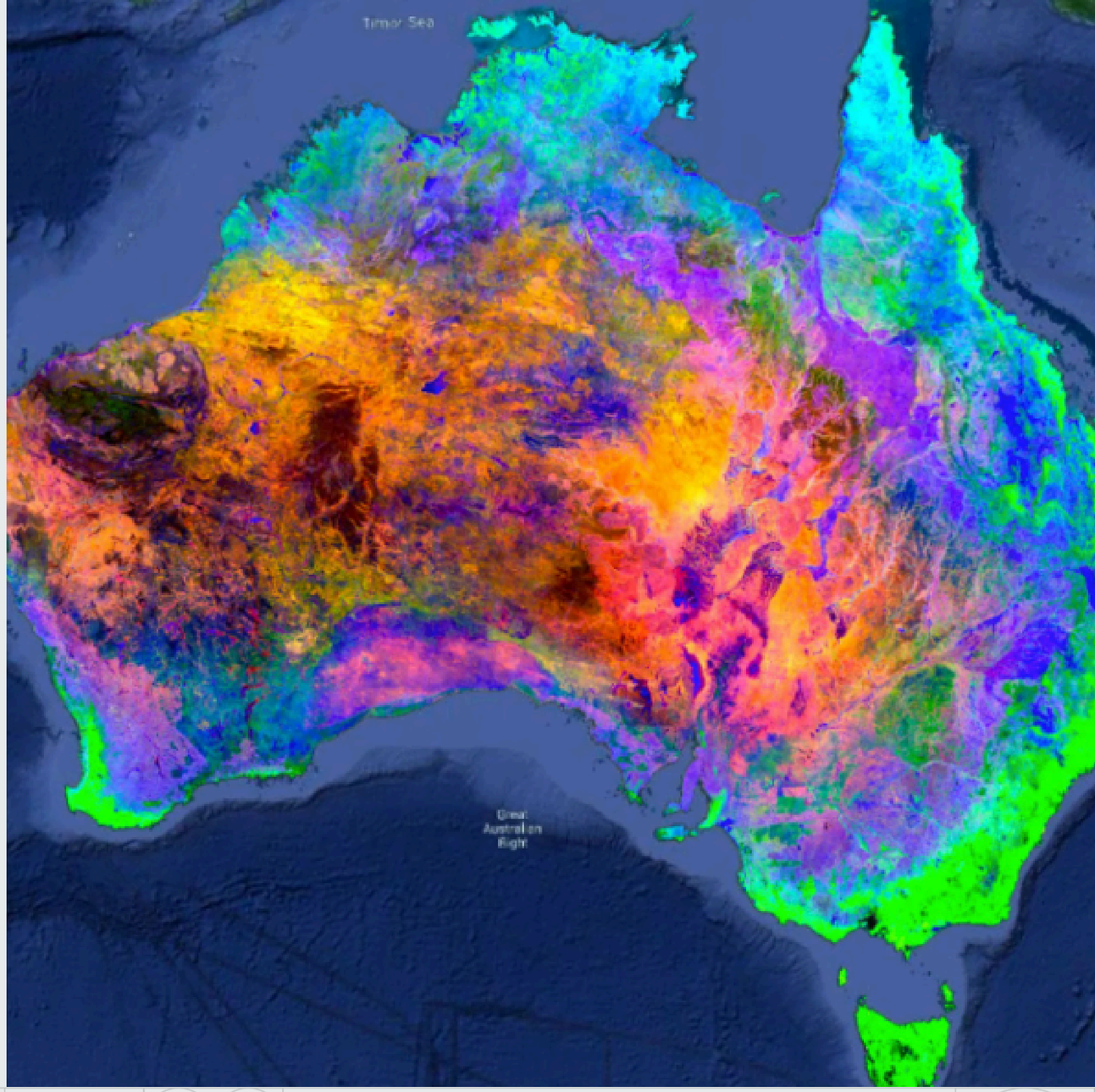


Executive Summary

- We saw a 3x reduction in field mean absolute error with 2 samples per strata compared to 0 samples
- Illustrate how the results of Milestone 3 support the strategic direction that Cloud Ag is proposing:
- 1m Ha extension project to get the model localised across all of Australia's improved pasture land
- SOC Innovation Challenge proving out how Perennial approach can reduce the number of samples required to achieve confidence in the results, down to a point where the $3/Ha target is achievable

Mapping the entire contintent

Perennial work led to a $1.7M AUD grant to scale soil carbon quantification in Australia using remote sensing and digital soil mapping.



