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AIR RESOURCES BOARD

Public Workshop: Natural and Working Lands Carbon Inventory Methods

February 7th , 2025

Dr. Matthias Falk

Update to the 2025 Natural and Working Land Inventory

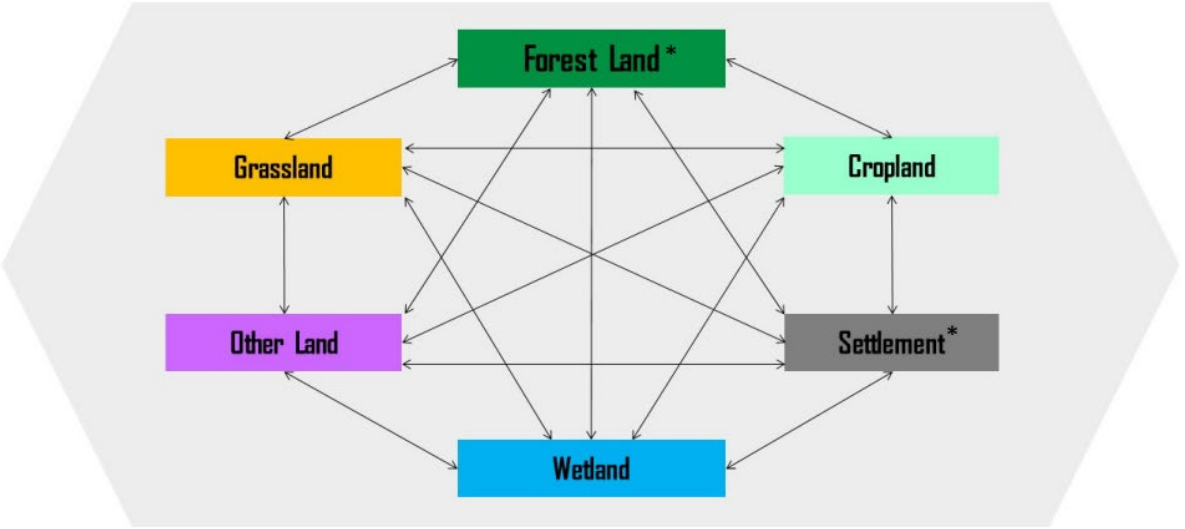
- Present 2025 Natural Working Lands Carbon Inventory Update proposed methods
- Solicit public feedback on the methods with which the inventory will be updated

CARB

Background

- CARB is responsible to
  - Identify and track the State's pathway to achieving carbon neutrality by 2045
  - Develop inventories of both anthropogenic GHG emissions and changes in statewide ecosystem Carbon Stocks.
  - Publish the Carbon Inventory of all of California's Natural and Working Lands
  - Publish the SB901report on GHG emissions of fires, and forest management activities

Natural and Working Lands



Tracking California's Carbon Neutrality Goals

AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

±

Natural and Working Lands

-

Other Carbon Removal

=

Carbon Neutral

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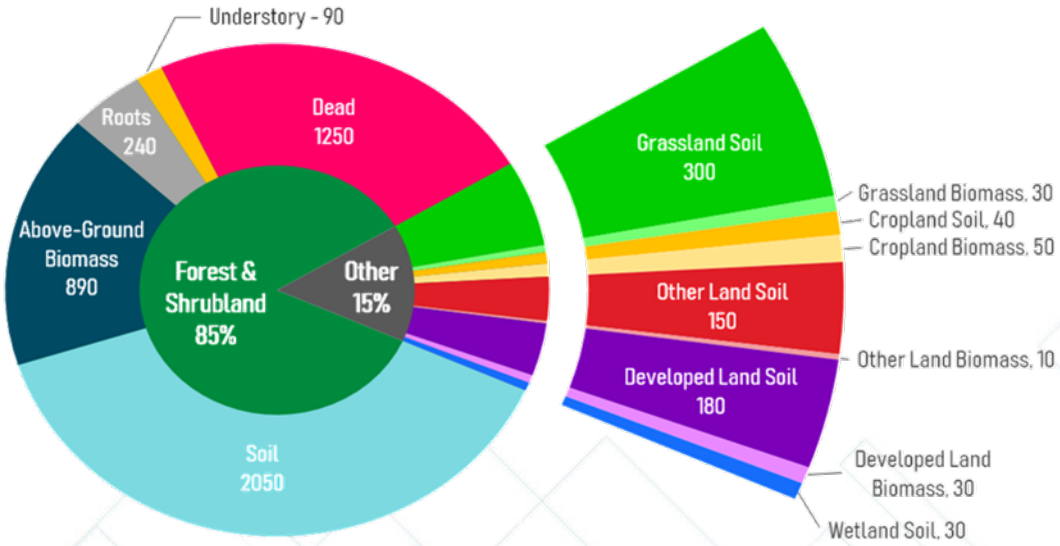
Purpose and intent of the NWL Carbon Inventory

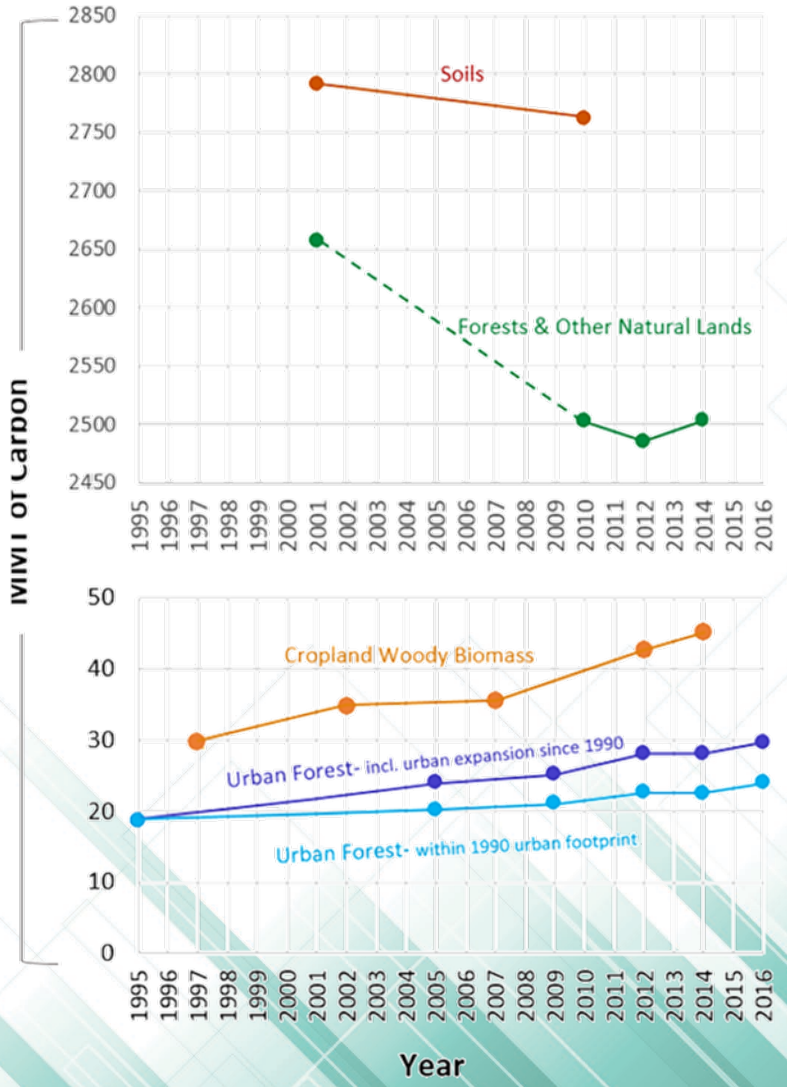
- California's NWL Carbon Inventory accounts for all organic carbon stocks.

- California's NWL Carbon Inventory
  - tracks carbon stocks and how they change over time.
  - helps California achieve its climate goals
  - measures progress toward our carbon targets, and assists with planning efforts

NWL Carbon Inventory

2018 CARB NWL Inventory





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New Needs for Inventory

Quantify the impacts of land management activities

Track and assess progress towards the Nature Base Solution targets

Assist county, air district, and other local planning groups with inventories

Lots of new science and data to utilize

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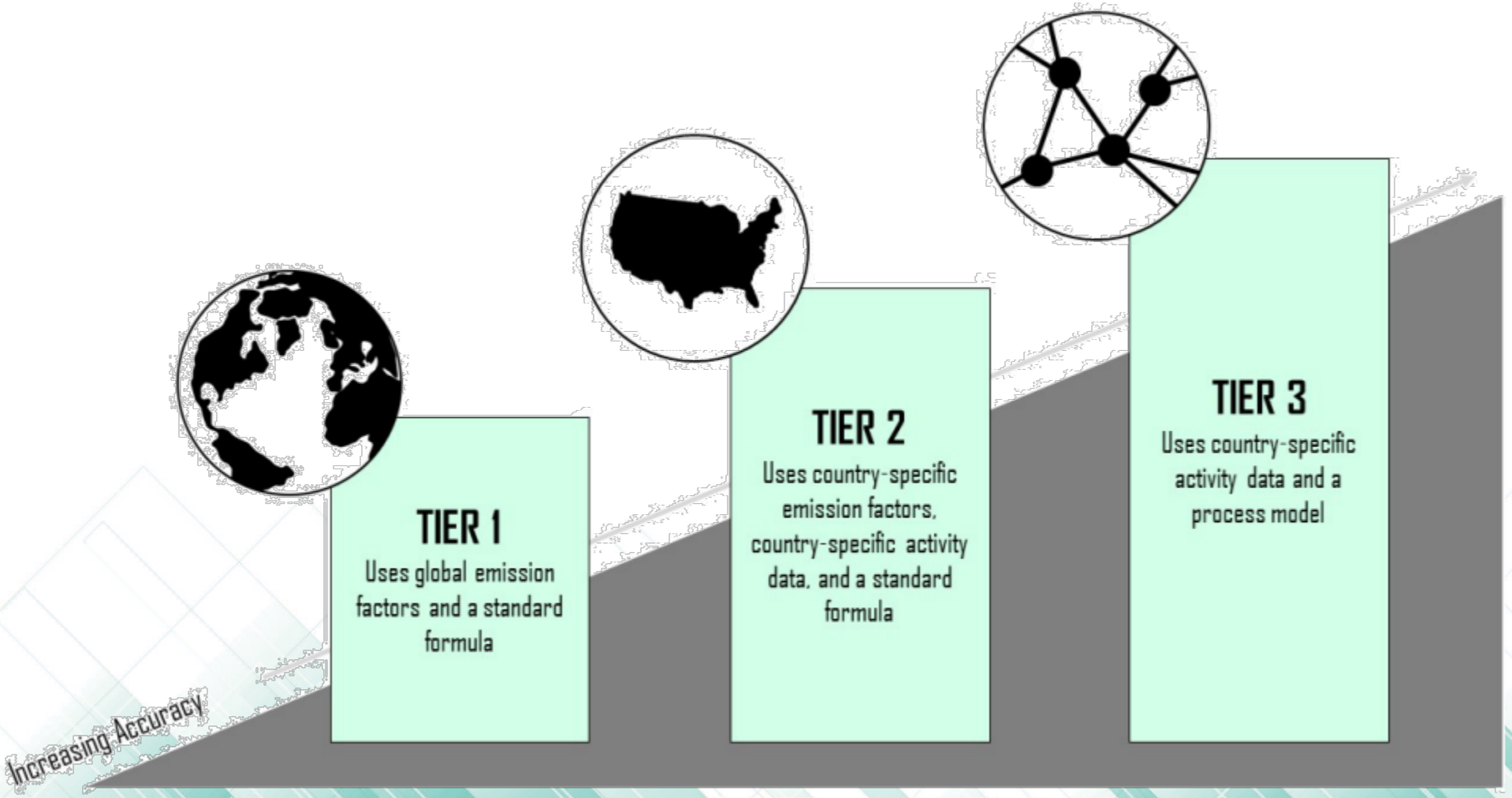
Updating the NWL carbon inventory methodology

- CARB is currently updating its methodology for estimating carbon stocks and carbon stock change for the 2025 NWL Carbon Inventory Update

- Proposed key changes to the methodology of the inventory:
  - Use open-source models and input data sets
  - Incorporate enhanced spatial data on the state of California's landcover
  - Strengthen how disturbance events change carbon stock estimates
  - Develop a unified framework for estimating soil organic carbon
  - Update estimates using the Harvested Wood Products Carbon (HWP-C) model

Inventory Enhancements



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Inventory Guiding Principles

- Spatial Scale
- Temporal Scale
- Spatial Resolution
- Temporal Resolution
- Thematic Resolution
- Sensitivity
- Practical Considerations

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Report on greenhouse gas emissions of wildfire, prescribed fire, and forest management activities (SB901)

In 2025 CARB will prepare the next report on state-wide retrospective estimates of:

1. Annual greenhouse gas (GHG) emissions associated wildfires and prescribed burning activities;
2. Changes in ecosystem carbon stocks associated with other non-fire forest management activities (e.g., timber harvest, forest thinning, and other activities that reduce fire risk).

Draft Timeline

- Draft Timeline for the inventory development and 901 reporting
    - This public meeting (Early February 2025)
    - Inventory Publication (Late Summer 2025)
    - Public Workshop on inventory update results (Fall 2025)
    - SB901 report publication (Dec 31, 2025)
    - Public Workshop on SB901 report results (Early 2026)

Today's Agenda

- NBSS staff have organized the presentations according to the standard IPCC Land-Use categories as well as Harvested Wood Products and Soils
- Each topic will consist of a 10-15 minute presentation followed by 15-20 minutes of comments
- **Topics Schedule**
  - 9:00 - 9:15 – Introduction and Background
  - 9:15 - 9:45 – Soils
  - 9:45 - 10:15 – Agriculture and Grasslands
  - 10:15 - 10:30 – *Break*
  - 10:30 - 12:00 – Forest & Shrublands
  - 12:00 - 1:00 – *Lunch*
  - 1:00 - 1:30 – Harvested Wood Products
  - 1:30 - 2:00 – Other lands
  - 2:00 - 2:30 – Developed Lands
  - 2:30 - 3:00 – Wetlands

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A Unified Soil Carbon Inventory Framework

February 7, 2025

Dr. Chelsea Carey

Soil Organic Carbon: Framing

- **Large reservoir**: More carbon in soil organic carbon pool than the atmosphere and plants combined
- **Dynamic exchange**: Captures and releases carbon, acting as a net sink or source depending on conditions
- **Responsive to drivers**: Sensitive to climate change, disturbance, and management
- **Long-term storage**: Can remain stored for centuries to millennia

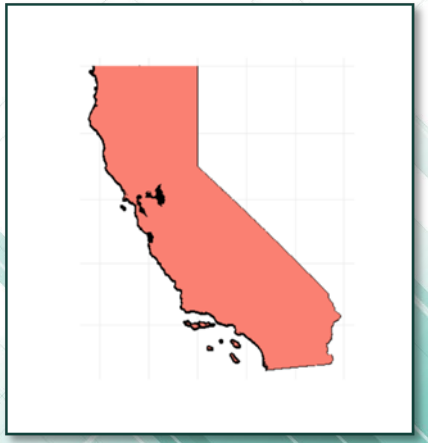
Soil Organic Carbon: Mineral and Organic Soils

Organic Soils

- Organic soils contain high levels of soil organic matter that develop under poorly drained conditions
- Most organic soils are in the Delta and have been drained for land use purposes
- Organic soils are also found in coastal wetlands outside of the Delta

Mineral Soils

- Mineral soils have lower levels of soil organic matter and usually occur under moderate to well drained conditions
- Mineral soils underly the majority of California



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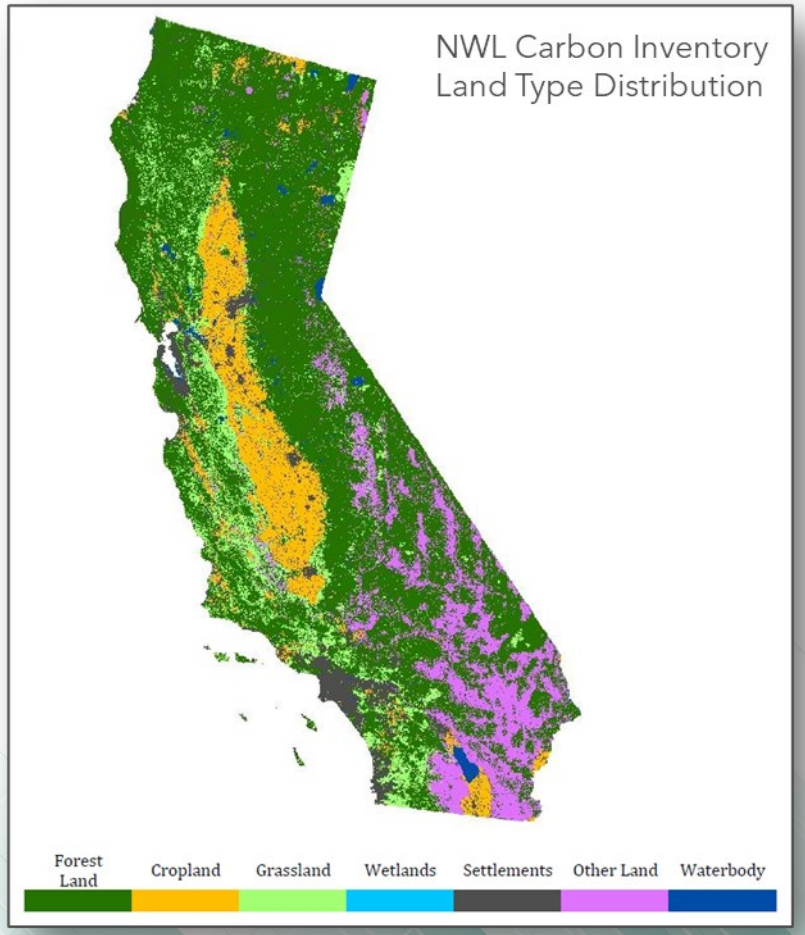
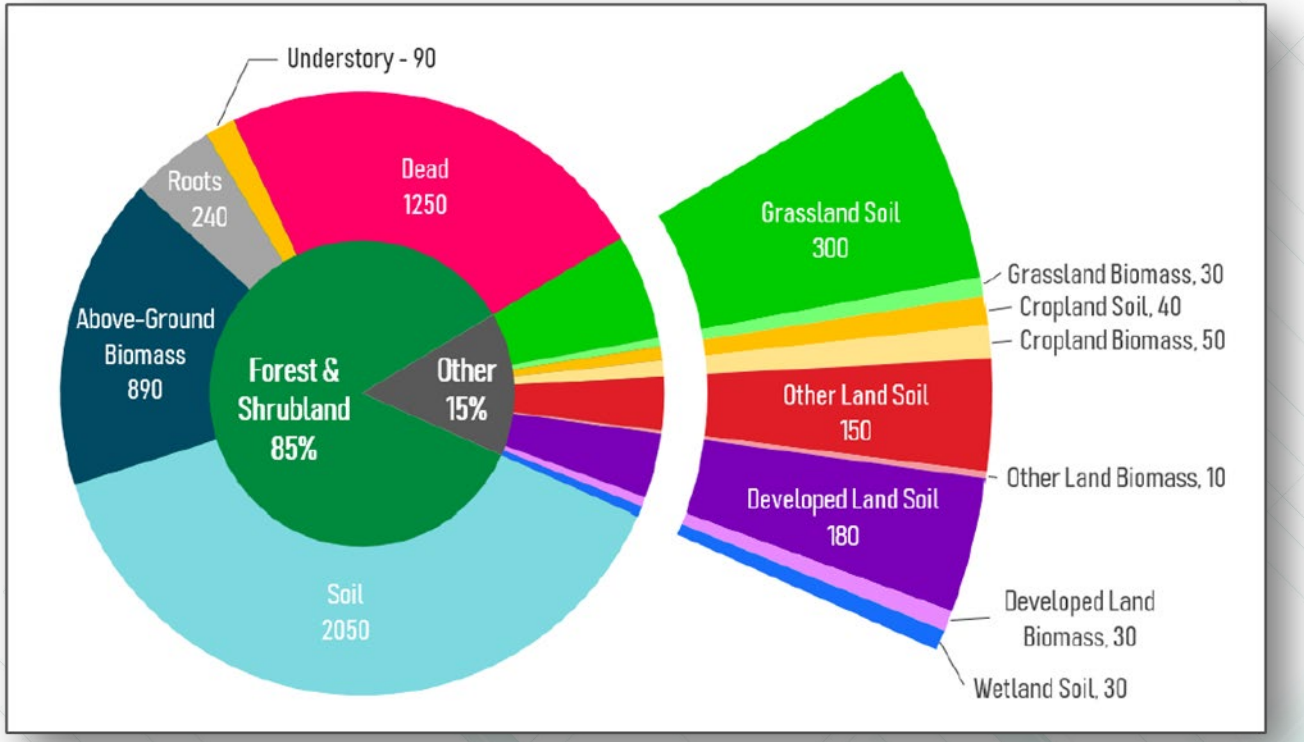
Soil Organic Carbon: Prior Inventory Estimates





51% of NWL organic carbon is stored in top 30 cm of soil

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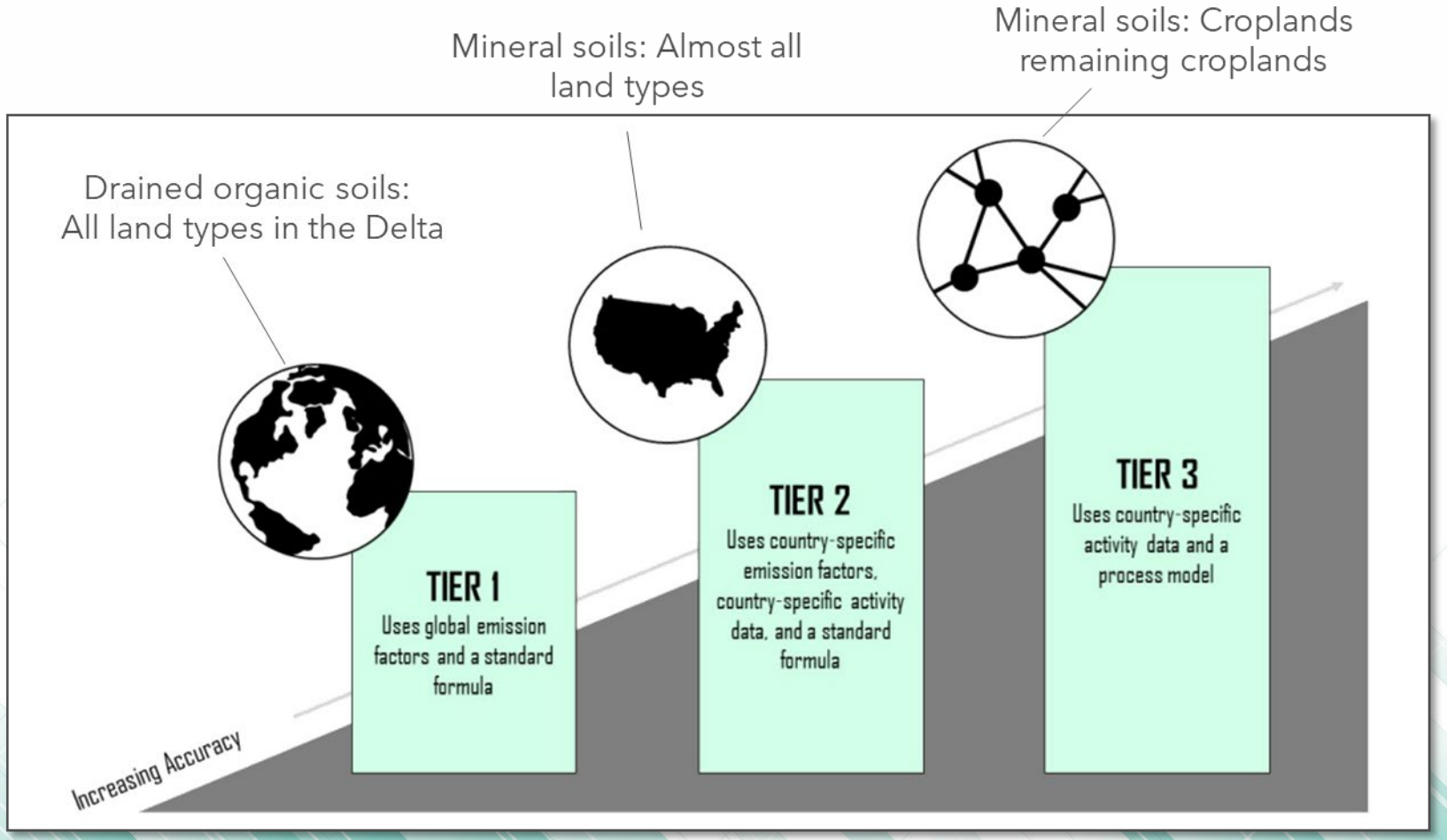
2018 NWL Carbon Inventory Methods