How Perennial can help you measure soil health accurately & at scale

01.
Standarized: use one model across all geographies and crops

02.
Scalable: build to be run in millions of hectares

03.
Low Effort: minimal data required from farmers

04.
Scientifically Rigouros: validated by the scientific community and registry bodies

Thank you

Contact

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Address Boulder, CO

Perennial

www.perennial.earth

James R. Kellner – biographical sketch (ORCID: 0000-0002-9861-4857)

I am a remote sensing scientist and professor at Brown University and the Chief Scientist for Perennial Climate Inc., a private company focused on the development of remote sensing technology for mapping organic carbon content in agricultural soils. I have been a PI or co-Investigator on numerous grants from federal and state government agencies, including the USDA, NASA, DOD, the National Science Foundation, and the State of North Dakota. I am a co-Investigator on the NASA Global Ecosystem Dynamics Investigation (GEDI) and member of the NASA GEDI Mission and Competed Science Teams. GEDI is focused on aboveground carbon mapping in the world's forests and woodlands. I have 20 years of experience with remote sensing data and have developed and conducted field campaigns related to calibration and validation of remote sensing data in locations around the world.

Education

James Cook University – Tropical Biology – Bachelor of Science – 2000

Dartmouth College – Ecology and Evolutionary Biology – Master of Science - 2005

The University of Georgia – Plant Biology – Doctor of Philosophy –2008

Carnegie Institution for Science – Global Ecology – Postdoc – 2008, 2009, 2010

Appointments

Associate Professor (Ecology, Evolution, and Organismal Biology and Institute at Brown for Environment and Society) – Brown University – July 2020 – present.

Chief Scientist – Perennial Climate Inc. – 2019 – present.

Assistant Professor (Ecology, Evolution, and Organismal Biology and Institute at Brown for Environment and Society) – Brown University – July 2013 to June 2020.

Assistant Professor (Geographical Sciences) – University of Maryland, College Park – January 2011 to June 2013.

Postdoc (Global Ecology) – Carnegie Institution for Science – June 2008 to January 2011.

Collaborators (including former advisors, students and postdocs)

Albert, Loren P.; Armston, John; Asner, Gregory P.; Becknell, Justin; Blair, J. Bryan; Burley, John T.**;** Cavanaugh, Kyle C.**;** Cushman, K. C.; Davies, Andrew; Dub ayah, Ralph; Duncanson, Laura; Fatoyinbo, Lola; Feller, Ilka; Friedl, Mark; Goetz, Scott; Hancock, Steve; Healey, Sean; Hofton, Michelle; Hubbell, Stephen P., Hurtt, George; Kinney, Kealoha, Luthcke, Scott; Patterson, Paul, Questad, Erin; Rezaei, Ahya, Saarela, Svetlana; Seo, Eugene; Silva, Carlos E.; Smith, Laurence; Yang, Xi; Zhang, Dafeng

Grants (five most relevant)

2020 – 2023 Machine-learning algorithms for level-4 GEDI aboveground biomass density. National Aeronautics and Space Administration. Lead investigator: **James R. Kellner**

2014 – 2029 Global Ecosystem Dynamics Investigator lidar. National Aeronautics and Space Administration. Investigator: **James R. Kellner**. Lead investigator: R. O. Dubayah

2012 – 2017 Remote sensing technology for threatened and endangered plant species recovery. Department of Defense SERDP-ETSCP. Investigator: **James R. Kellner**. Lead investigator: Erin J. Questad.

2012 – 2016 Collaborative research: Multiscale drivers and effects of biotic change in the global mangrove saltmarsh ecotone. National Science Foundation. Investigator: **James R. Kellner**. Lead investigator: Ilka Feller.

2011 – 2013 Causes and consequences of fire regimes through space and time in tropical dryland ecosystems. USDA Forest Service. Lead investigator: **James R. Kellner**.

Synergistic activities

I am a co-Investigator on the NASA Global Ecosystem Dynamics Investigation and a member of the NASA GEDI Mission and Competed Science Teams. I am a Guest Editor of a Special Issue in Environmental Research Letters focused on the Global Ecosystem Dynamics Investigation, and a Guest Editor of a special issue of Remote Sensing of Environment focused on carbon accounting using remote sensing. Outside of university and Perennial professional obligations, I speak about carbon accounting in the context of the global financial architecture. Most recently I was an invited panelist at an event in NYC hosted by Bloomberg and the Global Carbon Trust, and on a panel in the City of London hosted by the Office of the Lord Mayor.

Publications (all peer-reviewed publications in the last four years)

2019 Cushman, K. C., and **J. R. Kellner.** Prediction of forest aboveground net primary production from high-resolution vertical leaf-area profiles. Ecology Letters 22:538–546. https://doi.org/10.1111/ele.13214

2019 **Kellner, J. R.**, Armston, J. D., Birrer, M., Cushman, K. C., Duncanson, L. I., Eck, C., Falleger, C., Imbach, B., Král, K., Krůček, M., Trochta, J., Vrška, T., Zgraggen, C. New opportunities for forest remote sensing through ultra-high-density drone lidar. Surveys in Geophysics. 40(4): 959–977. https://doi.org/10.1007/s10712-019-09529-9

2019 Hancock, S., Armston, J., Hofton, M., Sun, X., Tang, H., Duncanson, L. I., **Kellner, J. R.**, and R. O. Dubayah. The GEDI simulator: A large-footprint waveform lidar simulator for calibration and validation of spaceborne missions. Earth and Space Science 6(2):294–310. https://doi.org/10.1029/2018EA000506

2019 Duncanson, L., Armston, J., Disney, M., Avitabile, V., Barbier, N., Calders, K., Carter, S., Chave, J., Herold, M., Crowther, T., Falkowski, M., **Kellner, J. R.**, Labriére, N., Lucas, R., MacBean. N., McRoberts, R. E., Meyer, V., Næsset, E., Nickeson, J. E., Paul, K. I., Phillips., O. L., Réjou-Méchain, M., Roman, M., Roxburgh, S., Saatchi, S., Schepashenko, D., Scipal, K., Whitehurst, A., Siqueira, P. R., Williams, M. The importance of consistent validation of global forest aboveground biomass products. Surveys in Geophysics. 40(4):979–999. https://doi.org/10.1007/s10712-019-09538-8

2019 Patterson, P. L., Healey, S. P., Stahl, G., Saarela, S., Holm, S., Andersen, H., Dubayah, R. O., Duncanson, L., Hancock, S., Armston, J., **Kellner, J. R.**, Cohen, W. B., and Yang, Z. Statistical properties of hybrid estimators proposed for GEDI - NASA's Global

Ecosystem Dynamics Investigation. Environmental Research Letters 14:0065007. https://doi.org/10.1088/1748-9326/ab18df

2019 **Kellner, J. R.** Albert, L. P., Burley, J. T., and Cushman, K. C. The case for remote sensing of individual plants. American Journal of Botany. 106(9):1–4. https://doi.org/10.1002/ajb2.1347

2019 Clark, D. B., Ferraz, A., Clark, D. A., **Kellner, J. R.** Letcher, S. G., Saatchi, S. Diversity, distribution and dynamics of very large trees across and old-growth lowland Neotropical rain forest landscape. PLoS One. 14(11). https://doi.org/10.1371/journal.pone.0224896