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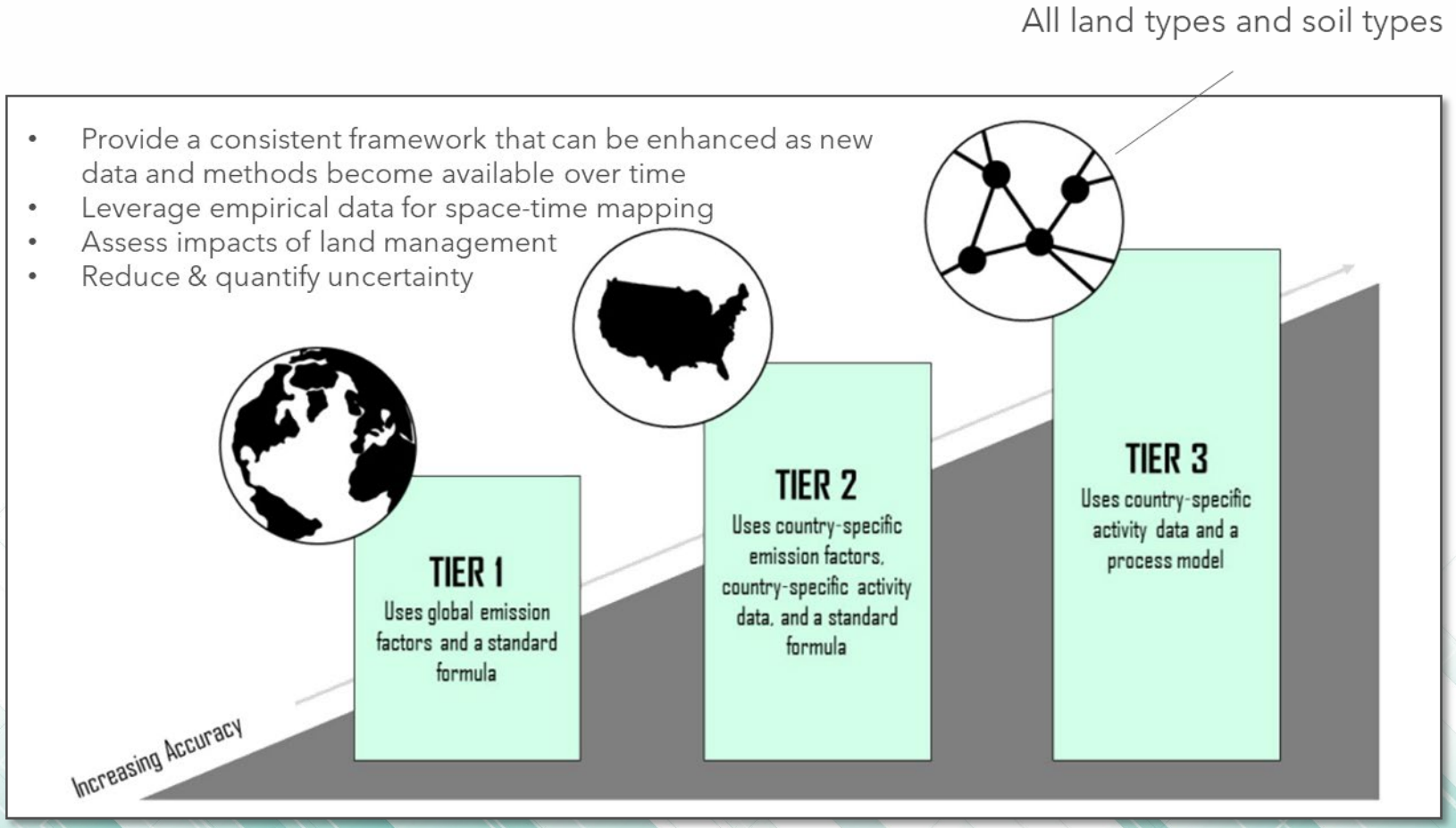
Proposed 2025 Updates: A Unified Framework



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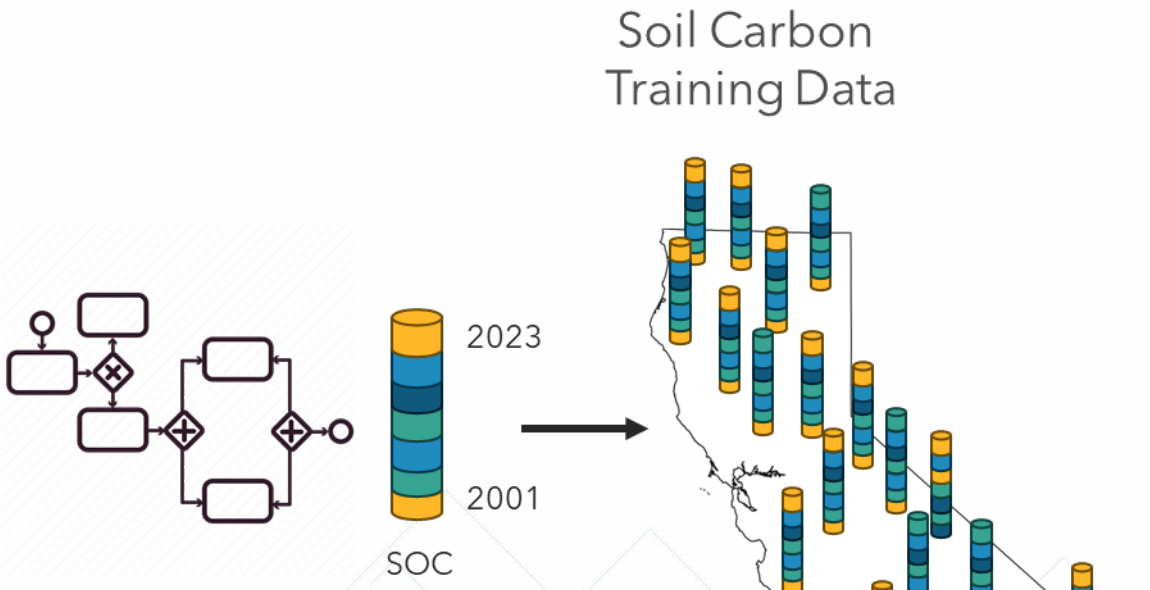
Proposed 2025 Updates: Step 1

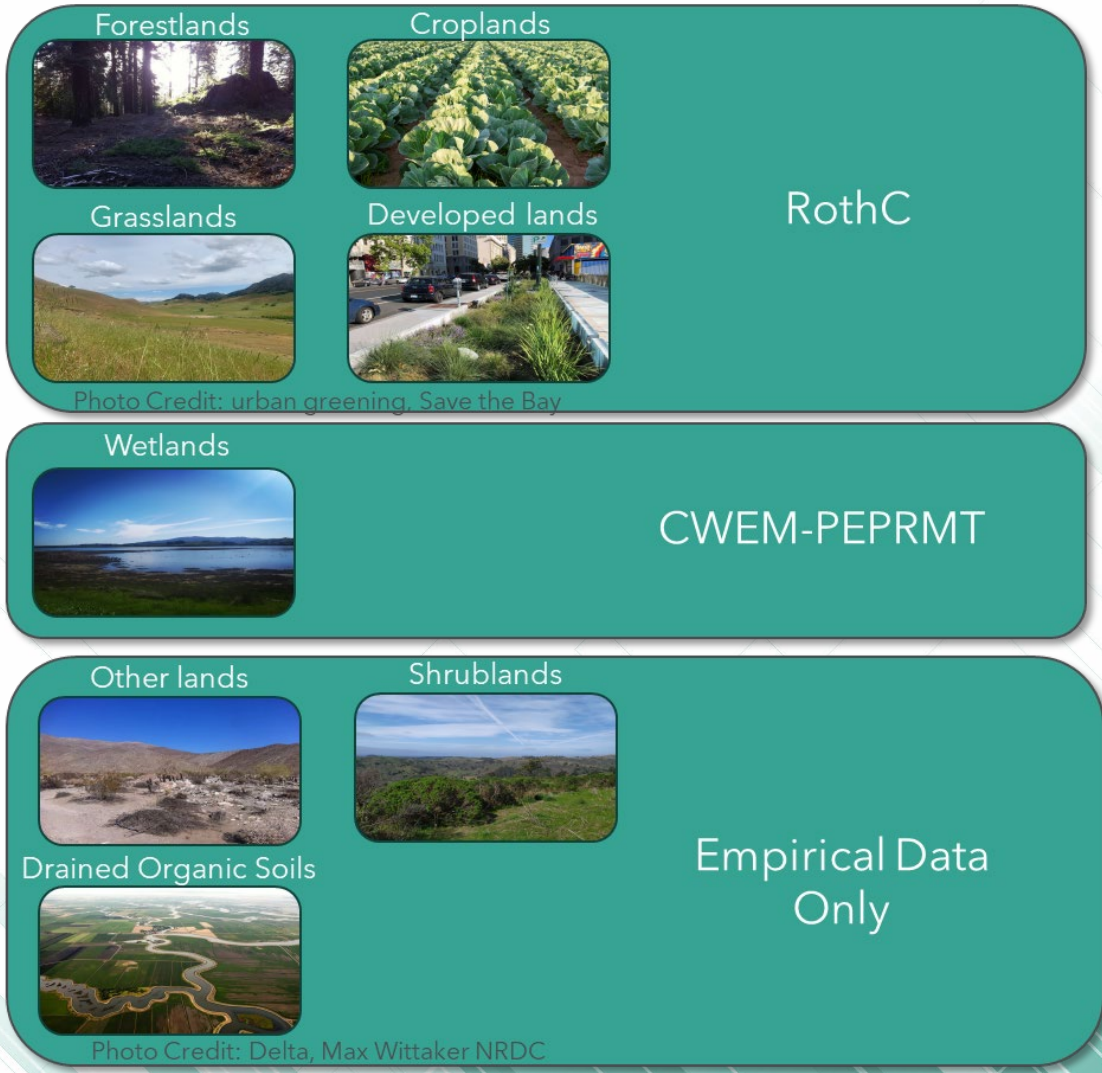
We propose an approach that combines empirical measurements, process-based modeling, and machine learning to map soil carbon over time

- Step 1: Generate a time-series dataset by combining empirical measurements with process-based modeling
  - Mechanistic modeling
  - Temporal variability
  - Novel conditions
  - Examples include DayCent, DNDC, RothC, CWEM-PEPRMT, MEMS 2.0

Proposed 2025 Updates: Step 1 Illustrated



Step 1. Compile Empirical Data & Run Process-Based Model(s)



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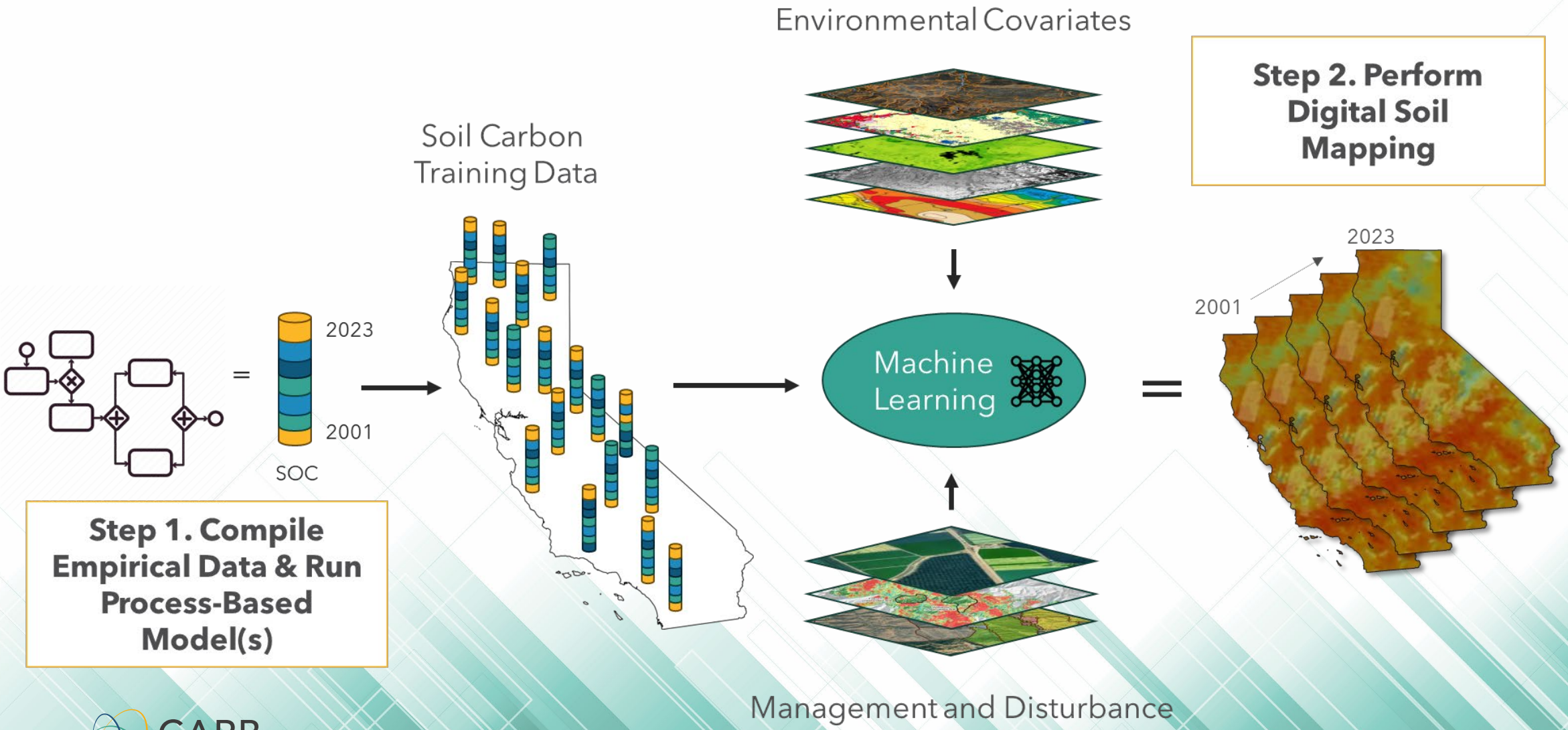
Proposed 2025 Updates: Step 2

We propose an approach that combines empirical measurements, process-based modeling, and machine learning to map soil carbon over time

- Step 2: Scale the time-series data wall-to-wall across California using machine learning
  - Empirical modeling
  - Spatial variability
  - Landscape scale
  - Low computational demands
  - Examples include random forest and boosted trees

Proposed 2025 Updates: Step 2 Illustrated



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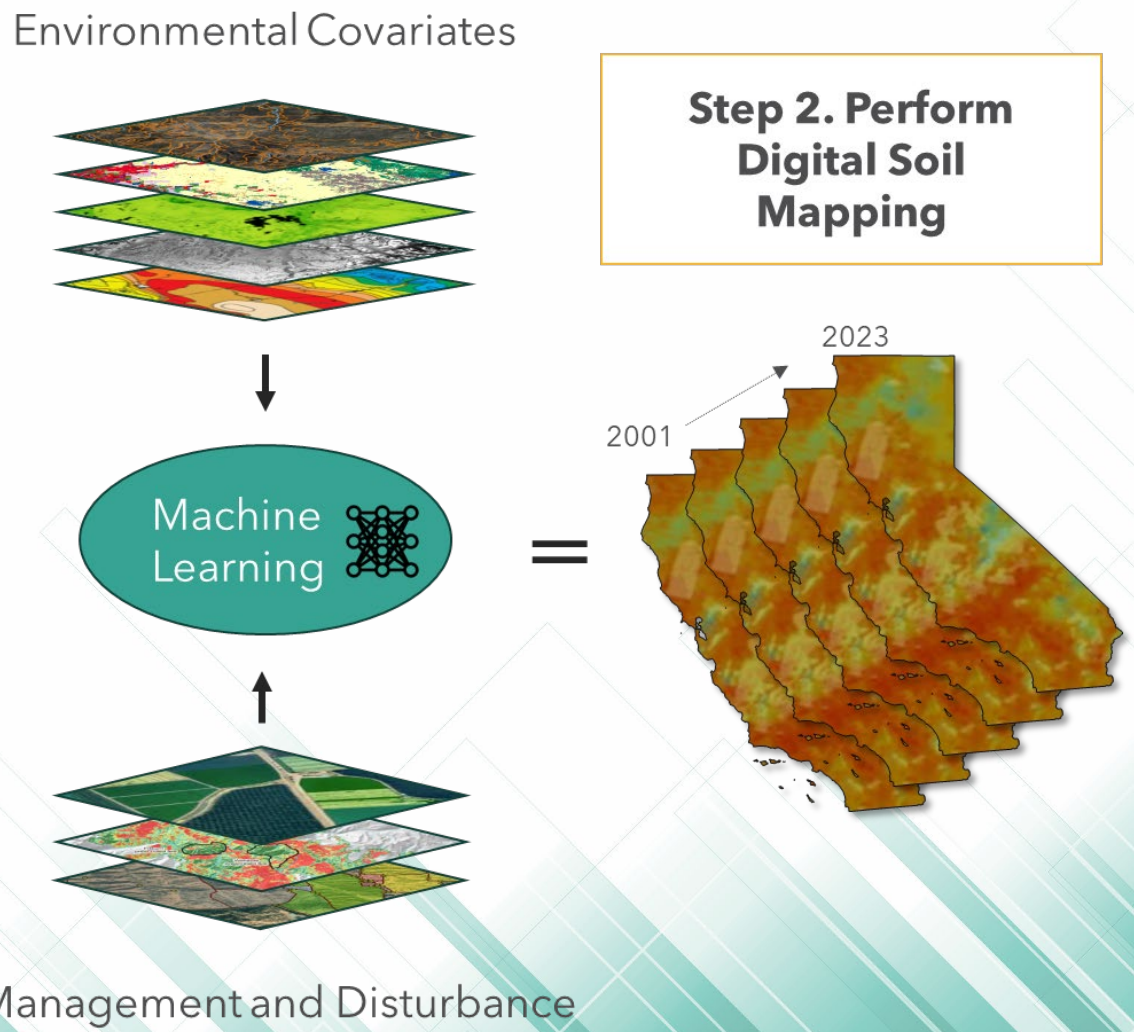
Proposed 2025 Updates: Covariates

Covariates
Climate
Vegetation
Topography
Parent Material
Forest Management
Fire
Cover Cropping
Grazing
Other land-type specific layers as available



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Proposed 2025 Updates: Summary

- We propose a unified framework to assess soil organic carbon across all land types in California.
- The framework combines the strengths of two well-founded approaches: process-based modeling and machine learning.
- It facilitates Tier 3 for all land types. Quantifies and displays associated uncertainty.
- The framework provides a foundation that can be built upon as new models and data become available.