2020 Dubayah, R., Blair, J. B., Goetz, S., Fatoyinbo, L., Hansen, S., Healey, S., Hurtt, G., **Kellner, J. R.**, Luthcke, S., Armston, J., Tang, H. Duncanson, L., Hancock, S., Jantz, P., Marselis, S. M., Patterson, P., Qi, W., Silva, C. The Global Ecosystem Dynamics Investigation: high-resolution laser ranging of the Earth's forests and topography. Science of Remote Sensing (1). https://doi.org/10.1016/j.srs.2020.100002

2020 Krůček, M., Král, K., Cushman, KC, Missarov, A., **Kellner, J.R.** Supervised Segmentation of Ultra-High-Density Drone Lidar for Large-Area Mapping of Individual Trees. Remote Sensing. 12(19): 3260. https://doi.org/10.3390/rs12193260

2020 VanValkenburgh, P., Cushman, KC, Butters, L. J. C., Vega, C. R., Roberts, C. B., Kepler, C., **Kellner, J.** Lasers without lost cities: Using drone lidar to capture architectural complexity at Kuelap, Amazonas, Peru. Journal of Field Archaeology 45 sup1 S75-S88. https://doi.org/10.1080/00934690.2020.1713287

2020 Duncanson, L., Neuenschwander, A., Hancock, S. Thomas, N., Fatoyinbo, T., Simard, M. Silva, C. A., Armston, J. Luthcke, S. B., Hofton, M. **Kellner, J. R.**, Dubayah, R. Biomass estimation from simulated GEDI, ICESat-2 and NISAR across environmental gradients in Sonoma County, California. Remote Sensing of Environment. 242: 111779. https://doi.org/10.1016/j.rse.2020.111779

2020 Marselis, S. M. Abernethy, K. Alonso, A. Armston, J. Baker, T. R., Bastin, J-F., Bogaert, J., Boyd, D. S., Boeckx, P. Burslem, D. F. R. P., Chazdon, R., Clark, D. B., Coomes, D. Duncanson, L. Hancock, S. Hill, R. Hopkinson, C. Kearsley, E., **Kellner, J. R.**, Kenfack, D., Labrière, N. Lewis, S. L., Minor, D., Memiaghe, H., Monteagudo, A., Nilus, R., O'Brien, M., Phillips, O. L., Poulsen, J., Tang, H., Verbeeck, H., Dubayah, R. Evaluating the potential of full-waveform lidar for mapping pan-tropical tree species richness. Global Ecology and Biogeography. (29) 10: 1799 - 1816. https://doi.org/10.1111/geb.13158

2021 Lin, H., Tarnas, J. D., Mustard, J. F., Zhang, X., Wei, Y, Weixing, W., Klein, F., and **J. R. Kellner**. Dynamic aperture factor analysis/target transformation (DAFA/TT) for serpentine and Mg-carbonate mapping on Mars with CRISM near infrared data. Icarus. 355:114168. https://doi.org/10.1016/j.icarus.2020.114168

2021 Burley, J. T., **Kellner, J. R.**, Hubbell, S. P., Faircloth, B. F. Genome assemblies for two Neotropical trees: Jacaranda copaia and Handroanthus guayacan. *G3 Genes|Genomes|Genetics*, jkab010. https://doi.org/10.1093/g3journal/jkab010

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2022 **Kellner, J. R.**, Armston, J., Duncanson, L. Algorithm theoretical basis document for GEDI footprint aboveground biomass density. Earth and Space Science. https://doi.org/10.1029/2022EA002516

2023 Albert, L. P., Cushman, K. C., Zong, Y., Allen. D. W., Alonso, L., **Kellner, J. R.** Sensitivity of solar-induced fluorescence to spectral stray light in high-resolution imaging spectroscopy. Remote Sensing of Environment. (285) 113313. https://doi.org/10.1016/j.rse.2022.113313

2023 **Kellner, J. R.**, Kendrick, J., Sax, D. F. High-velocity upward shifts in vegetation are ubiquitous in mountains of western North America. PLoS Climate. https://doi.org/10.1371/journal.pclm.0000071

2023 **Kellner, J. R.**, and J. T. Burley. Individual-based remote sensing of canopy trees. In *The First 100 Years of Research of Barro Colorado Island: Plant and Ecosystem Science*, edited by Muller-Landau, H. C. and Wright, J. J. Smithsonian Institution Scholarly Press. In press.

2023 Pascual, A., Guerra-Hernández, J., Armston, J., Duncanson, L., Minor, D. M., **Kellner, J. R.**, Dubayah, R. O. Assessing the performance of NASA's GEDI L4A footprint aboveground biomass density models using National Forest Inventory and airborne laser scanning data in Mediterranean forest ecosystems. Forest Ecology and Management. (538). https://doi.org/10.1016/j.foreco.2023.120975

2023 Cushman, K. C., Armston, J., Dubayah, R. O., Duncanson, L., Hancock, S., Janik, D., Král, K., Krůček, M., Minor, D. M., Tang, H., **Kellner, J. R.** Impact of leaf area on estimates of aboveground biomass density in deciduous broadleaf forest from simulated GEDI lidar. Environmental Research Letters (18). https://doi.org/10.1088/1748-9326/acd2ec

2023 **Kellner, J. R.**, Demuth, K. M., DiCintio, J., Feng, Y. K., Khim-Young, M., Krutsinger, A., Maddalena, J., Morales, M., Wright, L. A., Schurman, D. Data-driven calculation of organic carbon stocks in North American agricultural land. Submitted to Geoderma.

2023 Fu, P., Demuth, K., DiCintio, J., Feng, K., Khim-Young, M., Krutsinger, A., Maddalena, J., Morales, M., Rustowicz, R., Wright, L. A., Schurman, D., **Kellner, J. R.** Mapping soil organic carbon in US croplands at 10 m spatial resolution: depth as a covariate in a data-driven approach. In review with Geoderma.

Published datasets (last four years)

2021 Dubayah, R.O., J. Armston, **J.R. Kellner**, L. Duncanson, S.P. Healey, P.L. Patterson, S. Hancock, H. Tang, M.A. Hofton, J.B. Blair, and S.B. Luthcke. 2021. GEDI L4A Footprint Level Aboveground Biomass Density, Version 1. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1907

2021 Dubayah, R.O., Armston, J., **Kellner, J. R.**, Duncanson, L., Healey, S.P. Patterson, P.L., Hancock, S., Tang, H., Bruening, J., Hofton, M. A., Blair, J. B., Luthcke, S. B. 2021. GEDI L4A Footprint Level Aboveground Biomass Density, Version 2. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1986

2021 Clark, D,B., Clark, D. A., ; **Kellner, J. R.** (2021). Canopy height distributions and estimated above-ground biomass across a tropical rain forest landscape in Costa Rica, 1992 – 2018. https://doi.org/10.5061/dryad.fn2z34tst

2022 Dubayah, R. O., Armston, J., Healey, S. P., Yang, Z., Patterson, P. l., Saarela, S., Stahl, G., Duncanson, L., **Kellner, J. R.** GEDI L4B Gridded Aboveground Biomass Density, Version 2. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2017

2022 Dubayah, R. O., Armston, J., **Kellner, J. R.**, Duncanson, L., Healey, S. P., Patterson, P. L., Hancock, S., Tang, H., Hofton, M. A., Blair, J. B., Luthcke, S. R. GEDI L4A Footprint Level Aboveground Biomass Density, Golden Weeks, Version 1. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2028

2022 Dubayah, R. O., Armston, J., **Kellner, J. R.**, Duncanson, L., Healey, S. P., Patterson, P. L., Hancock, S., Tang, H., Bruening, J., Hofton, M. A., Blair, J. B., Luthcke, S. B. GEDI L4A Footprint Level Aboveground Biomass Density, Version 2.1. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2056

Christian D. Clanton - biographical sketch (ORCID: 0009-0003-8213-3164)

Christian is a data scientist and computer vision expert with experience in applied physics, astronomy, and geospatial observation. He has built and led data science teams developing state-of-the-art AI and machine learning-based capabilities, and currently serves as the Head of Data Science at Perennial. Prior to Perennial, Christian was the Sr. Director of Model Engineering at Orbital Insight and led their Data Science and Computer Vision department, and served as a NASA Postdoctoral Program fellow at Ames Research Center researching the statistics of extrasolar planet detections.