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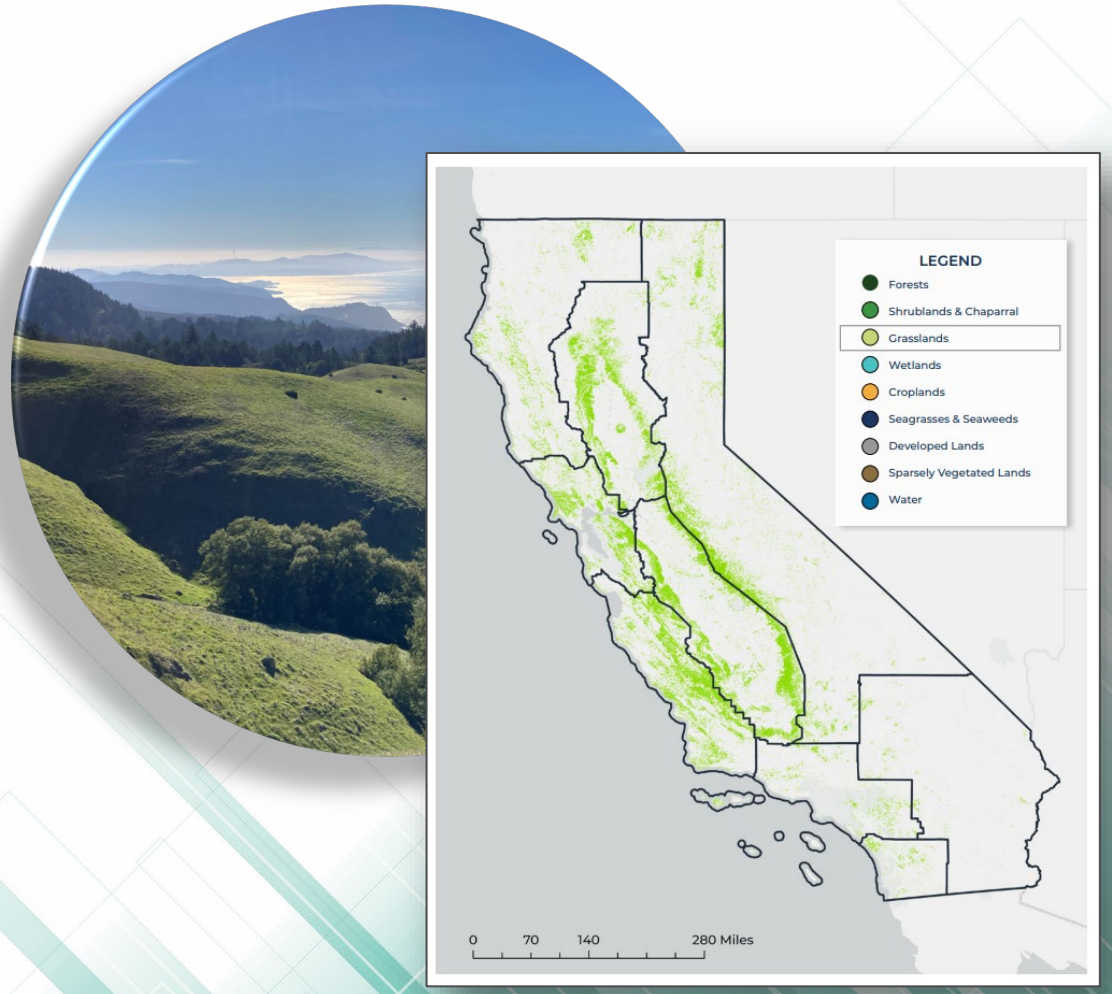
Natural and Working Lands Carbon Inventory 2025 Update Agricultural Lands

February 7, 2025

Dr. Tara Seely
Dr. Chelsea Carey

Agricultural Lands are Croplands and Grasslands



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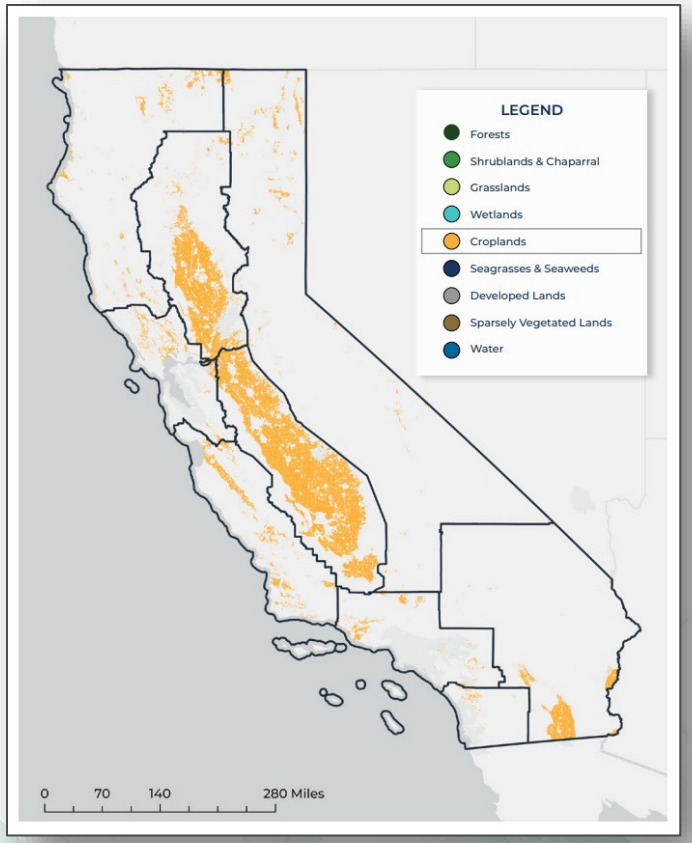
Croplands



NWL Climate Smart Strategy

Photo credits: Stockcake, © 2024 Future Forest Inc.; Adobe Stock; NRCS; © 2024 Blue Diamond Growers Almond Insights

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Grasslands

NWL Climate Smart Strategy

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Tracking California's Carbon Neutrality Goals

AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

Natural and Working Lands (NWL)

Other Carbon Removal

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Pools of Carbon in the Natural and Working Lands Carbon Inventory

GHG ± CO_2 - = Carbon Neutral

AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

Natural and Working Lands

Other Carbon Removal

Biomass Carbon **Soil Organic Carbon**

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Nature-based Solutions as Potential Carbon Drivers

AB 1757 Nature-Based Solution (NBS) in Developed Lands	2045 Target
Cropland Acreage targets	**(acres/year)**
Healthy soils practices	190K
Conservation	19.5K
Cropland Percentage targets	**(percentage)**
Convert systems from conventional to organic	20%
Grassland Acreage targets	**(acres/year)**
Restoration (inc. healthy soils practices)	5.1K
Conservation	33K
Beneficial fire	1.5M
Fuels reduction activities	1M
Oak woodland afforestation	52.9K

Biomass Carbon

Cropland: Annuals

Cropland: Orchards

Grasslands

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Biomass Carbon: Annual Croplands

- Biomass assumed to be ephemeral
- Crop residues incorporated into soil modeling

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Photos: Adobe Stock; Britannica

Biomass Carbon: Orchards

- NWL Inventory emphasizes woody perennials
- Carbon stocks are persistent

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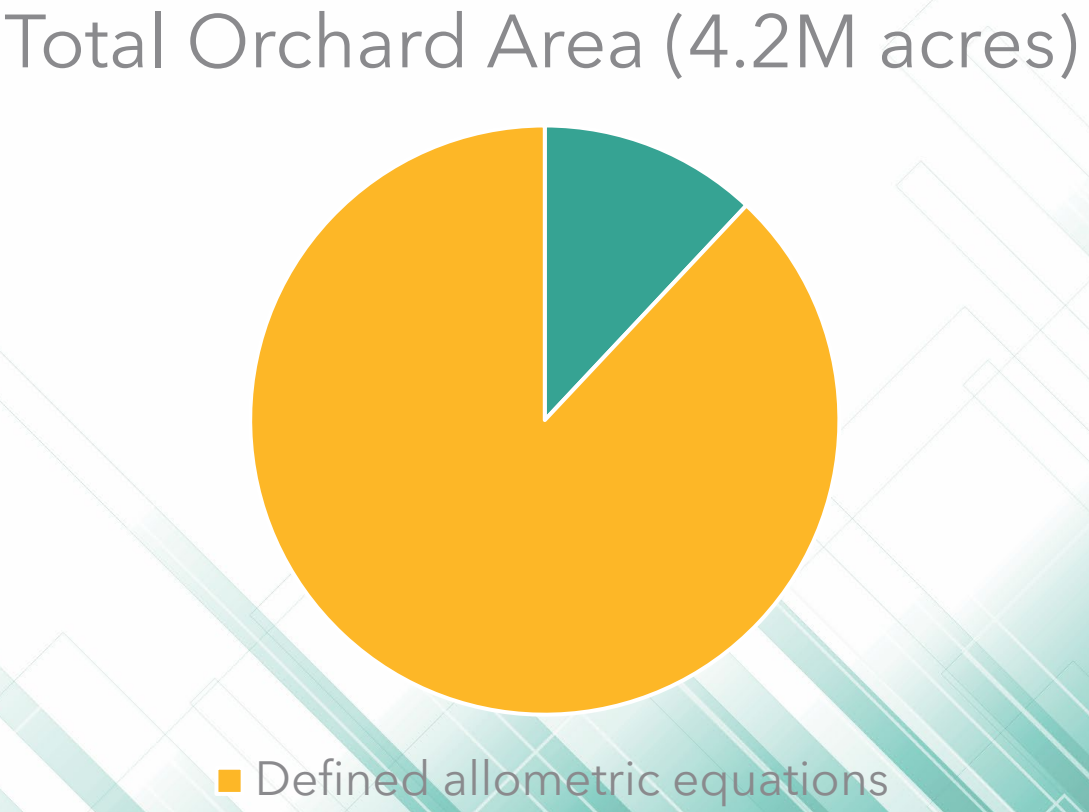
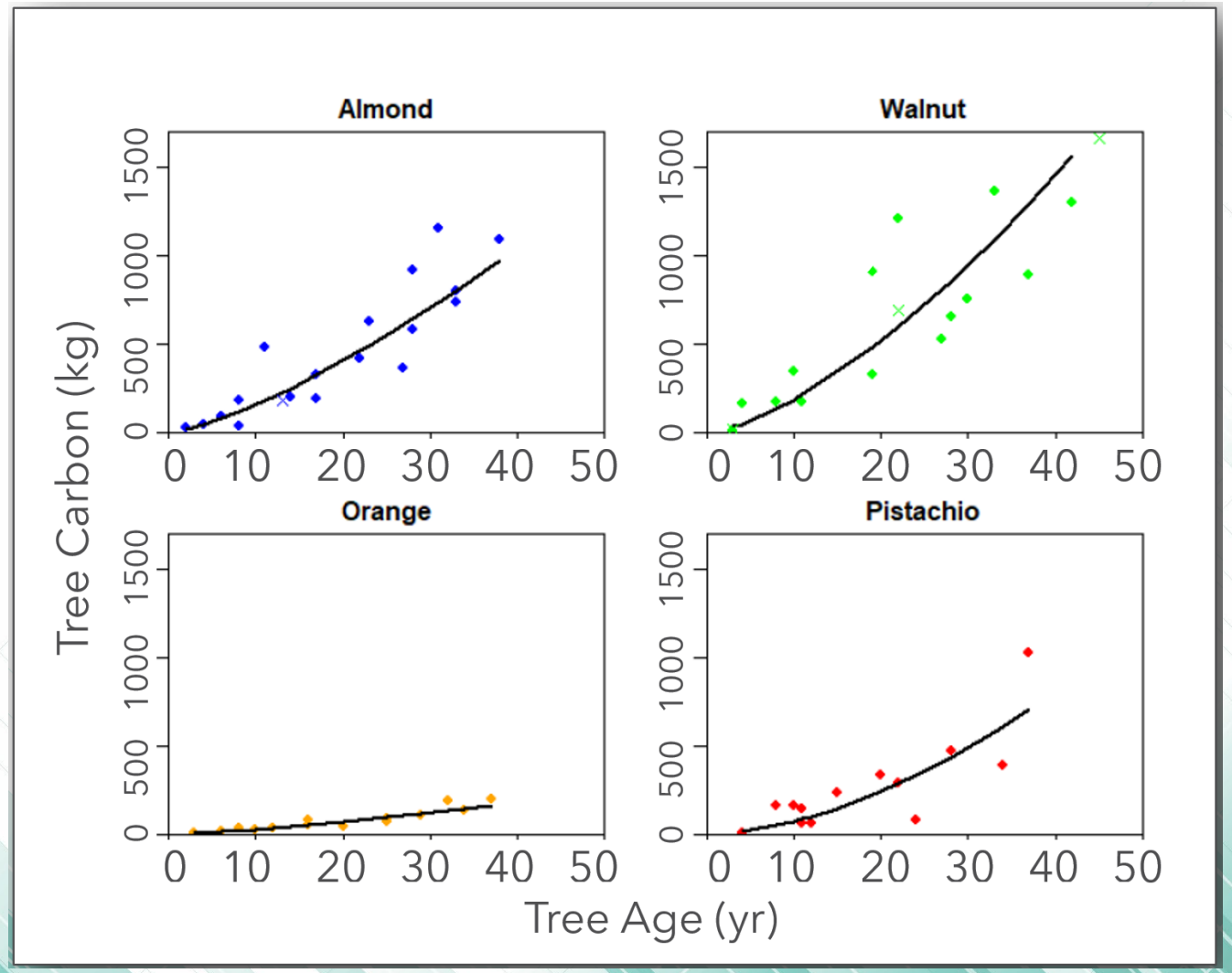
Orchards: Species with Defined Allometry

- Equations translate orchards to carbon
  - Defined for:
    - Almonds
    - Walnuts
    - Pistachios
    - Oranges
    - Vineyards



Orchards: How Allometry is Derived

1. Diameter and height derived from google street view and field measurements
2. Carbon derived from USDA allometric formula
3. Tree density scales allometry to field-level



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Orchards:
Key New Feature - Map of Orchard Age

Crop type and date planted, data produced by Department of Water Resources

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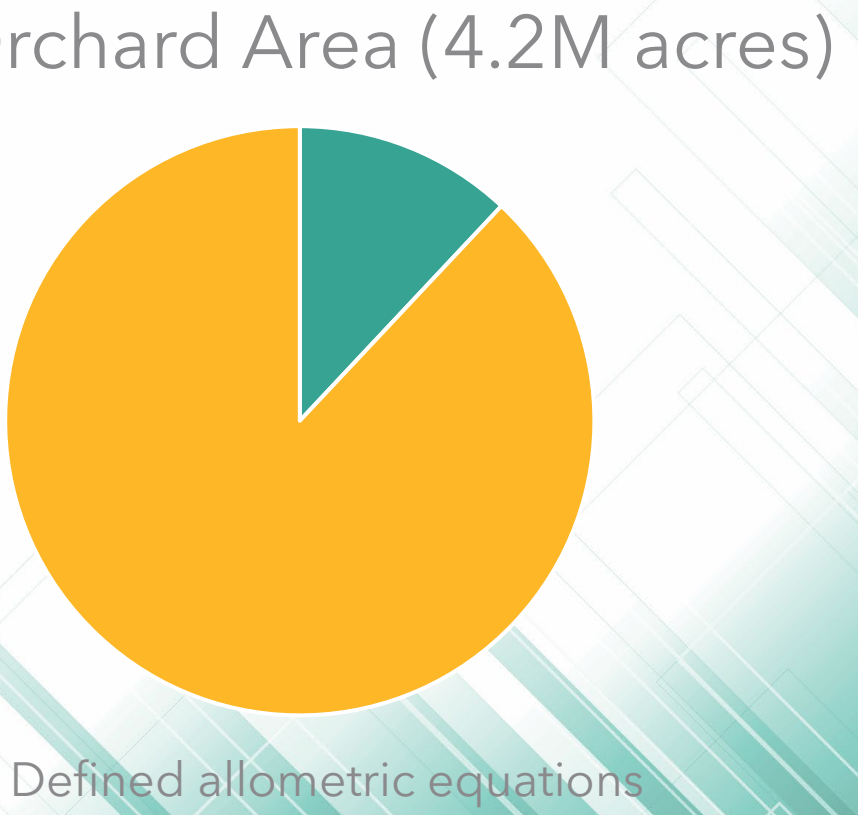
Orchards:
Key New Feature - Additional allometry

Undefined allometric species:

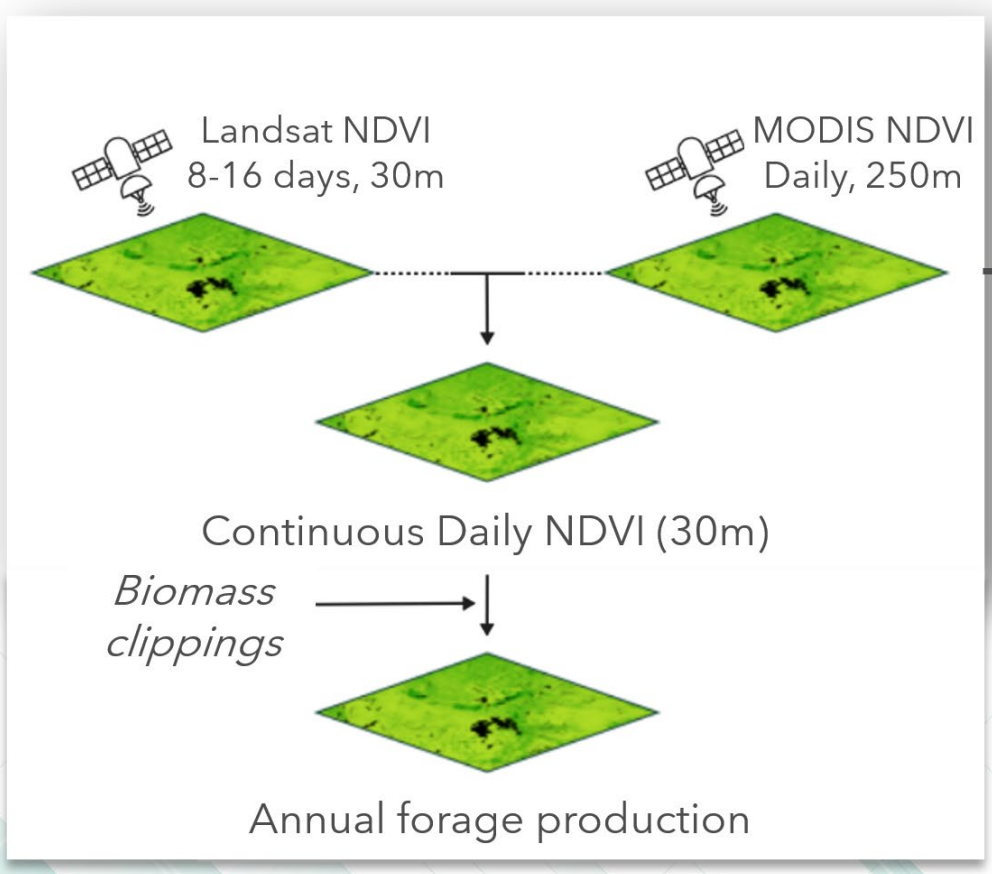
- Peaches and nectarines
- Plums, Prunes and Apricots
- Avocados
- Olives
- Cherries

Estimate allometry from:

- Wood density (Literature review)
- Tree height (Meta canopy height map)
- Tree spacing (NAIP imagery)



Biomass Carbon: Grasslands



Normalized Difference Vegetation Index (NDVI)

Liu et al. 2022

Key New Features:
Higher spatial resolution and accuracy

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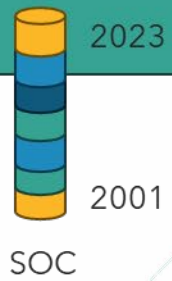
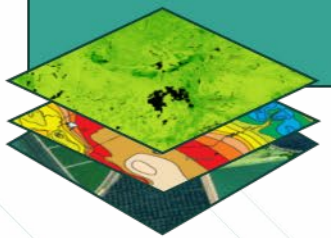
Soil Organic Carbon: A Unified Framework

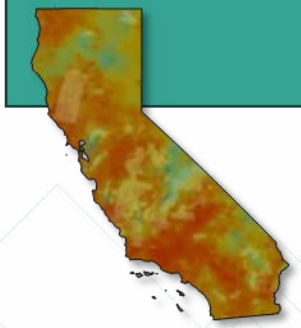
Generate a time-series training dataset (Empirical measurements + Process-based modeling)



Scale the time-series data wall-to-wall (Digital soil mapping with covariates)



Produce statewide maps of soil carbon over time



Key New Features:
Open-source, improved specificity and accuracy, includes management and disturbance effects

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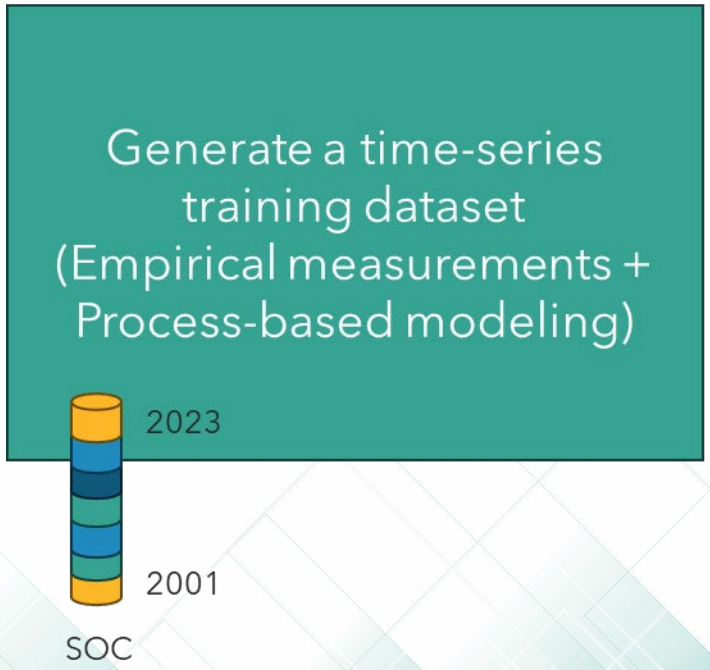
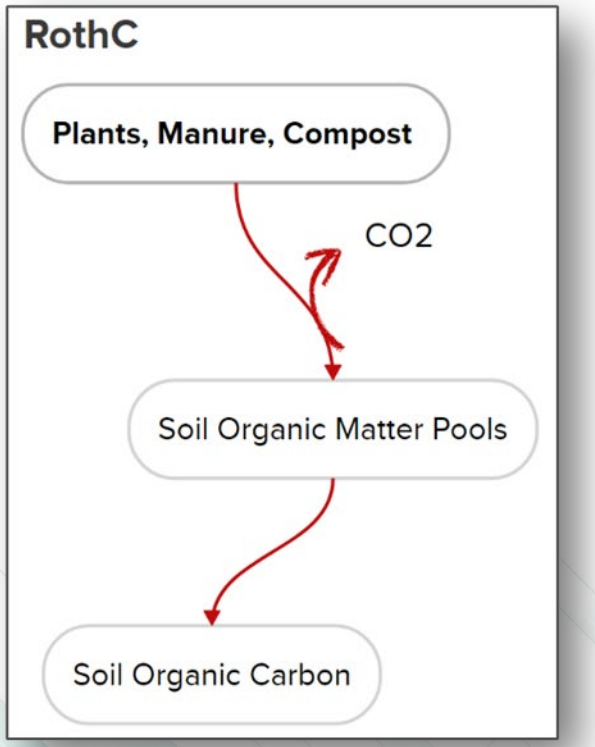
Soil Organic Carbon: Roth-C





- Open-source
- Simplified
- Well-vetted and widely used for grasslands and croplands
- Precedence in national GHG inventories
- Can simulate management

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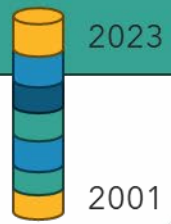
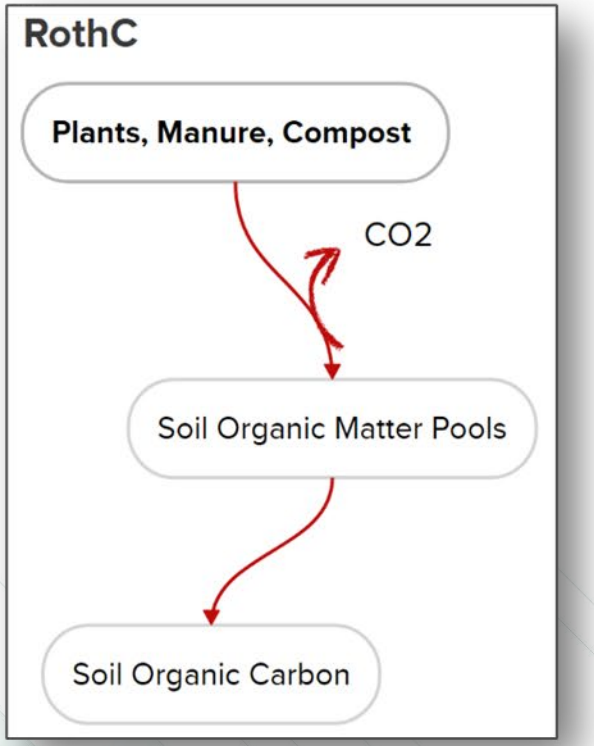
Soil Organic Carbon: Roth-C Management Integration

Generate a time-series training dataset (Empirical measurements + Process-based modeling)





Cover Cropping

Livestock grazing

Fire

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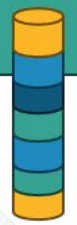
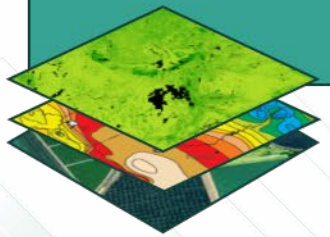
Photo credit: cover cropping, Shasta Valley RCD; Fire, Lenya Quinn-Davidson, Sierra Club Magazine.