Education

California Institute of Technology – Applied Physics – Bachelor of Science with Honors – 2010
The Ohio State University – Astronomy – Master of Science – 2014
The Ohio State University – Astronomy – Doctor of Philosophy – 2016

Work Experience

VP, Head of Data Science – Perennial Climate Inc. – March 2023 to Present
Sr. Director of Model Engineering – Orbital Insight – March 2022 to February 2023
Director of Model Engineering – Orbital Insight – August 2020 to March 2022
Director of Data Science – Orbital Insight – July 2019 to August 2020
Manager, Data Science – Orbital Insight – August 2018 to July 2019
Data Scientist – Orbital Insight – July 2017 to August 2018
NASA Postdoctoral Program Fellow – NASA Ames Research Center – July 2016 to July 2017
Graduate Student Research and Teaching Assistant – The Ohio State University, Department of Astronomy – August 2011 to May 2016
Research Scientist – California Institute of Technology – June 2010 to May 2011

Synergistic activities

Christian has been directly involved in the development and deployment of state-of-the-art machine learning, deep learning, and statistical models that leverage remotely-sensed and geospatial data for the past decade. These models performed a variety of tasks, including classification, object detection, and segmentation of satellite imagery, construction of time series datasets, anomaly detection, predictions of physical quantities, and more. As an astronomer, Christian developed a novel statistical framework for synthesizing extrasolar planet detection data from multiple detection techniques with disjoint, yet overlapping, sensitivities to the physical properties of planets and the stars they orbit.

Publications

De Rosa, G., Fausnaugh, M. M., Grier, C. J., et al. (2018). Velocity-resolved Reverberation Mapping of Five Bright Seyfert 1 Galaxies. *The Astrophysical Journal*, 866, 133.

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Johnson, J. A., Clanton, C., Howard, A. W., et al. (2011). Retired A Stars and Their Companions. VII. 18 New Jovian Planets. *The Astrophysical Journal Supplement Series,* 197, 26.

Kirk M. Demuth – biographical sketch

I am a licensed professional pilot and Vice President of Operations for Perennial Climate Inc., a private company focused on the development of remote sensing technology for mapping organic carbon content in agricultural soils. I oversee all operational logistics for the company, including airborne and field sampling campaigns. I have successfully executed sampling campaigns that generated thousands of physical soil samples for Perennial in multiple US states under a wide range of conditions, including sponsored research under grants to Perennial from the states of Colorado and North Dakota. These campaigns include managing relationships with landowners, overseeing collection, storage, and transportation of soil sample data with analytical laboratories, and integration of laboratory data into digital workflows.

Education

Kansas State University – Technology Management – Bachelor of Science – 2007

Kansas State University – Professional Pilot – Associate of Science – 2007

Appointments

Vice President of Operations – Perennial Climate, Inc. 2023 – present.

Director of Operations – Perennial Climate, Inc. 2020 – 2023.

Chief Operating Officer – Air Data Solutions – 2018 – 2020.

Chief Operating Office and co-founder – AgPixel LLC – 2013 – 2018

Publications

2023 Kellner, J. R., **Demuth, K. M.**, DiCintio, J., Feng, Y. K., Khim-Young, M., Krutsinger, A., Maddalena, J., Morales, M., Wright, L. A., Schurman, D. Data-driven calculation of organic carbon stocks in North American agricultural land. Submitted to Geoderma.

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