Soil Organic Carbon: Digital Soil Mapping

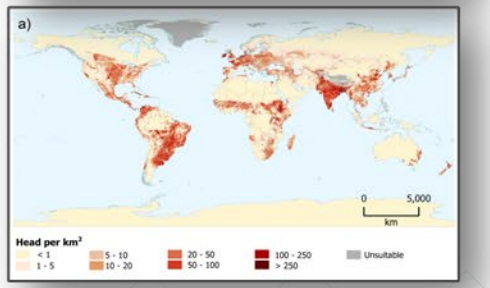
Generate a time-series training dataset (Empirical measurements + Process-based modeling)



Scale the time-series data wall-to-wall (Digital soil mapping with covariates)



Cover Cropping



Livestock grazing

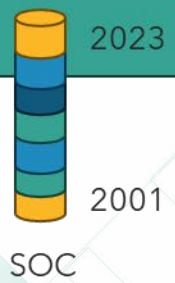
Fire

CARB

Photo credit: cover cropping, DWR LandIQ; grazing, Gridded Livestock of the World Database; fire, CalFIRE Historical Wildland Fire Perimeters

Soil Organic Carbon:
A Unified Framework Revisited

Generate a time-series training dataset (Empirical measurements + Process-based modeling)



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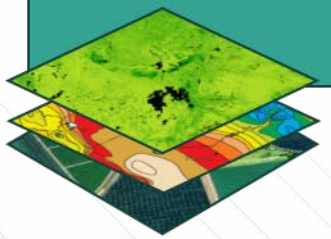
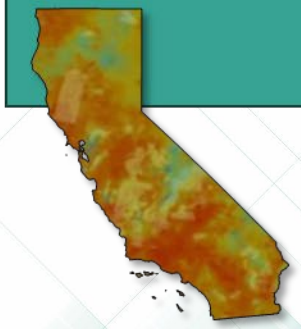


Produce statewide maps of soil carbon over time



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Data Needs & Acquisition

- We need calibration sites and information on implementation statewide
  - e.g., compost application, tillage, whole orchard recycling, range seeding, grazing system, etc.
- Data acquisition:
  - Requesting forage biomass, soil organic carbon, and management data
  - Scientists, extension specialists, private landowners, nonprofits
  - Ongoing

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Going Forward

- Seeking **carbon datasets** or **field sites** to help with calibration
- Seeking records on **management practices**
- Public workshop in early February

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Forest and Shrubland

February 7th, 2025

Dr. Matthias Falk
Dr. Ryan Bart
Dr. Kyle Lunneberg

Introduction

- CARB is responsible for California's forest and shrublands Carbon Inventory
- CARB publishes an SB901 report every 5 years
- "Carbon stocks" are a static measurement of stored carbon
- "GHG emissions" are an active release of carbon into the atmosphere.
- The carbon inventory assess carbon stock and stock-change over multiyear time scales.
- Additional steps are needed to quantify fire GHG emissions
- This presentation includes proposed new methods for NWL Carbon Inventories for Forest and Shrublands

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Tracking California's Carbon Neutrality Goals

AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

Natural and Working Lands

Other Carbon Removal

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Today's presentations in this section

Landfire-C	– Dr. Matthias Falk
Forest Inventory Ensemble	– Dr. Ryan Bart
Shrubland Inventory	– Dr. Kyle Lunneberg

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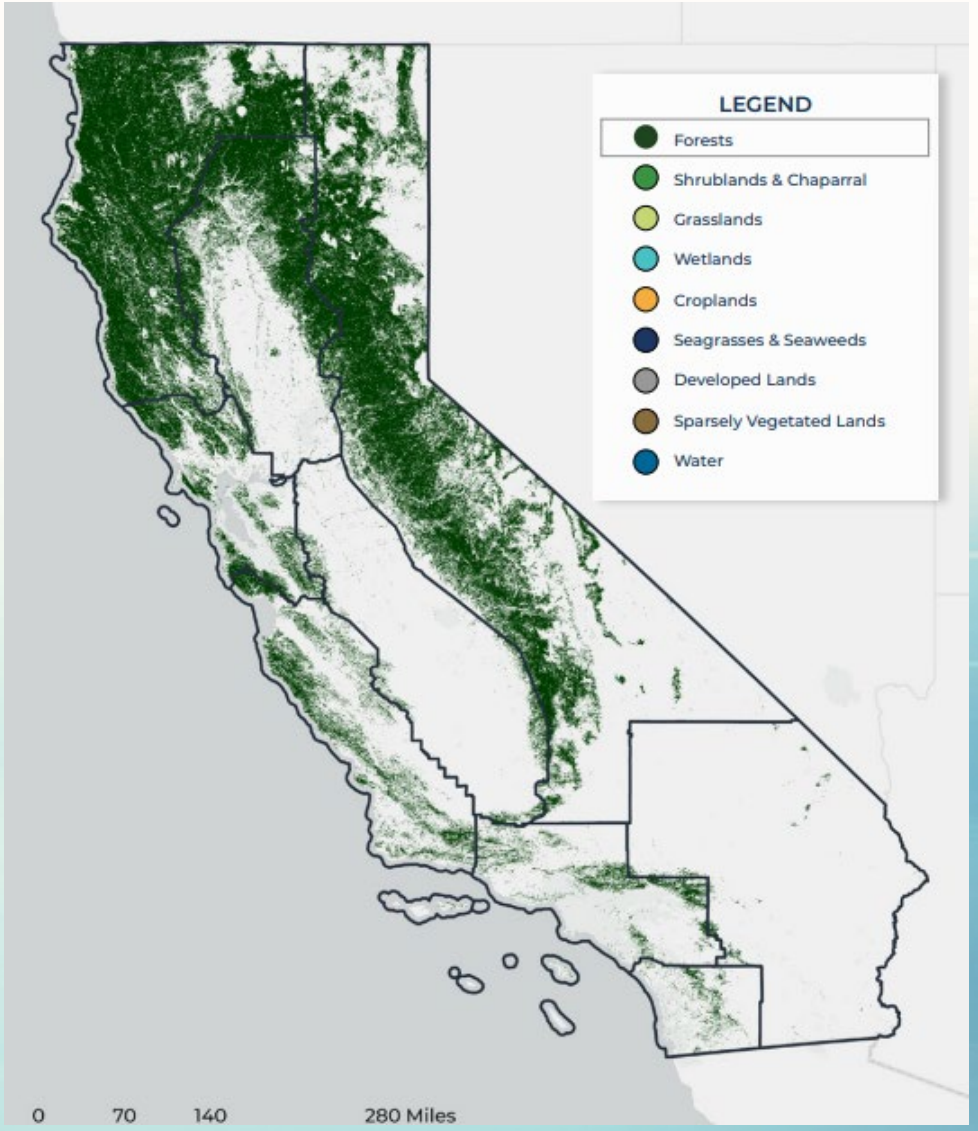
Forests

- Within natural and working lands, forests are the second-largest vegetation category by area
- Forests comprise 27% of the state's area
- Forests are defined as locations with greater than 10% canopy cover.
- Primary Drivers of Change:
  - Disturbance (Wildfire, Pathogens, Drought)
  - Type Conversion
  - Management (Fuels treatments and restoration)
  - Climate



Forests in California – Depicts the LANDFIRE-derived areas classified as forests within California. (Natural and Working Lands Climate Smart Strategy)

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Nature Based Solutions in Forests

AB 1757 Nature-Based Solution (NBS) in Forests	2045 Target
Wildfire Risk Reduction (Acreage targets)	**(acres/year)**
Beneficial Fire	1.5M
Other fuel reduction (thinning, mechanical treatment, etc.)	1 M
Forest Health and Resilience (Acreage targets)	**(acres/year)**
Afforestation (adding trees)	52.9K
Conservation	55.1K
Restoration	322.1K
Working Forest Conservation	165.2K
Percentage targets	**(percentage)**
Low to moderate severity fires as percentage of all wildfires	90%
Decrease the rate of illegal conversion and forest degradation	90%

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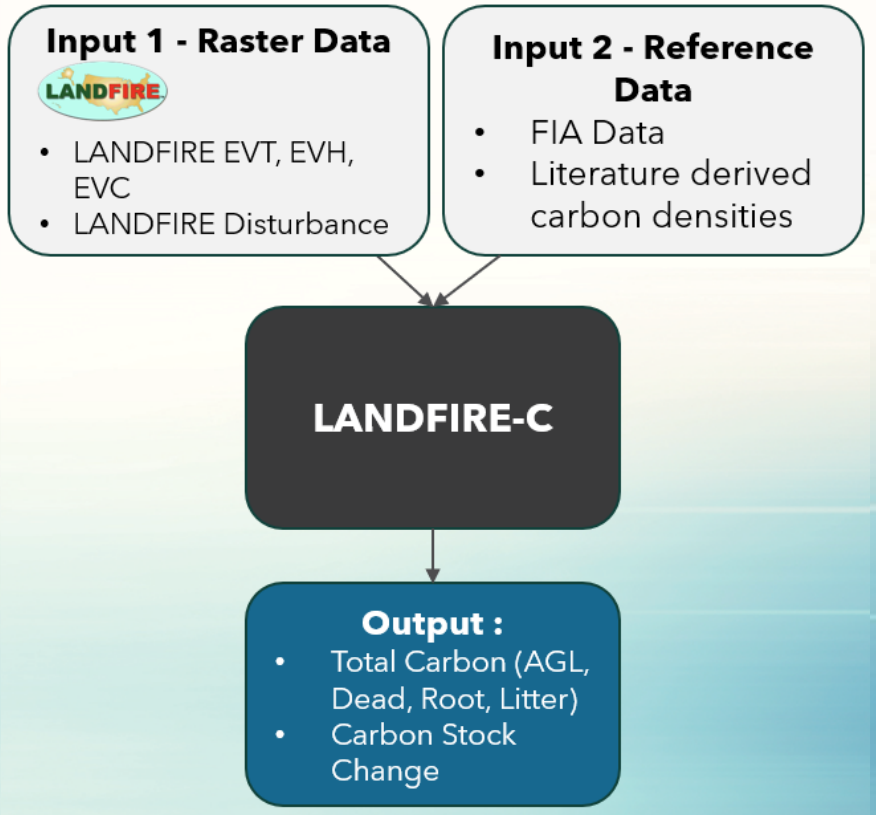
LANDFIRE-C

- LANDFIRE-C is a carbon accounting framework based on
  - Landfire (landfire.gov) land cover/disturbance change data
  - USFS Forest Inventory Analysis (FIA) plot data and literature biomass densities
- LANDFIRE-C was developed for CARB by Battles et al. (2013), and refined by Gonzales et al. (2015)

Current Methodology

LANDFIRE-C Inputs
- LANDFIRE EVT - vegetation type
- LANDFIRE EVC - canopy cover
- LANDFIRE EVH – height
- LANDFIRE Disturbance

LANDFIRE-C Outputs
- Carbon by pool (calibrated using FIA)
- Carbon stock change for any inventory epoch



CARB

Current challenges

- Underlying vegetation type classification system frequently changes by adding vegetation types (splitting)
- Limited access to FIA plot data, limits update of carbon stock conversion functions and regional growth factors
- Remote Sensing does not reliably detect dead wood such as logs and snags on the landscape
    - Limitation of the state of the science, limiting detection of dead wood after fire
    - Can lead to overestimation of carbon stock loss on the landscape
- All remote sensing-based carbon maps suffer this post-fire limitation and overestimate the immediate impact of wildfire on carbon stocks

Proposed Updates to Landfire-C

- Regular updates to the model that converts Landfire inputs to carbon-stocks via lookup tables
- Enhance CARB's mapping effort of post-fire dead wood
- Incorporate new dead wood module into Landfire-C
- Leverage CARB's in-house fire modelling and expertise to better estimate combustion that occurs due to wildfire
- Incorporate better estimates of the post-fire carbon stocks on the landscape into Landfire-C
- Annualize the inventory: Allowing to track deadwood and other carbon pools that remain on the landscape by taking onto account decay rates and subsequent disturbances

Other Updates

- Migrate framework to a High-Performance Computing Cluster
- Change framework to rely solely on open-source code
- Use open-source geospatial data formats
- Use the previously presented unified soil carbon framework to estimate forest soil carbon
  - For forests, this approach will be modified to use MODIS NPP inputs to drive the soil carbon model RothC.

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Forest ensemble approach

Dr. Ryan Bart

Forest Carbon Ensemble

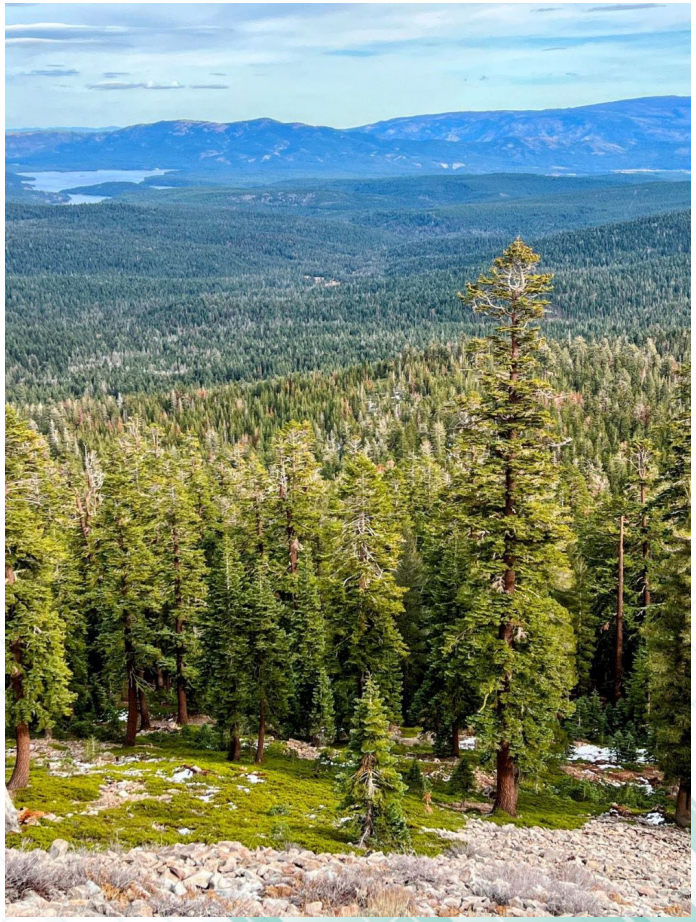
Multiple research groups have developed aboveground carbon datasets for California

Every method has different strengths and weaknesses.

Let's take advantage of all this science and work

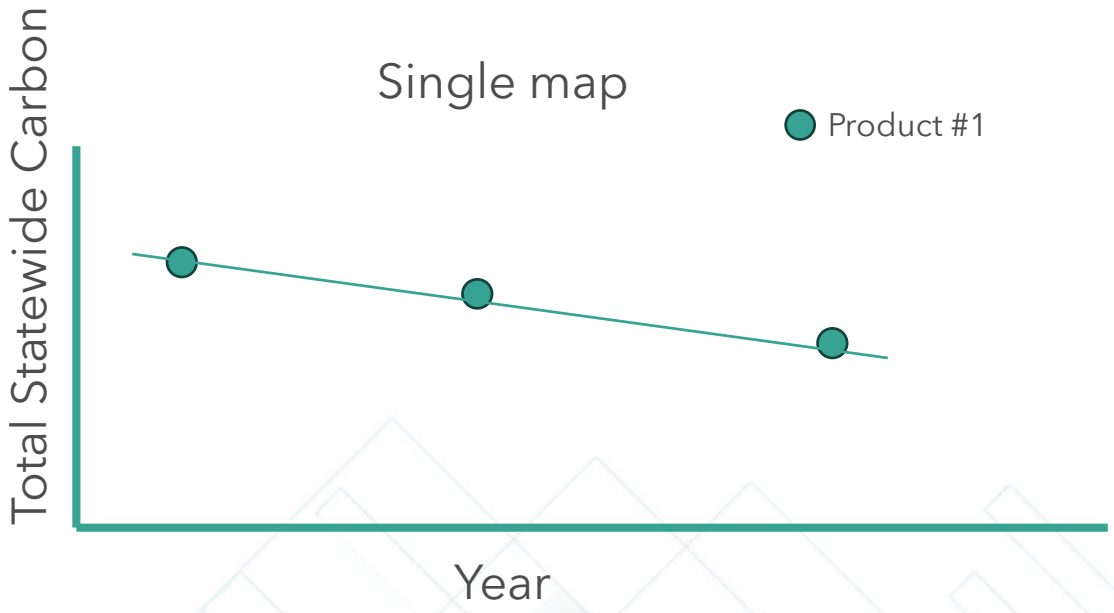
- Similarities to Coupled Model Intercomparison Project (CMIP)

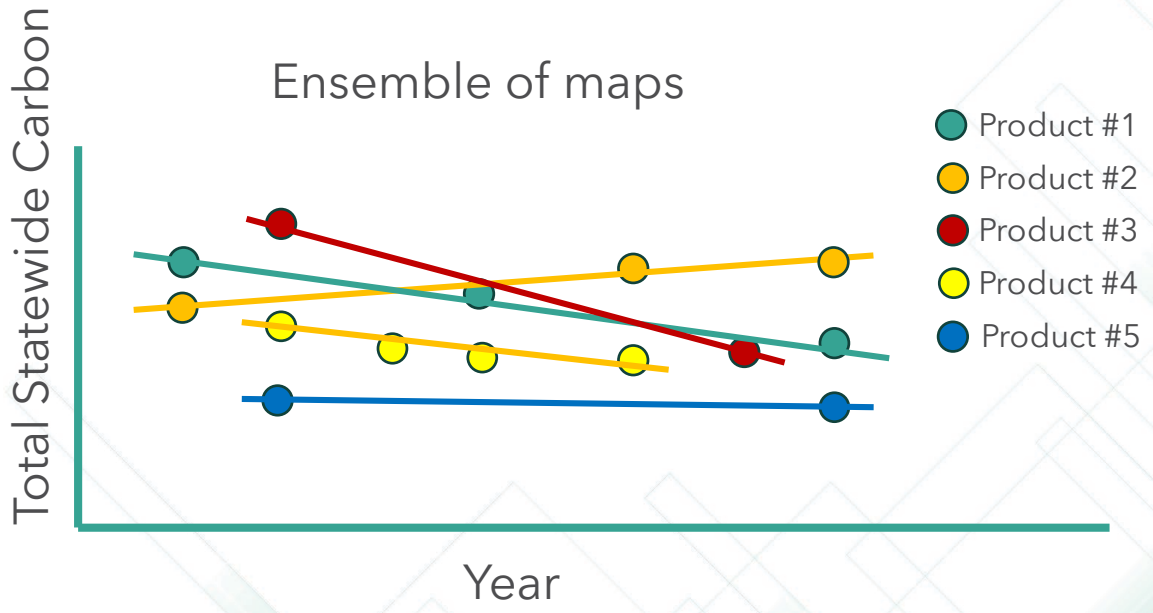
For the 2025 NWL inventory, CARB staff will develop an ensemble of carbon products, including LandFireC.



CARB

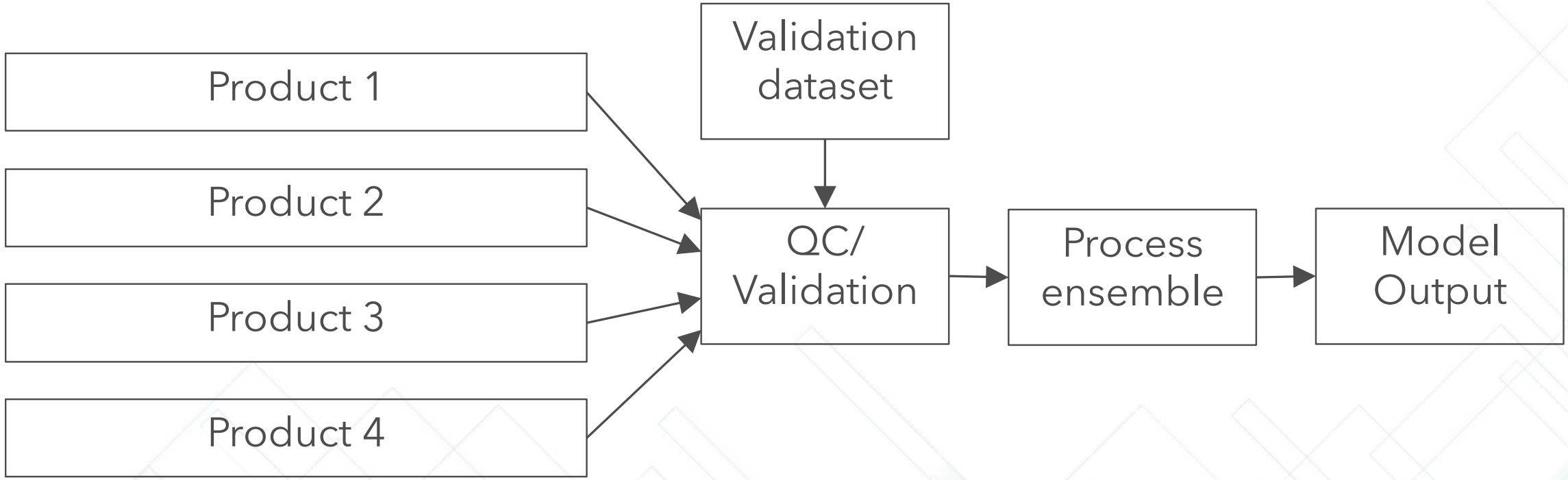
Ensemble Mapping





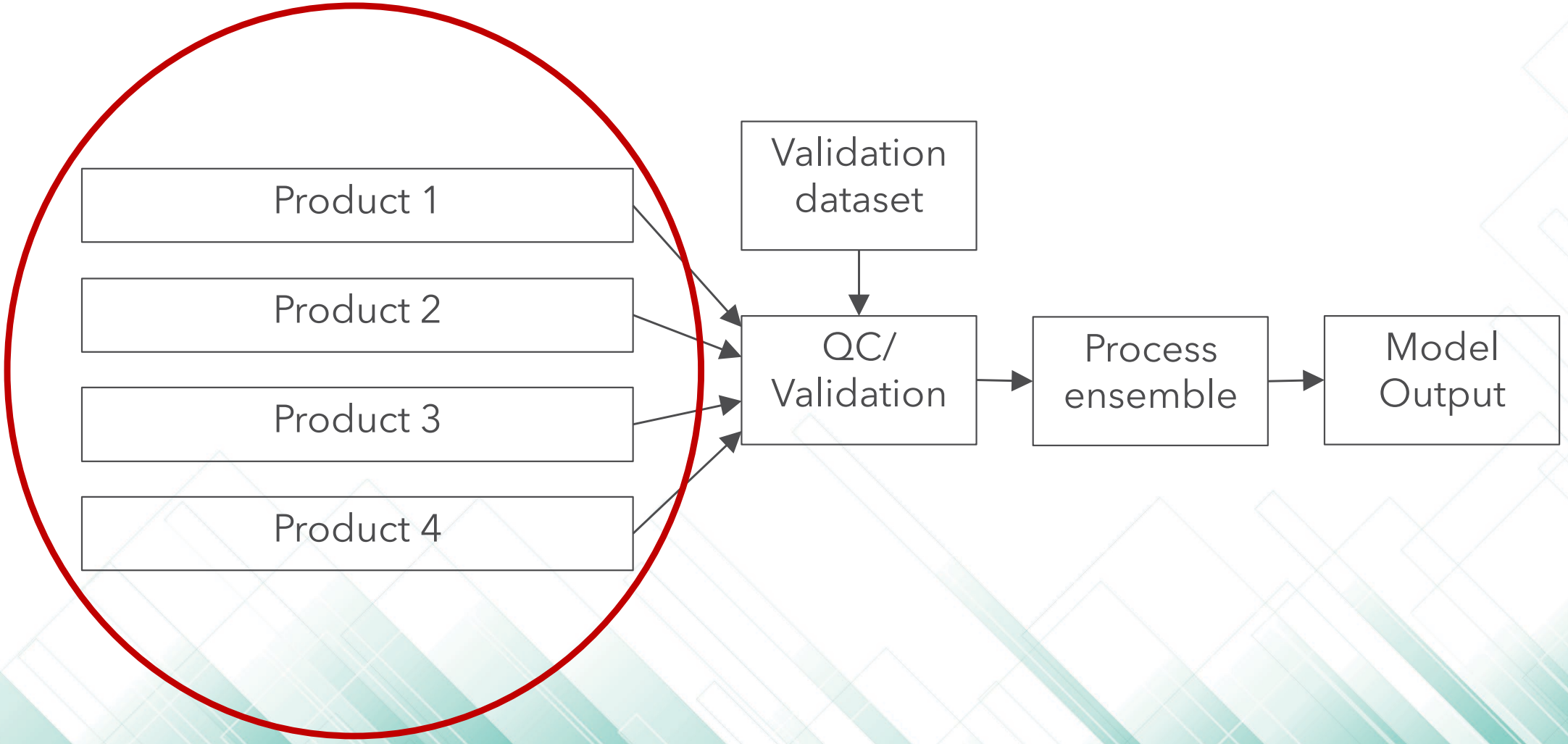
CARB

Ensemble Approach



CARB

Ensemble Approach - Products



CARB

Forest Carbon Products

All products must satisfy established criteria to be evaluated for ensemble inclusion.

- We will consider global, national, state, regional, and local products

Need common variable between products

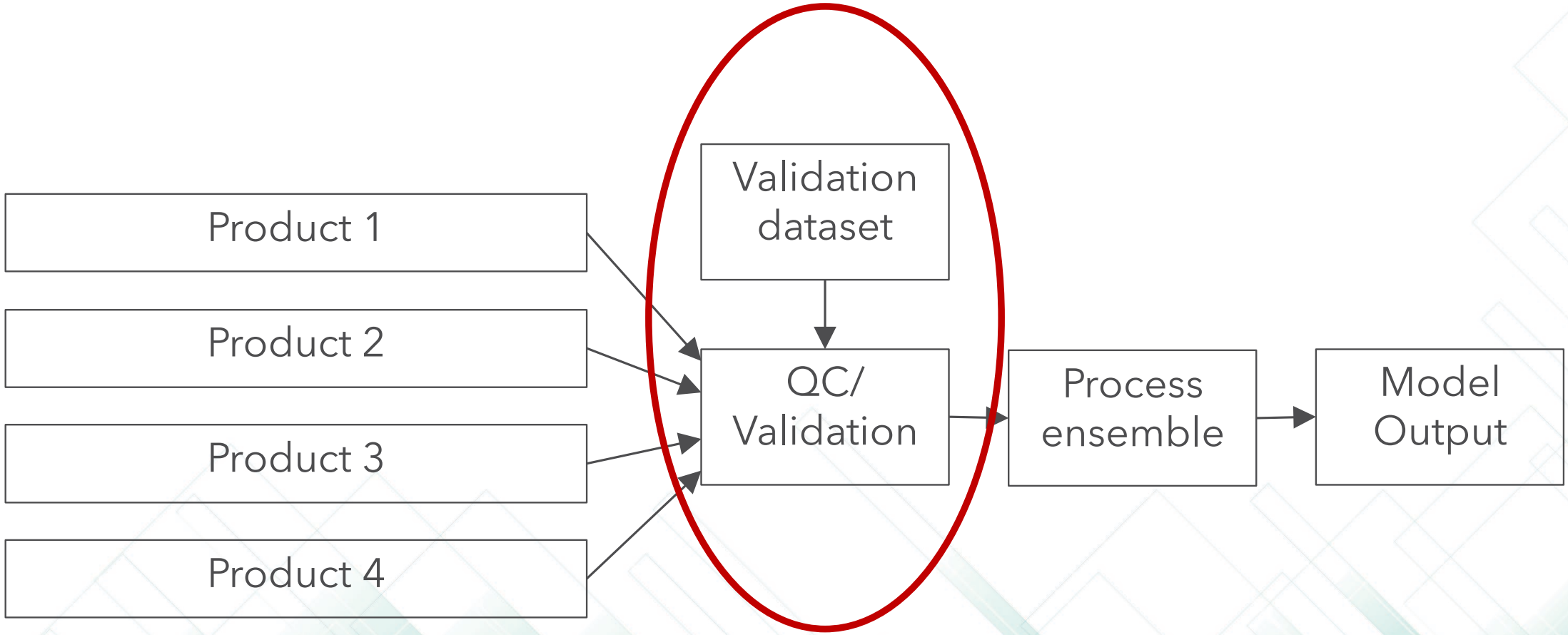
- Total Aboveground Live Carbon

Secondary variables

- Total Belowground Carbon
- Total Aboveground Dead Carbon
- Understory Carbon
- Litter carbon

CARB

Ensemble Approach - Validation



CARB

Forest Carbon Ensemble Validation

CARB is assembling an independent validation dataset of Total Aboveground Live Carbon

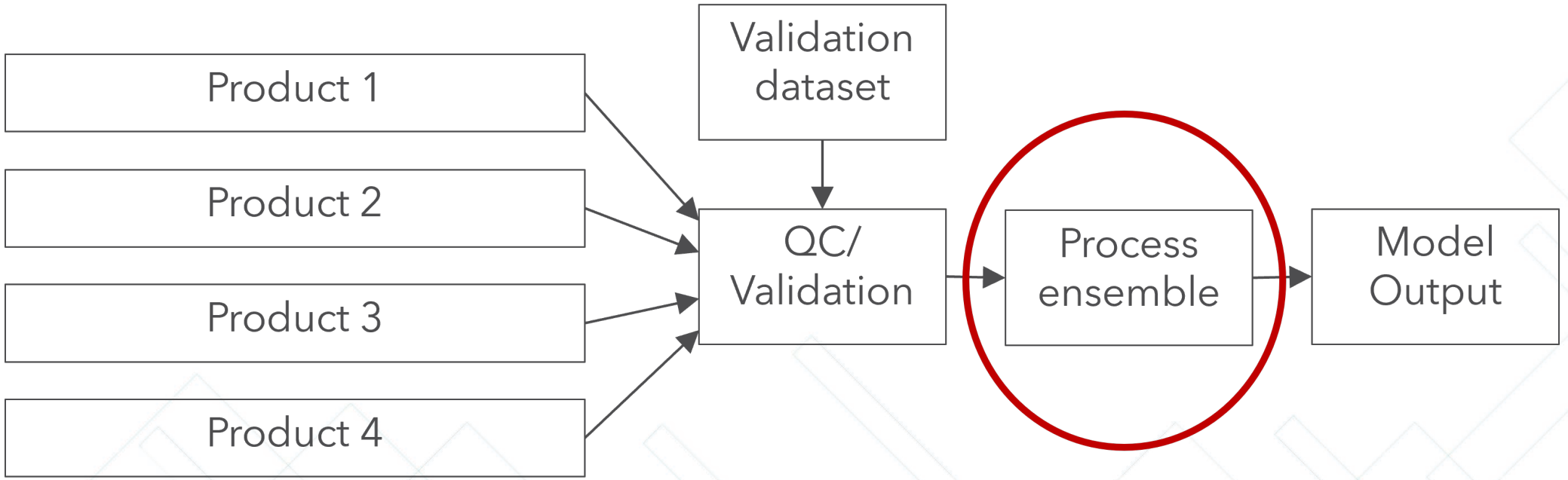
Validation procedure will allow us to weight carbon products for ensemble.

For regions of the state where validation is inadequate, an alternative approach will be used that identifies high-confidence pixels.

Product	Validation Measure	Ensemble Weight
#1	Bad	5%
#2	Good	45%
#3	Decent	35%
#4	Poor	15%

CARB

Ensemble Approach – Process



CARB

Forest Carbon Ensemble Process

- Process
  - For each pixel, we can generate a mean and confidence interval
  - The pixel level results can be aggregated to regional and/or state level
- Advantages of ensemble
  - Provides an estimate based on all available science, methods, and data
- Challenges
  - Ensemble statistical robustness due to limited number of carbon products available.
    - Products may have large biases.
    - Years with a single or no data point.
  - Temporal continuity of products (aka methodology changes).
- These challenges will be lessened with a validation dataset.

CARB

Forest Ensemble Summary

CARB will be introducing an ensemble approach of forest carbon products to inform the forest carbon inventory.

All carbon products will be validated against an independent dataset.

This ensemble will help bolster our work using LANDFIRE-C

We expect that this work will produce invaluable insights into forest carbon within California.

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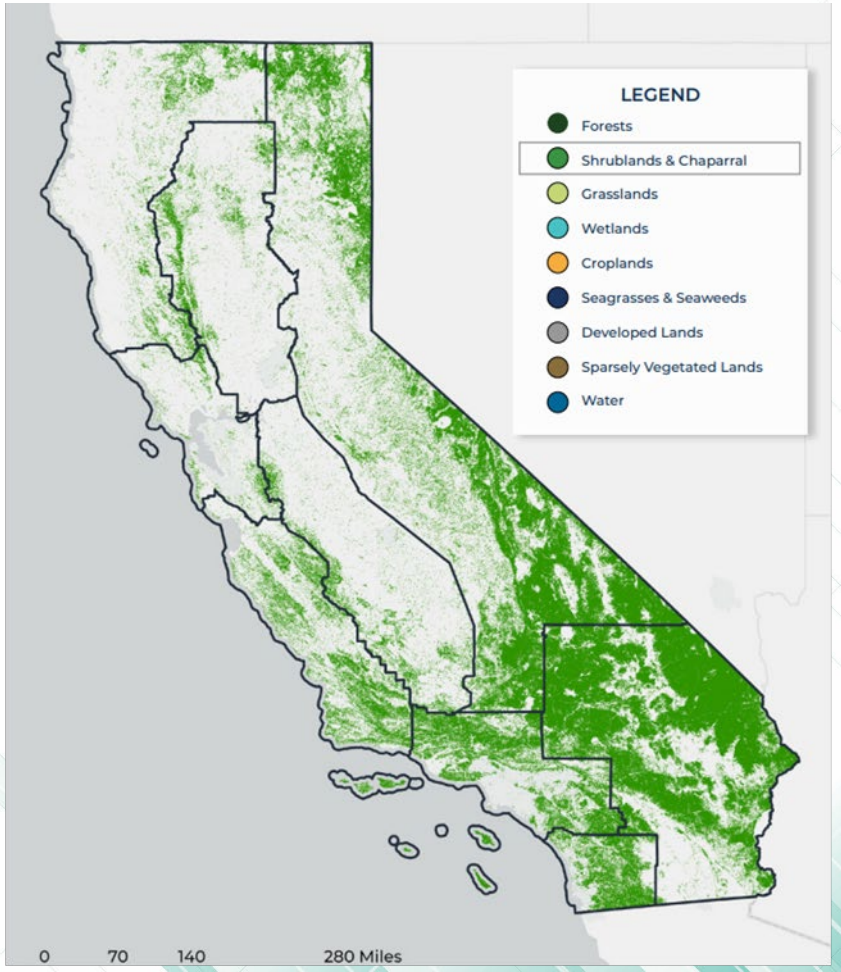
Natural and Working Lands Carbon Inventory 2025 Update Shrublands and Chaparral

Dr. Kyle Lunneberg

Shrublands and Chaparral

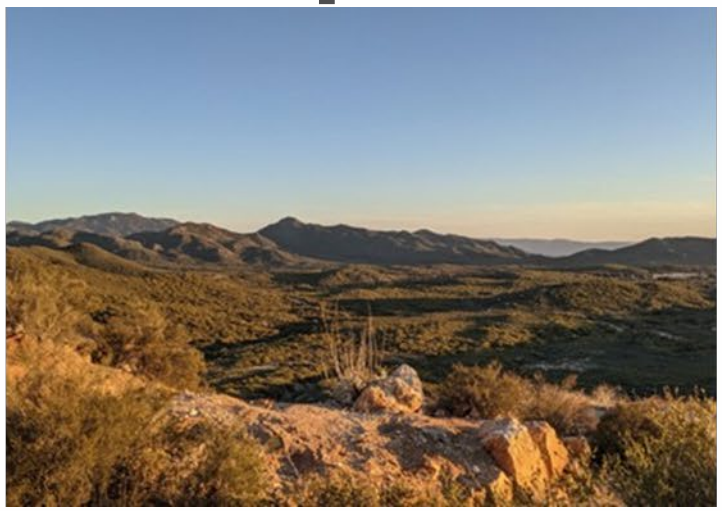
- Within natural and working lands, shrublands have the largest extent of any vegetation category, currently comprising 31% of the state
- Shrubland carbon stocks are reported under "forest" lands but have different underlying methodologies.
- Arid shrublands with greater than 10% canopy cover are included in this category
- Primary Drivers of Change:
  - Type Conversion (frequent wildfire and land use change)
  - Management
  - Climate



Shrublands in California – Depicts the LANDFIRE-derived areas classified as shrublands within California. (Natural and Working Lands Climate Smart Strategy)

CARB

Nature Based Solutions in Shrublands and Chaparral



AB 1757 Nature-Based Solution (NBS) in Shrublands

2045 Target

Acreage targets

(acres/year)

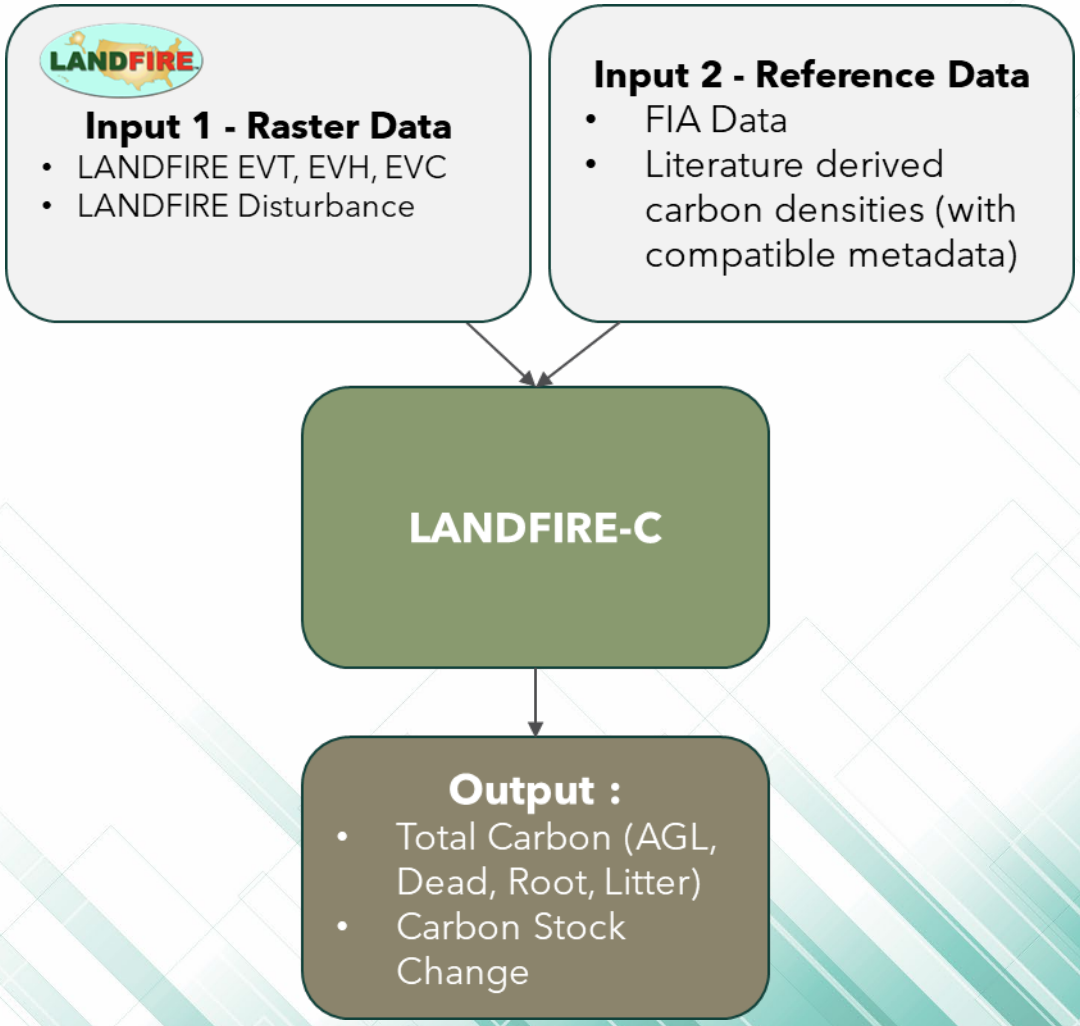
Conservation	104.6K
Restoration	45K

CARB

(Climate Smart Lands Strategy)

LANDFIRE-C

- The 2018 Inventory relied on literature values for shrublands (Gonzalez et al. 2015)
- These values can be continually updated as new literature values become available.
- It would be beneficial to expand the raster dataset to include other predictors commonly used for allometric equations.



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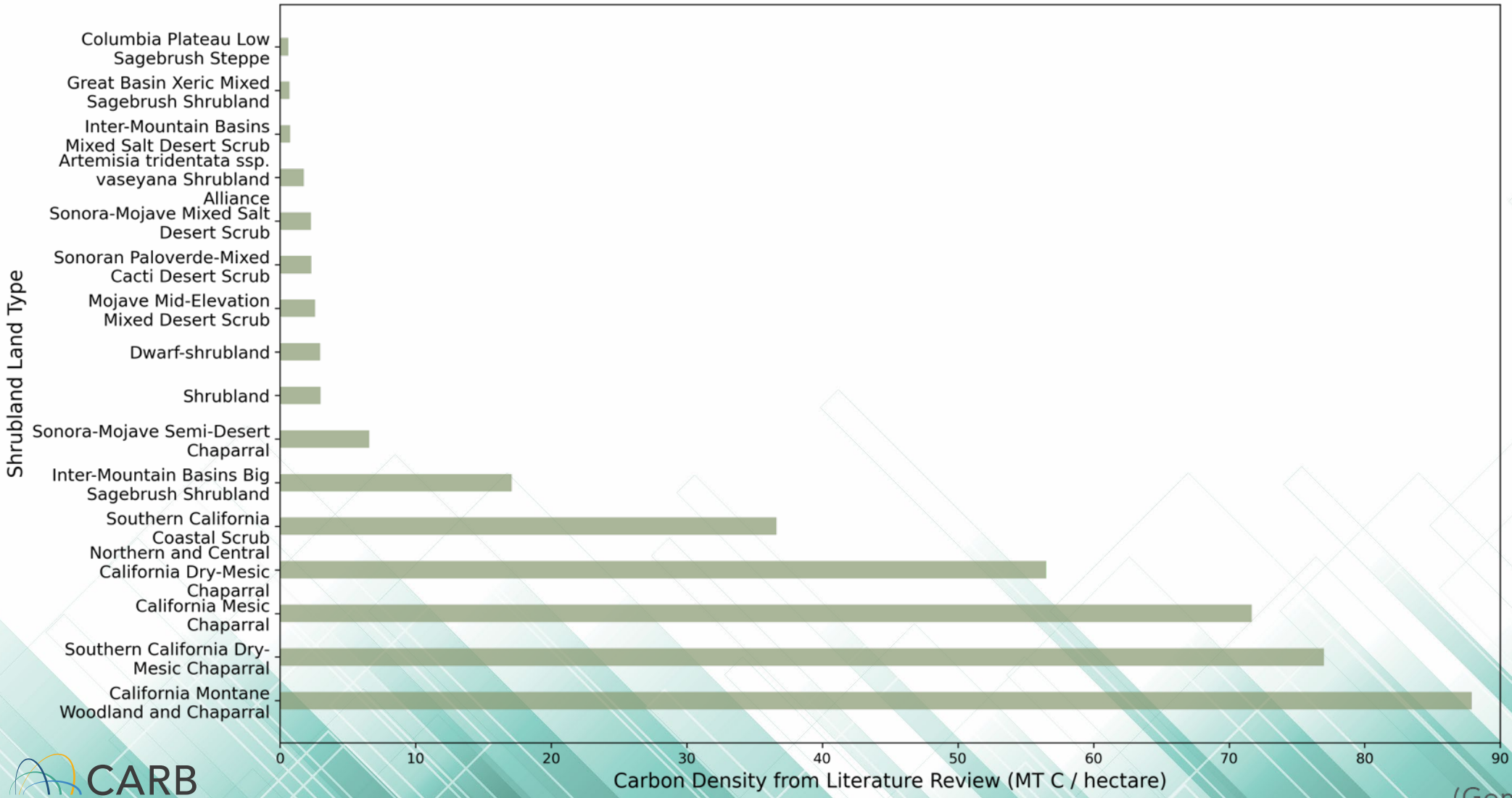
Literature Derived Carbon Densities



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(Gonzlaez et al. 2015)

National Agricultural Imagery Program (NAIP)

- The National Agriculture Imagery Program (NAIP) is a common source of high-resolution aerial imagery. It is produced every two years for California.

- Within this method, NAIP imagery will be used to:
  - Connect literature-derived allometric equations with LANDFIRE-C
  - Quantify the effects of disturbance and management events

CARB

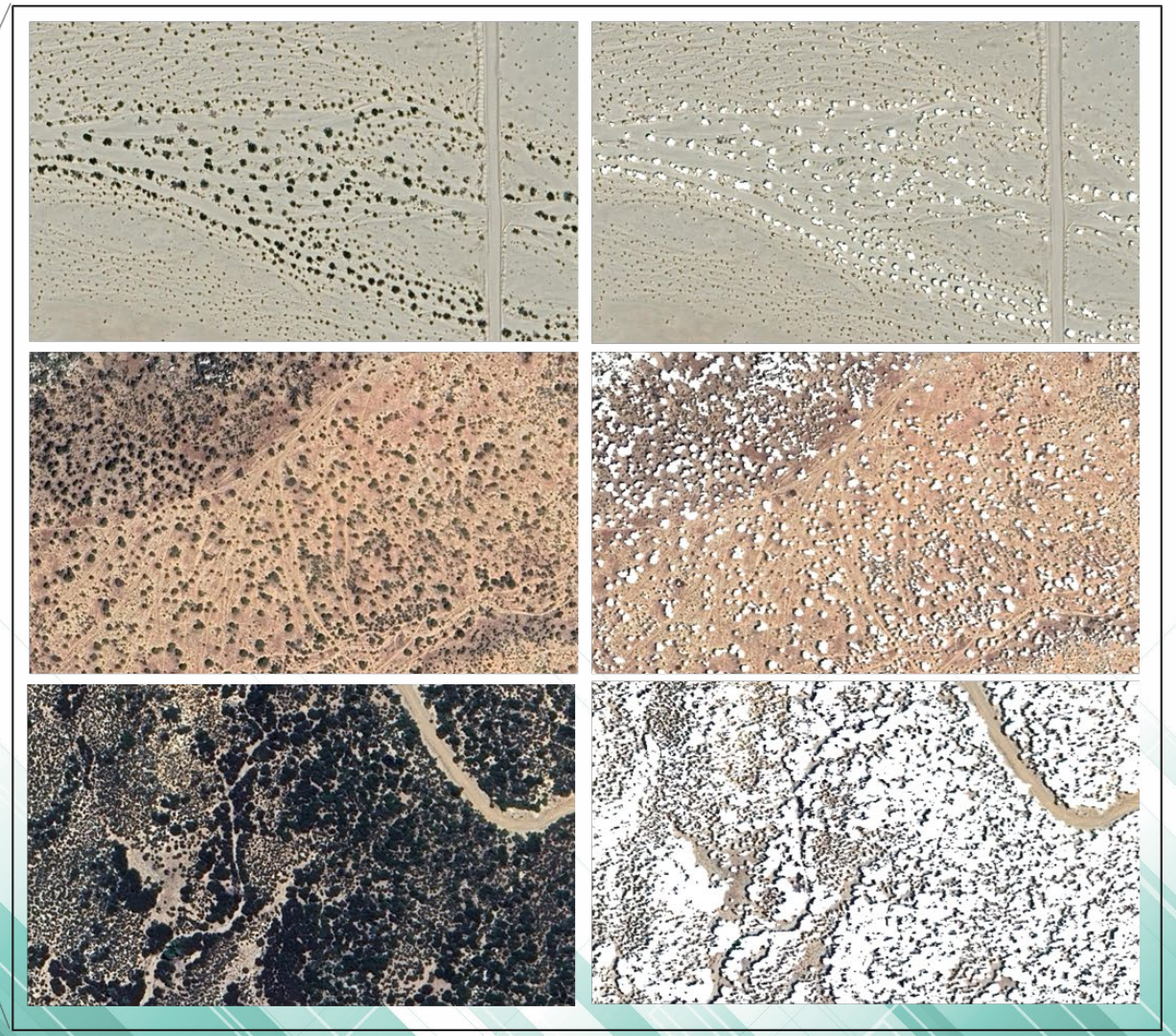
USDA

NAIP Analysis

Literature Biomass Carbon

NAIP Analysis

LANDFIRE-C



4.6%

19.5%

78.2%

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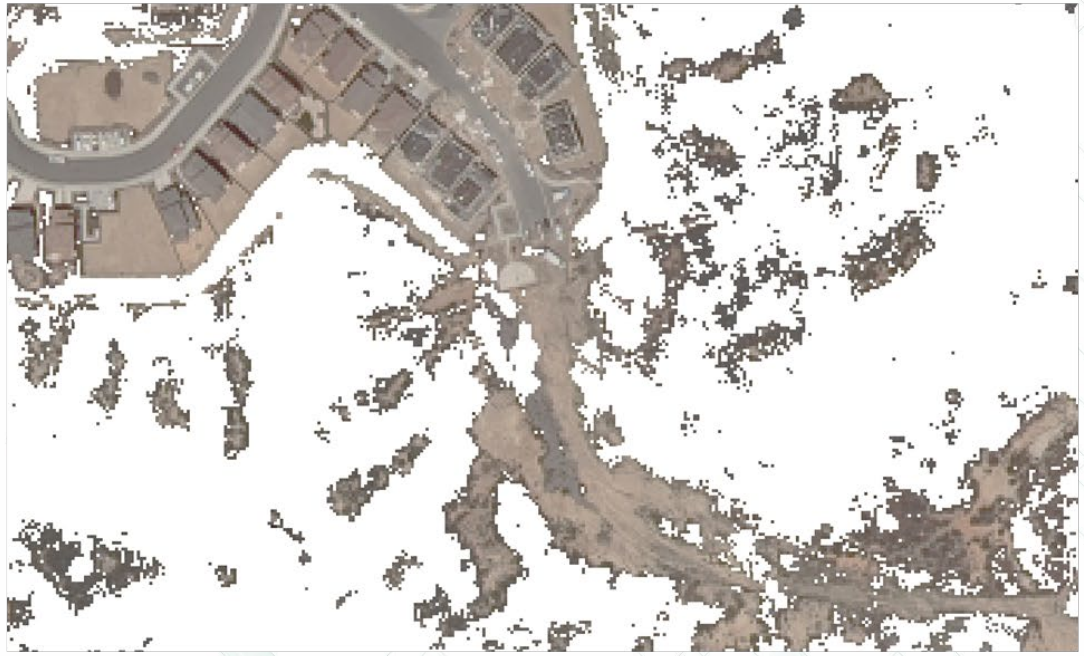
NAIP Example - 2010

NAIP Imagery

Remotely Sensed Canopy Cover



2001 — **2010** — 2024

NWL Inventory Time Period

CARB

NAIP Example - 2014

NAIP Imagery

Remotely Sensed Canopy Cover

2001 — 2014 — 2024

NWL Inventory Time Period

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NAIP Example - 2016

NAIP Imagery

Remotely Sensed Canopy Cover

2001 — 2016 — 2024

NWL Inventory Time Period

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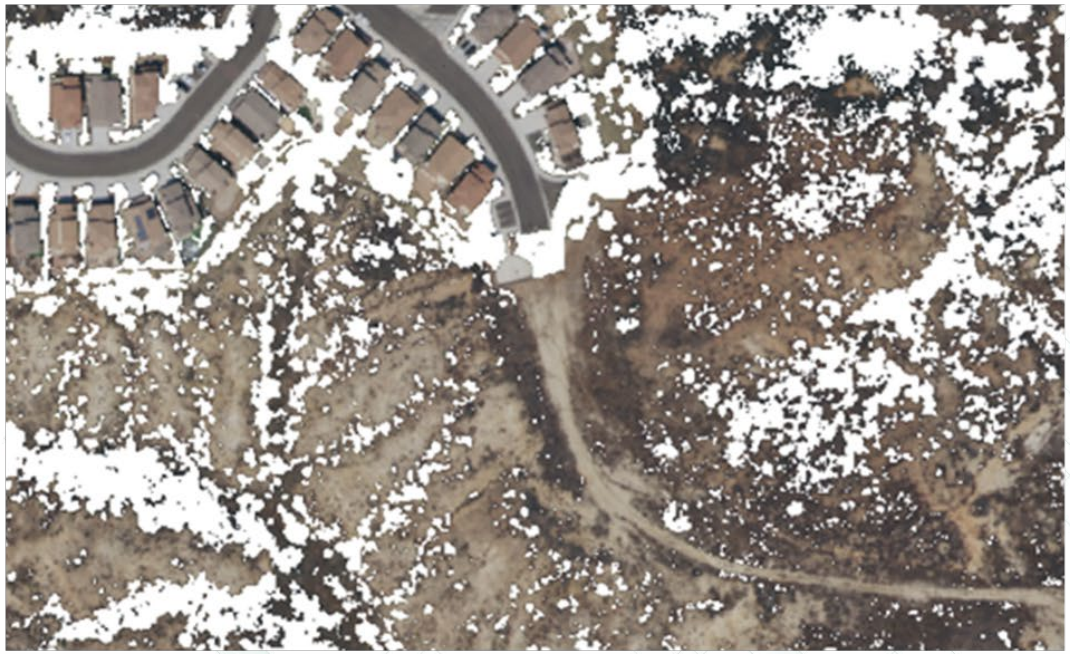
NAIP Example - 2018

NAIP Imagery

Remotely Sensed Canopy Cover



2001 — 2018 — 2024

NWL Inventory Time Period

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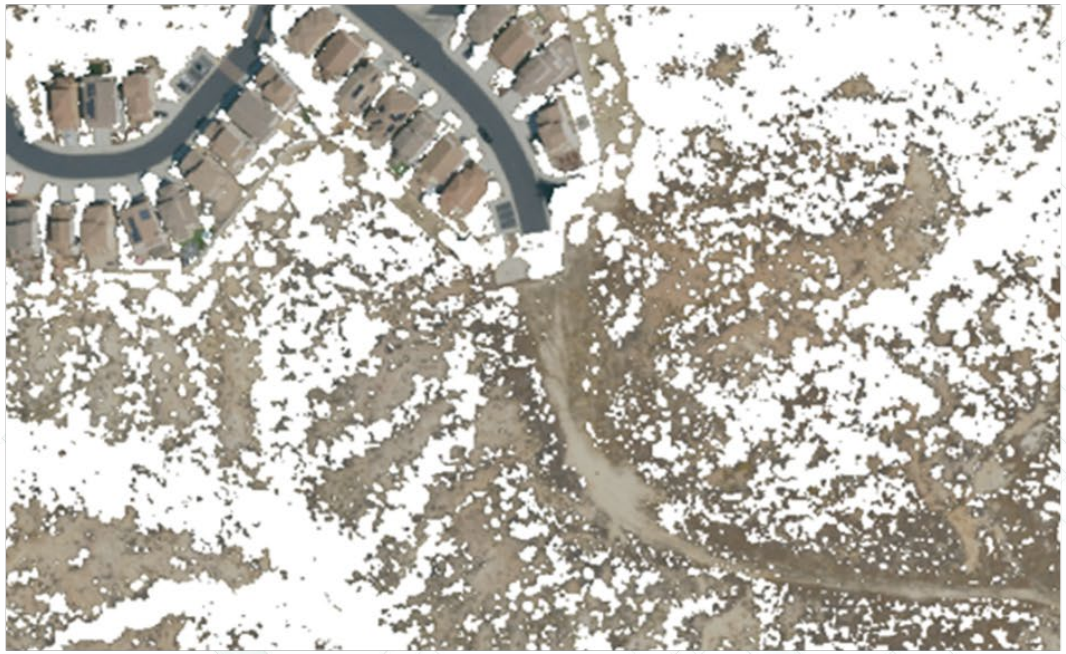
NAIP Example - 2020

NAIP Imagery

Remotely Sensed Canopy Cover



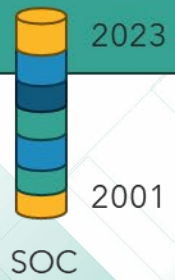
2001 🔥 2022 2024

NWL Inventory Time Period

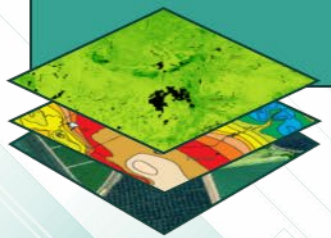
CARB

Soil Organic Carbon: A Unified Framework

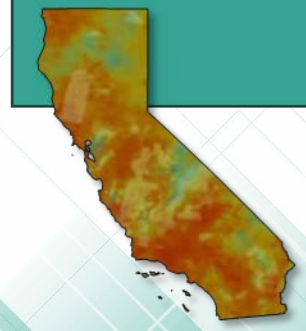
Generate a time-series training dataset (Empirical measurements + Process-based modeling)



Scale the time-series data wall-to-wall (Digital soil mapping with covariates)



Produce statewide maps of soil carbon over time



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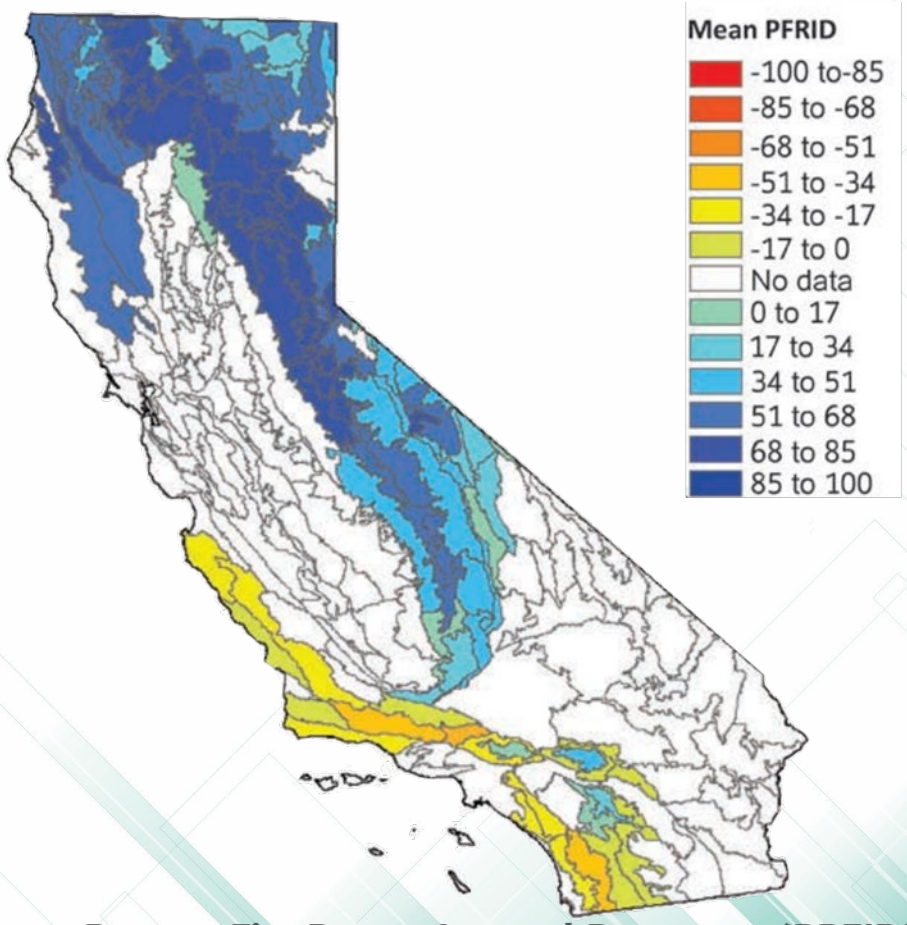
Frequent Wildfire

- Excessively frequent and recurring wildfire can result in type conversion to other ecosystems (such as annual grasslands), altering carbon stocks.

- When compared to estimated historic wildfire, current return intervals in Southern California shrublands are more frequent (Safford et al. 2014)



Percent Fire Return Interval Departure (PRFID): A negative score indicates wildfire frequency has increased when compared to historic baselines (Safford et al 2014)

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Summary

- Methodological updates will enhance carbon quantification by incorporating new biomass and soil carbon datasets

- Remote sensing of canopy cover will directly quantify the effects of management and disturbance, and provide additional information that can be connected to allometric equations

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AIR RESOURCES BOARD

Natural and Working Lands Carbon Inventory 2025 Update Harvested Wood Products (HWP)

February 7, 2025

Dr. Kelsey Brewer

CARB

Tracking California's Carbon Neutrality Goals

AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

Natural and Working Lands

Other Carbon Removal

CARB

Harvested Wood Product Types

Short-lived (temporary)

Biofuels

Bioenergy & heat

Medium-lived (semi-durable)

Pulp and paper products

Soil amendments

Long-lived (durable)

Lumber

Plywood and panels

CARB

Nature Based Solutions for Harvested Wood Products

AB 1757 Nature-Based Solutions (NBS)	2030 Target	2045 Target
Acreage targets	**(acres/year)**	**(acres/year)**
Fuel reduction activities (thinning, uneven-aged timber harvest, etc.)	700K	1M
Afforestation (adding trees)	52.9K	52.9K
Working forest conservation (extend harvest rotation, shift harvest intensity, etc.)	165.2K	165.2K
Reducing community wildfire risks (defensible space establishment)	11K	11K
Percentage targets	**(percentage)**	**(percentage)**
Decrease rate of illegal forest conversion and degradation	20%	90%
Treat priority roads that function as evacuation routes	50%	100%
Shift proportion of statewide high severity wildfire to low or moderate severity through fuel reduction activities	75%	90%

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Types of Wood Feedstocks

Thinning/logging residues

Saw wood

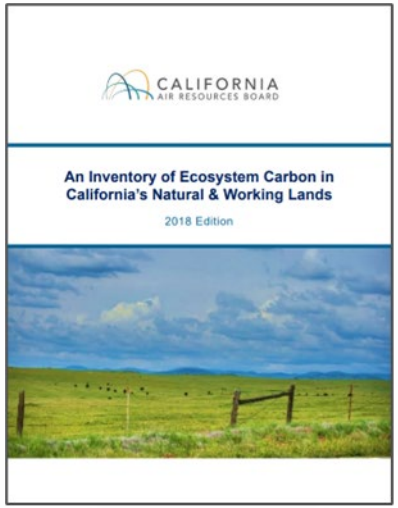
Recycled urban wood

Pulp wood

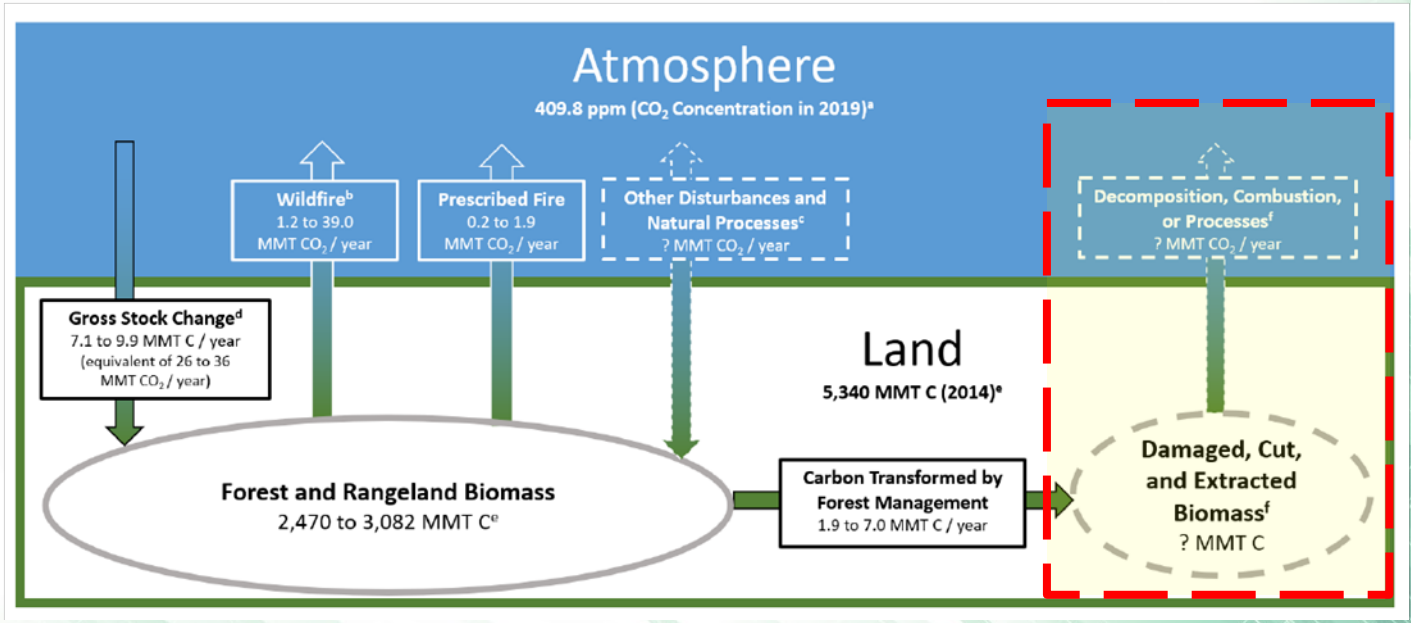
Snags (dead wood)

CARB

2018 NWL Carbon Inventory



Flows of carbon and CO_2 between the atmosphere and California's forests and other natural lands



From CARB SB 901 Report

CARB

Harvested Wood Products Carbon (HWP-C) Model

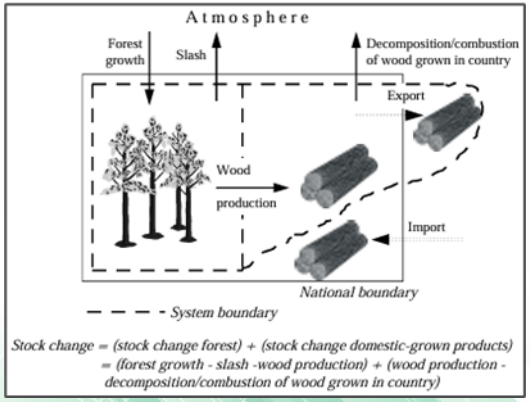
- Calculates cumulative carbon stocks and emissions to estimate carbon stored in HWP (such as lumber and paper) over time
- Tracks HWP carbon stocks from the moment a tree is harvested until the wood products eventually decay, are burned, or are disposed of in a landfill
- Originally developed by USFS for regional HWP carbon inventories (Stockmann et al., 2014)
- Later version developed (HWP-C vR 1.1.0) for California's specific context
  - Partnership between CAL FIRE, Oregon Department of Forestry, University of Montana, U.S. Forest Service, and Groom Analytics

CARB

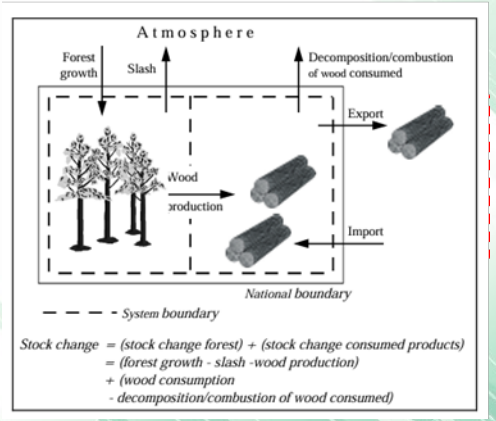
Current HWP-C vR 1.1.0 Model Boundaries

- Estimates the fate of carbon in all California produced HWP
- Does NOT track HWP imports and exports
- A large portion (perhaps the majority) of HWP in California are imported
- CARB is currently working on including imported HWP into the inventory, with the option to exclude exports

IPCC Production Approach



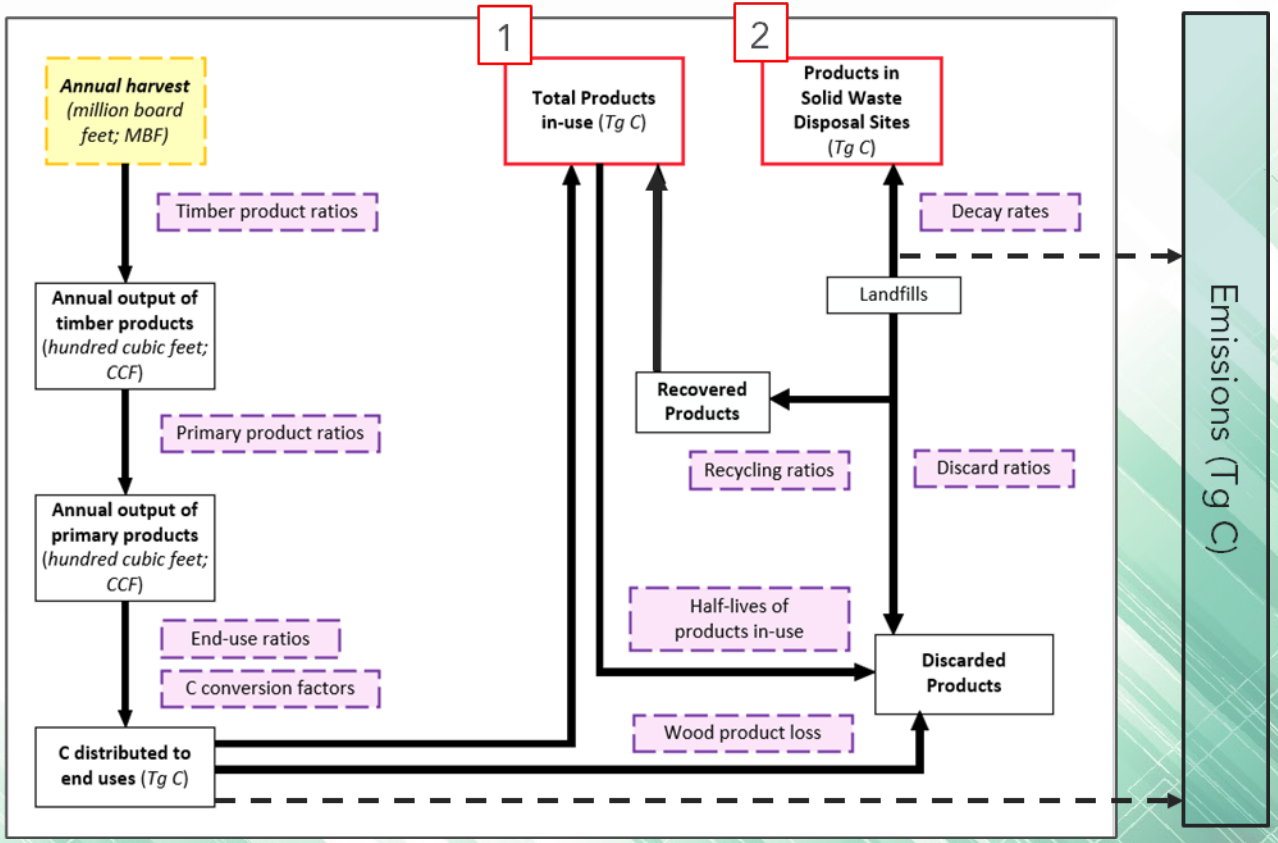
IPCC Stock-Change Approach



CARB

Source: Approaches for estimating the fate of C from forest harvesting and HWP (from IPCC)

Harvested Wood Products Carbon (HWP-C vR 1.1.0) Model



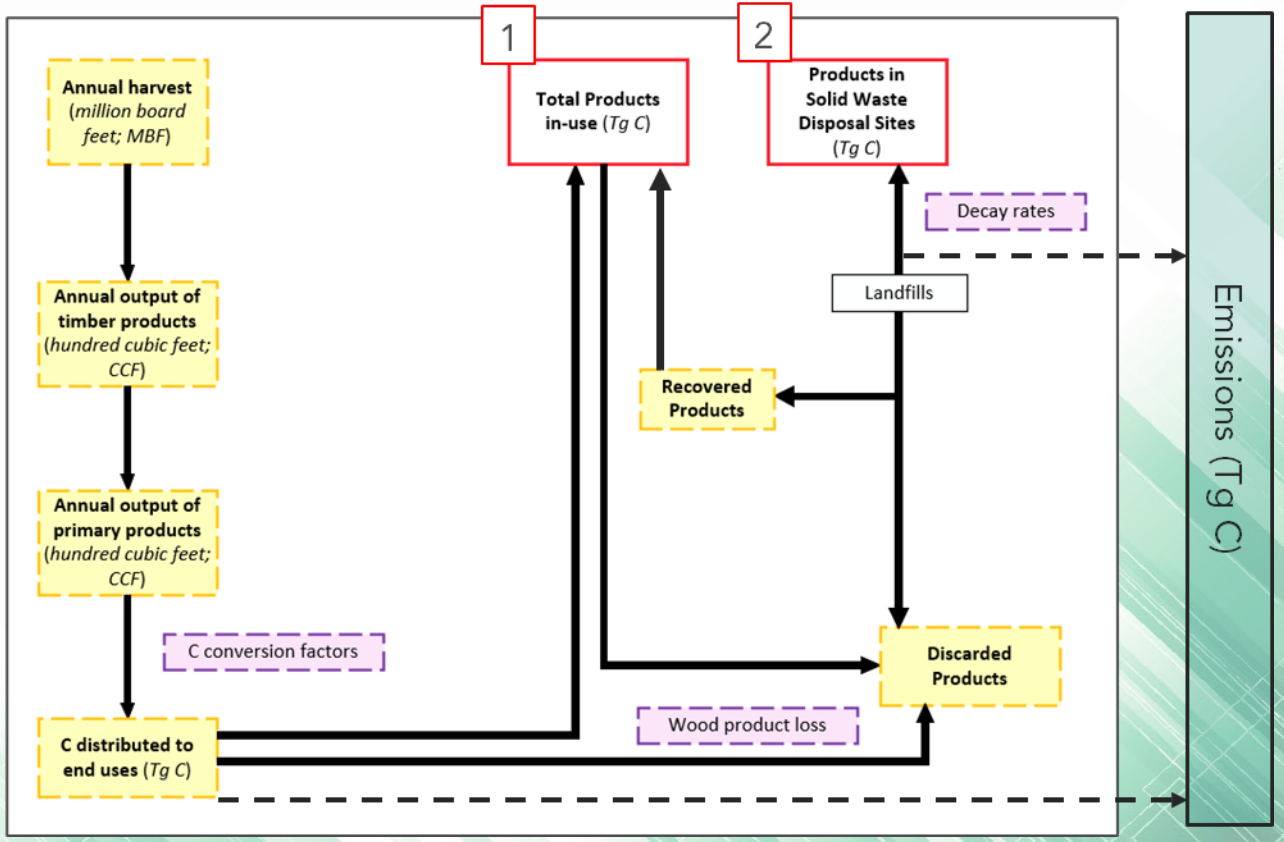
= input data (measured)

= fixed assumptions

CARB

Adapted from: Groom, J., and N. Tase. 2024. Harvested wood products carbon model, version R 1.1.0 (HWP-C vR 1.1.0) documentation. California Department of Forestry and Fire Protection Agreement No. 3540 0000277546; Oregon Department of Forestry Agreement No. ODF-1136A-20, Sacramento, CA and Salem, OR. https://jeremygroom.github.io/HWP-vR-Documentation/.

Updated Harvested Wood Products Carbon (HWP-C vR 1.1.0) Model



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Updates to Remaining Fixed Variables

Conversion factors
- Changes in wood density over time
- Species-specific variations
  - Hardwood vs. softwood, etc.

Pulp wood and wood product loss
- Technological advancements

Decay half-lives
- Landfill practices and technologies
- Regionally-specific climate conditions
- Decay functions

CARB

Data Sources

Input	Data Source(s)	Limitations
Domestic Production	USFS Timber Product Output (TPO) Reports	Produced in 5-year intervals
Domestic Production	California Department of Tax and Fee Administration (CDTFA) Timber Yield Tax Harvesting Statistics	Limited public availability; inadequate product disaggregation
Domestic Trade	US Census Bureau Commodity Flow Survey (CFS) Reports	Produced in 5-year intervals; limited public availability
Domestic Trade	Western Wood Products Association Lumber Statistics Reports	Limited availability of historic data; requires paid subscription
Domestic Trade	Regional Economic Models, Inc. (REMI) Gravity Modeling	Produces trade estimates; reliance on assumptions; regional data limitations
International Trade	Regional Economic Models, Inc. (REMI) Gravity Modeling	Produces trade estimates; reliance on assumptions; regional data limitations
International Trade	US International Trade Commission (US-ITC) Trade Data Reports	Requires assumptions based on port-of-entry
Disposal (Landfill)	CalRecycle Recycling and Disposal Reporting System (RDRS)	Variable reporting accuracy
Recycling and Composting	CalRecycle Recycling and Disposal Reporting System (RDRS)	Variable reporting accuracy

Existing Limitations

1. **Underestimation:** Data tracking begins in 2001, which excludes any HWP production and/or import before that time

2. **Data availability and accuracy:** infrequent reporting and disaggregation of wood products, as well as difficulty accessing accurate trade datasets

3. **Limitations of methods:** fixed assumptions based on aggregated data without regional specificity

Summary of Current and Future Workstream

1. **Integrate HWP empirical datasets:** includes timber products, primary products, and discard and recycling data

2. **Continued partnership on HWP-C updates:** work with CAL FIRE, USFS, and academic colleagues to improve functionality and accuracy of HWP-C model, including conversion factors and decay rates

3. **Spatially allocate HWP:** conduct spatially-explicit mapping of HWP within CA's built environment

CARB

CALIFORNIA
AIR RESOURCES BOARD

Natural and Working Lands Carbon Inventory
2025 Update
Sparsely Vegetated Lands (Other Lands)

February 7th, 2025

Dr. Kyle Lunneberg

Tracking California's Carbon Neutrality Goals

AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

Natural and Working Lands

Other Carbon Removal

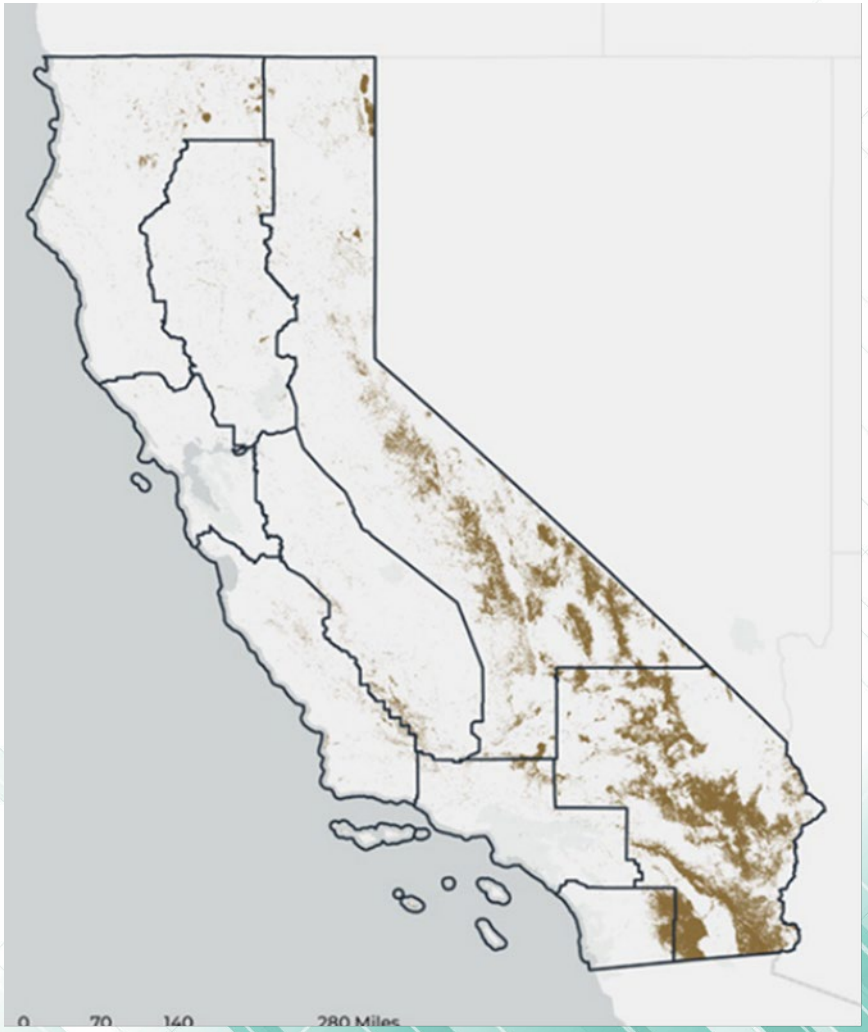
CARB

Sparsely Vegetated Lands

- Sparsely vegetated lands current cover approximately 10% of California

- This includes desert, beach and dune areas with less than 10% vegetation cover, bare rock landscapes, and areas covered in ice or snow

- Primary Drivers of Change:
  - Land Type Conversion
  - Disturbance
  - Management and Restoration
  - Climate



(Climate Smart Lands Strategy)

Nature Based Solutions

Photo Credit: Leor Pantilat

Photo Credit: James O'Neil

AB 1757 Nature-Based Solution (NBS) in Wetlands

2045 Target

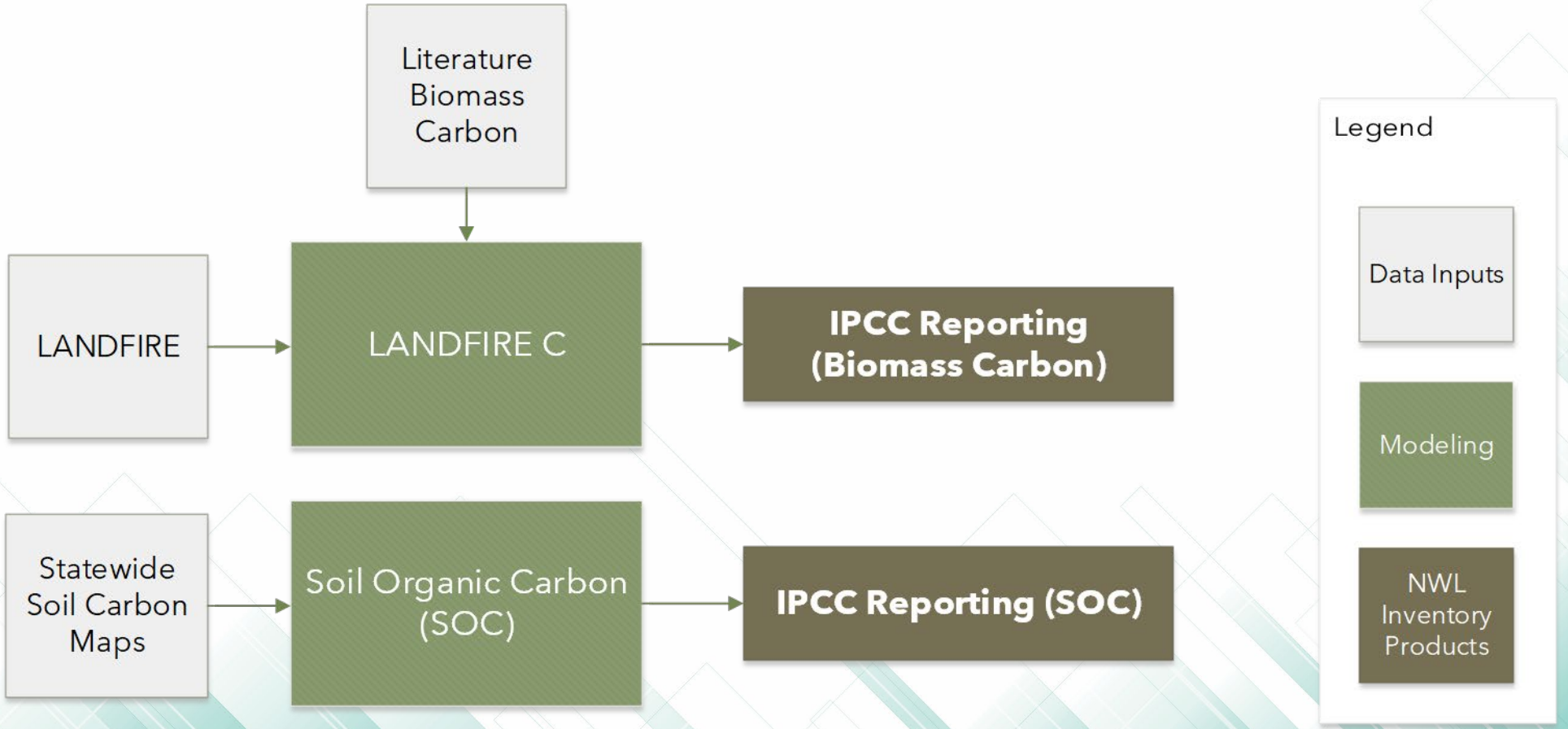
Acreage targets

(acres/year)

Conservation	40K
Restoration	55.1K

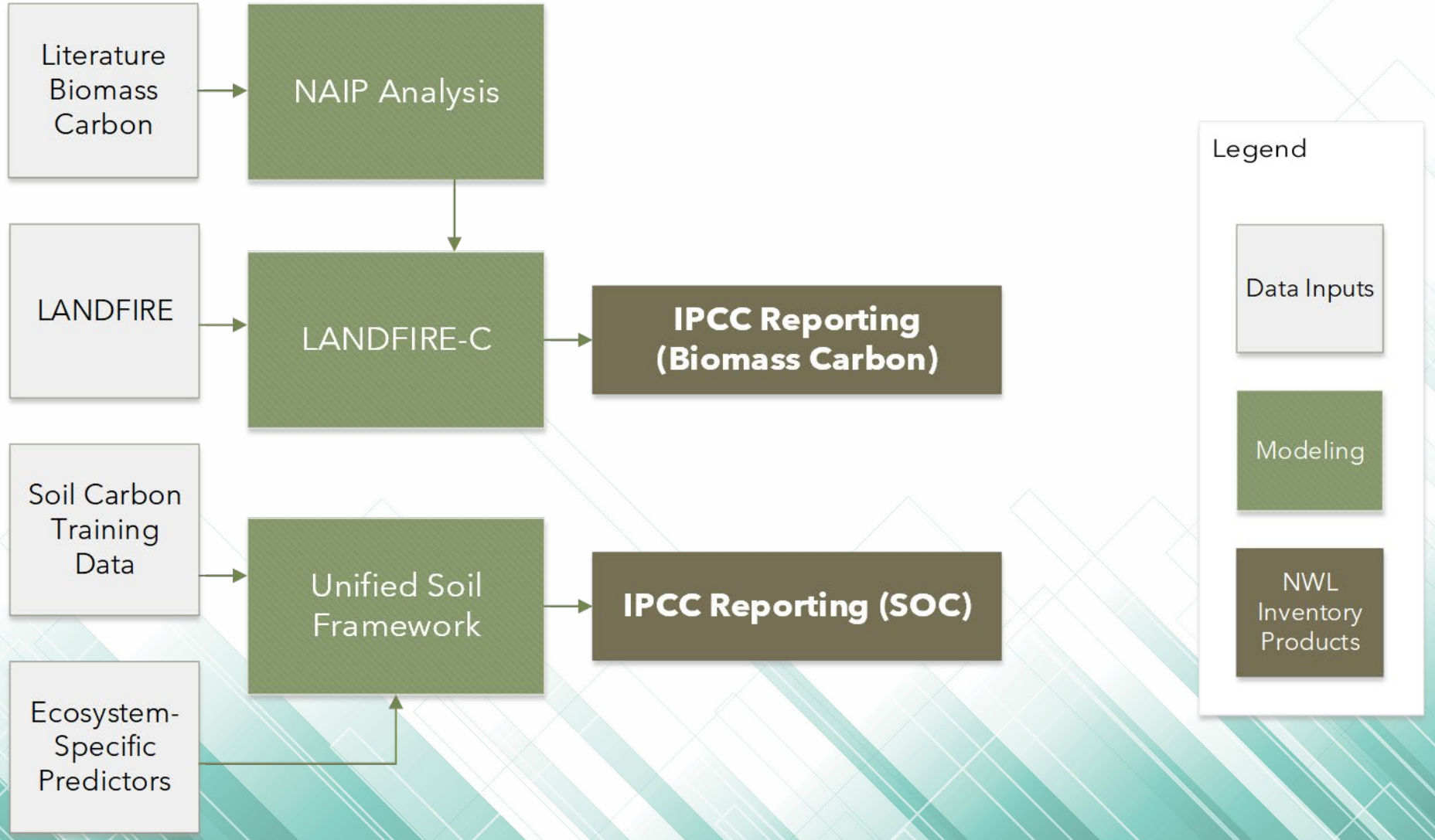
(Climate Smart Lands Strategy)

2018 Inventory Methodology



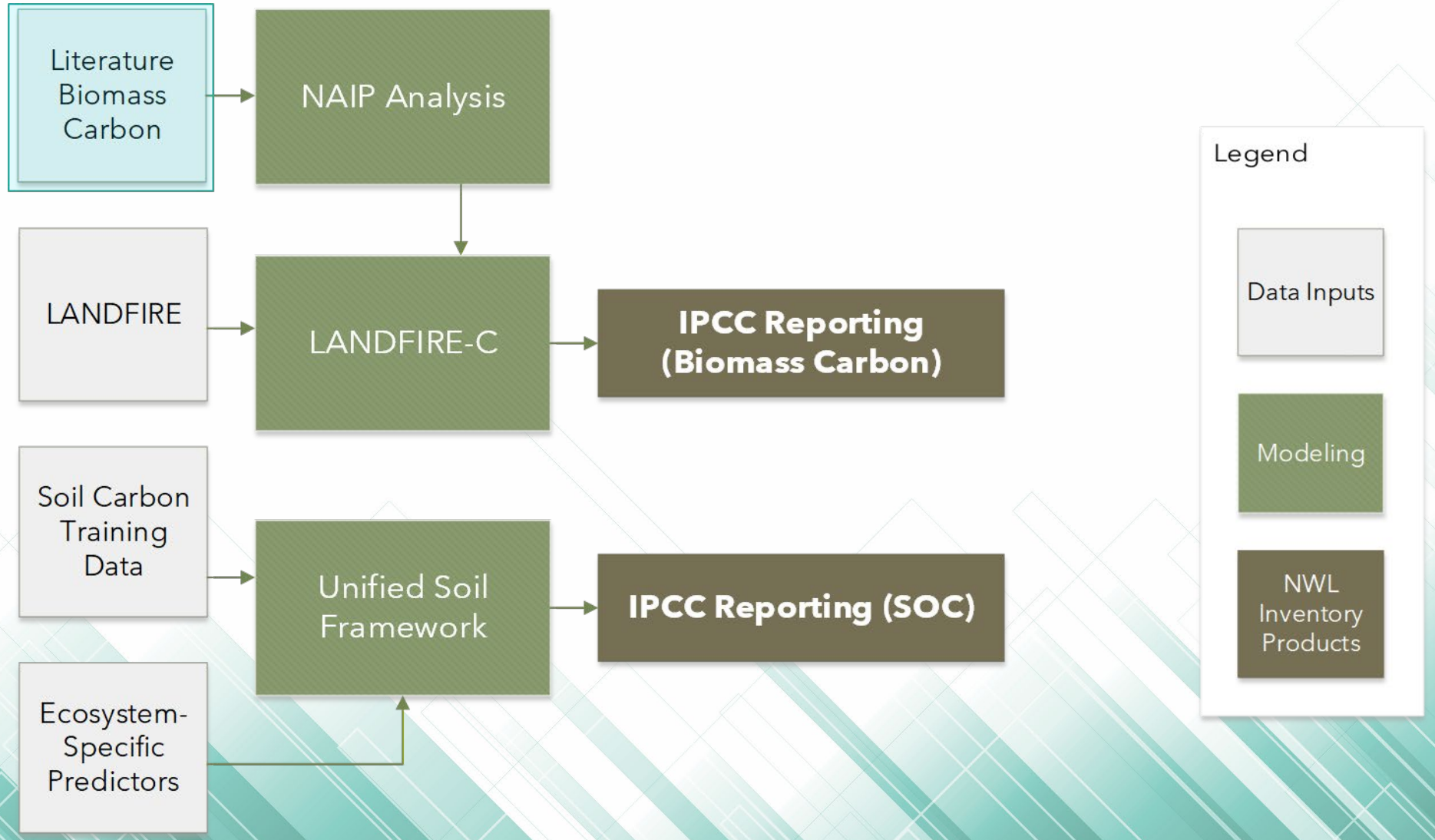
CARB

Proposed Methodology



CARB

Proposed Methodology – Biomass Carbon



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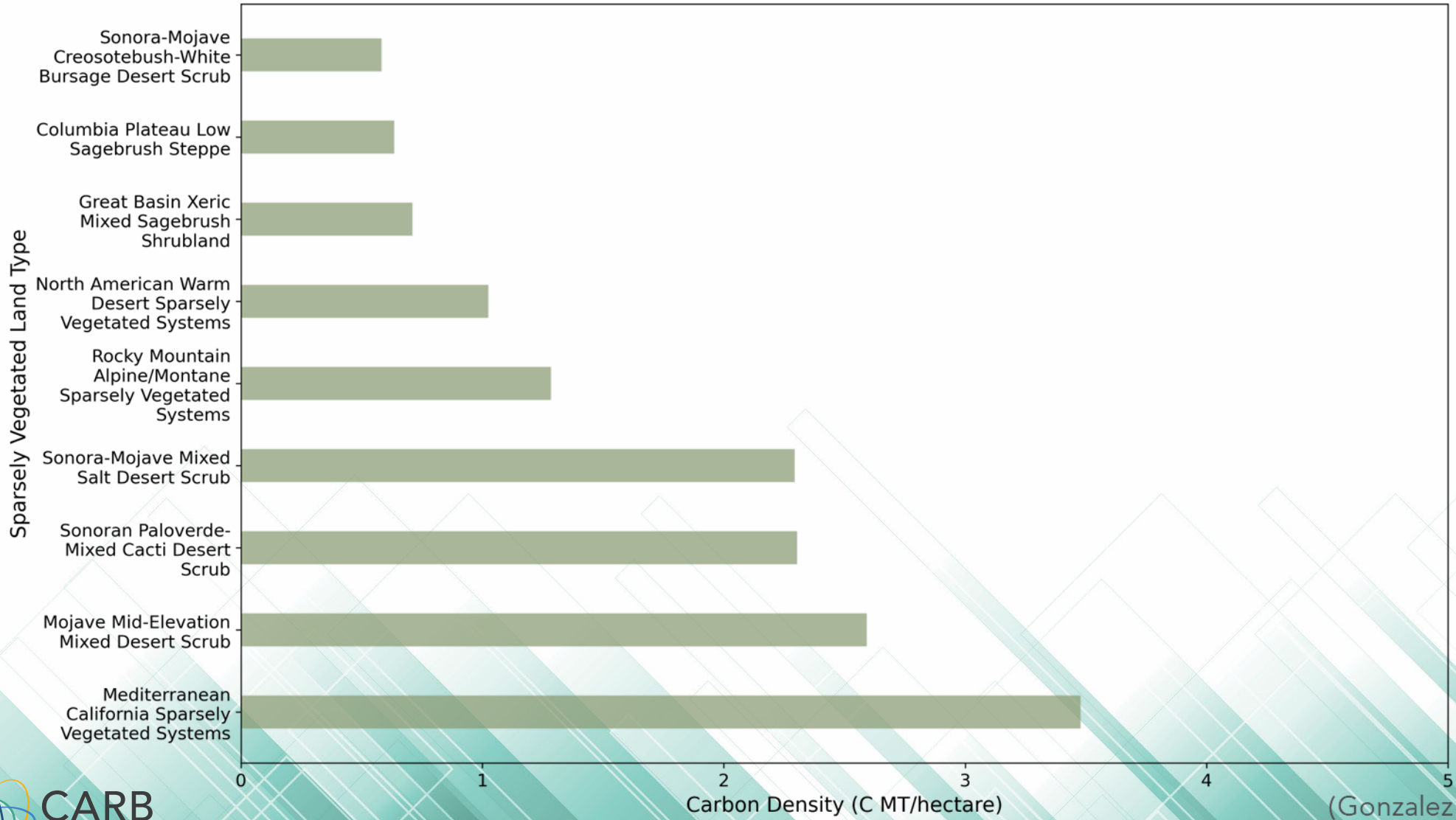
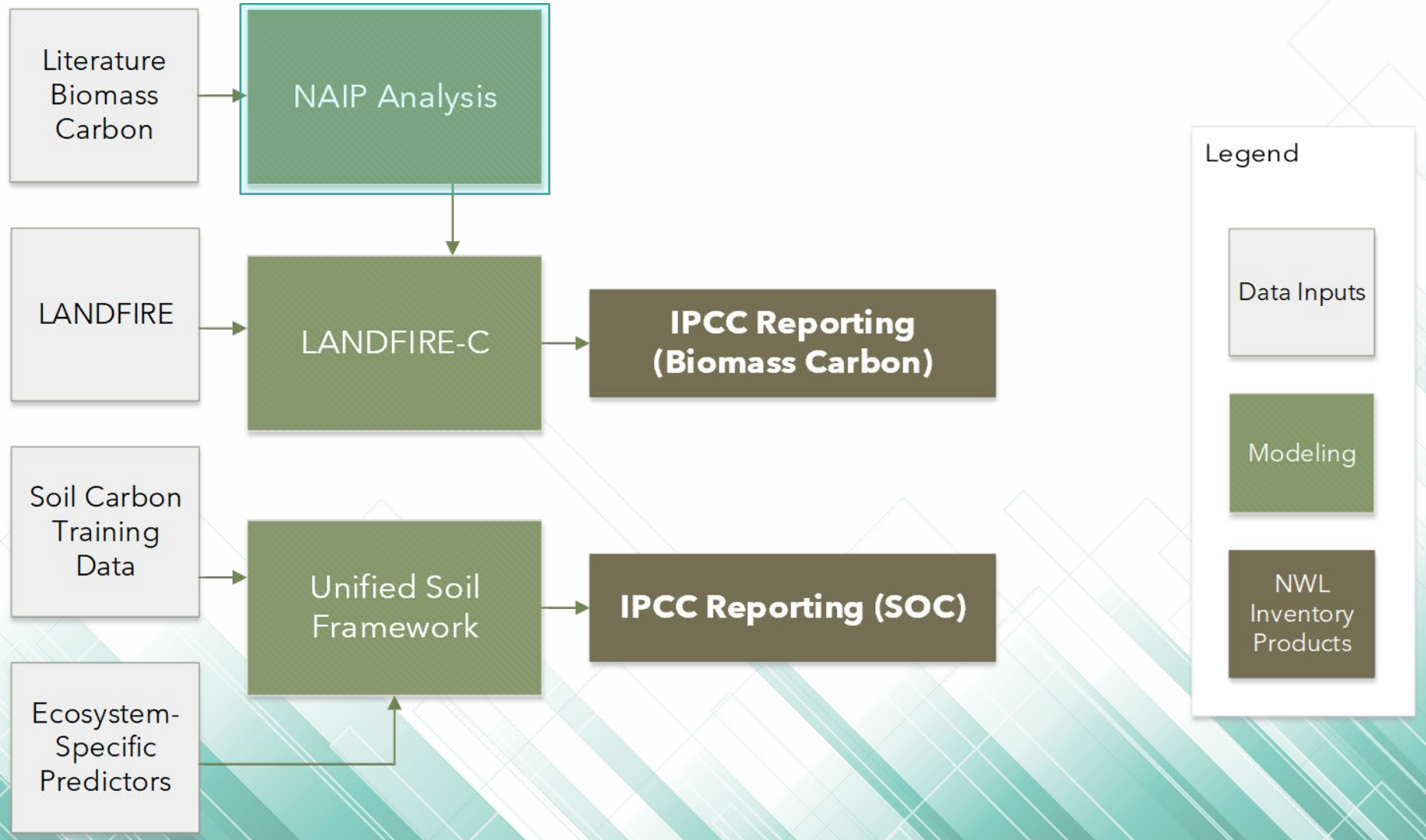
Current Literature Derived Carbon Densities



(Gonzalez et al. 2015)

CARB

Proposed Methodology – NAIP Analysis



CARB

National Agricultural Imagery Program (NAIP)

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CARB

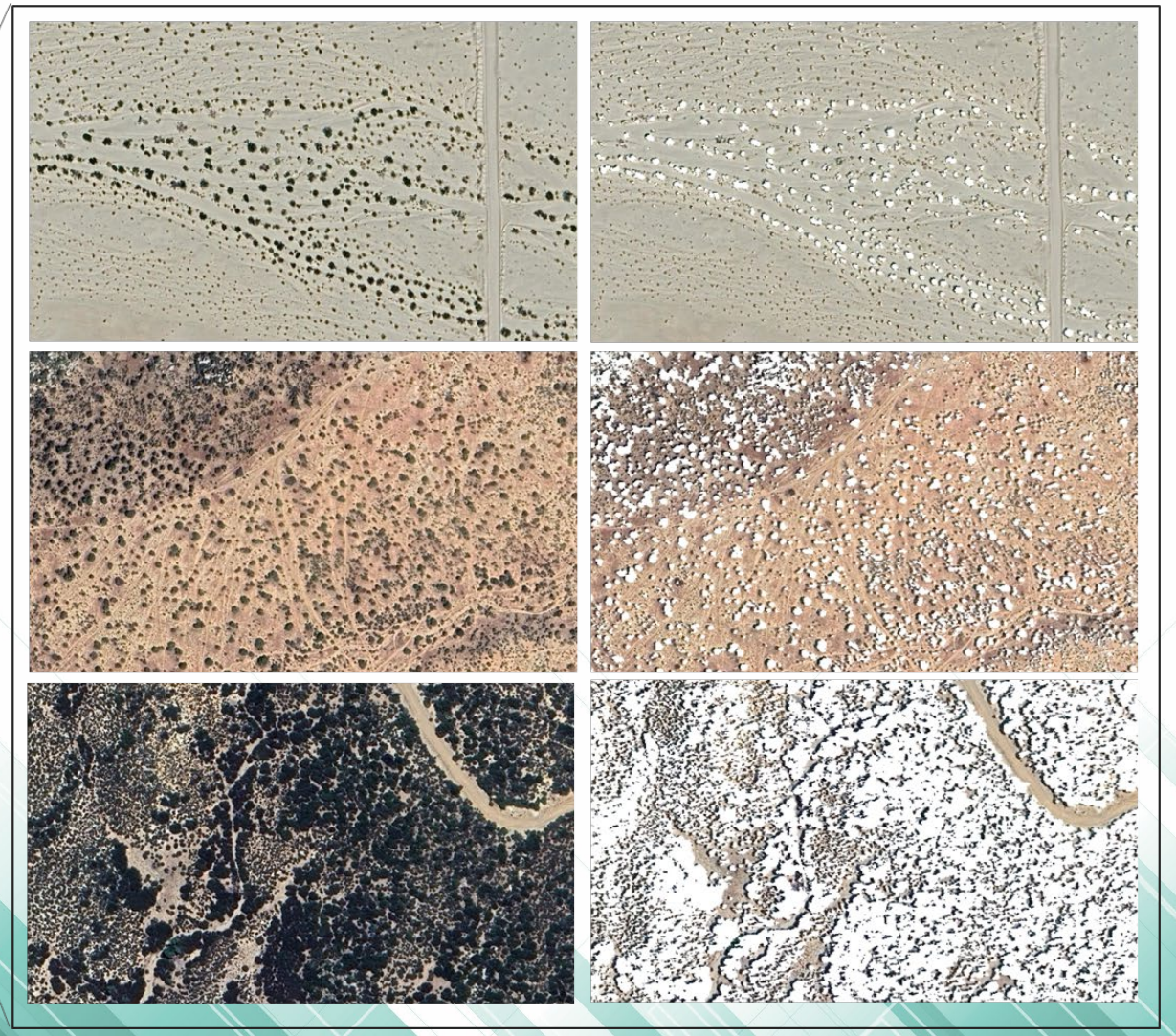
USDA

NAIP Analysis

Literature Biomass Carbon

NAIP Analysis

LANDFIRE-C



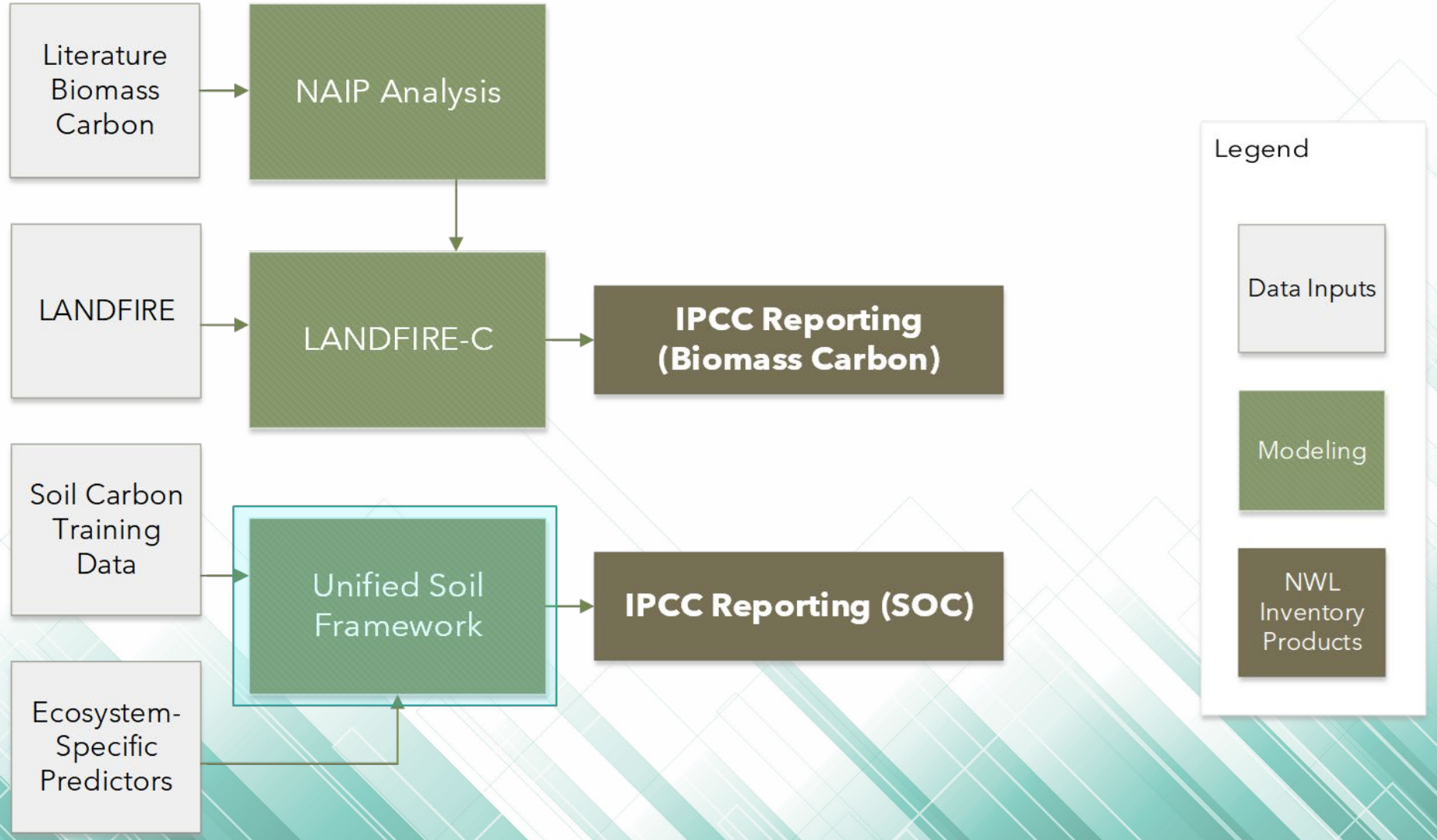
4.6%

19.5%

78.2%

CARB

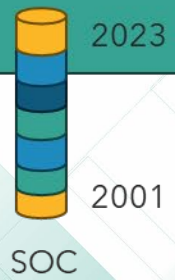
Proposed Methodology - Soils



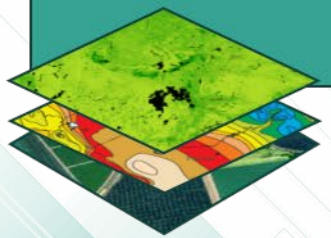
CARB

Soil Organic Carbon: A Unified Framework

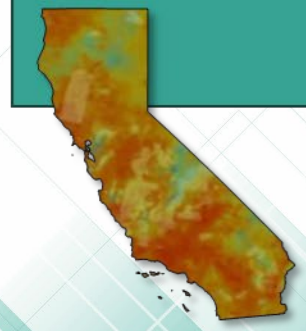
Generate a time-series training dataset (Empirical measurements + Process-based modeling)



Scale the time-series data wall-to-wall (Digital soil mapping with covariates)



Produce statewide maps of soil carbon over time



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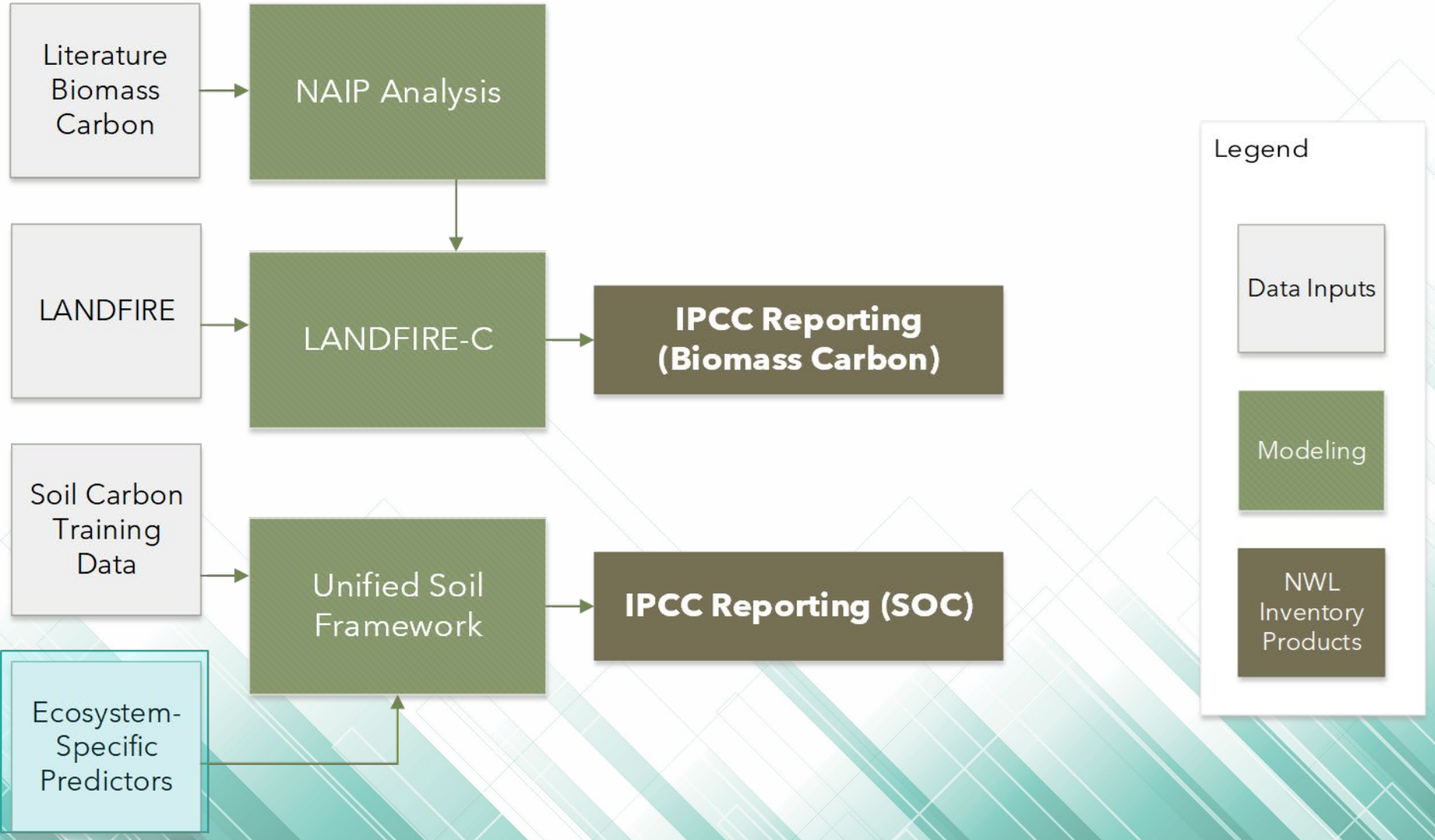
Calibration and Validation

- SOC carbon data is limited in sparsely vegetated lands.
- This method will include available data and quantify uncertainty.
- This forms a foundation to include future data and modeling of management/disturbance.

WoSIS SOC Database	
NLCD Class	**Number of Training Points**
Evergreen Forest	1394
Shrubland	574
Grassland	440
Cultivated Crops	267
Mixed Forest	84
Open Water	58
Wetland	40
Pasture	39
Barren Land	35
Developed Lands	19
Deciduous Forest	7
Total	**2957**

(Batjes et al. 2024)

Proposed Methodology – Soils Predictors



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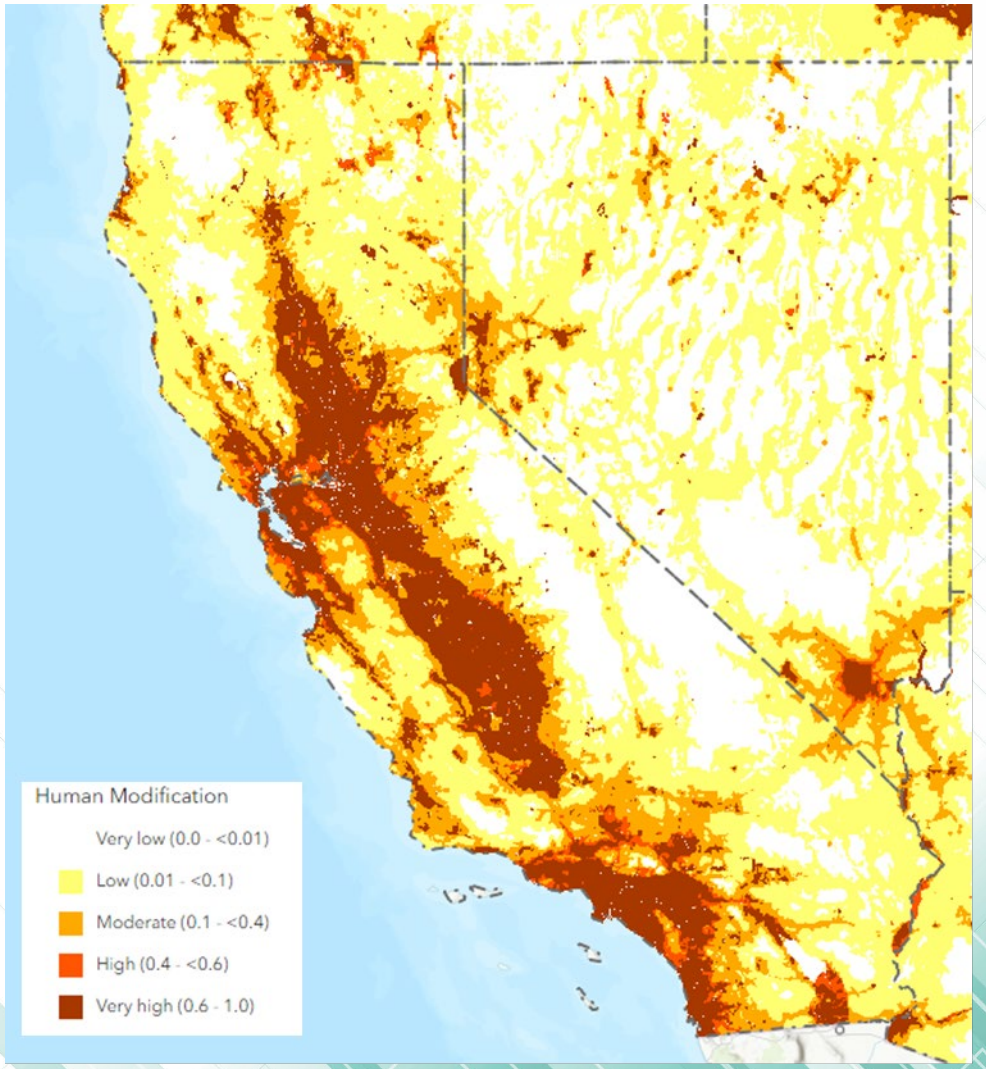
Biocrust Disturbance

- Biocrusts are biologically-active layers with strong effects on soil carbon storage
- These biocrusts form over decadal or centaury timescales but can be easily disrupted by human activity.
- A recent global meta-analysis found biocrusted soils in drylands had 70% higher SOC when compared to uncrusted soils (Xu et al. 2022)



(Theobald et al 2020)

Summary

- The proposed updates will enhance the quantification of biomass carbon and soil carbon for sparsely vegetated lands.
- Additions include new literature derived values, high resolution imagery analysis, and a unified soil organic carbon framework
- Existing limitations and future directions:
  - Soil Inorganic Carbon
  - Remote sensing of biocrust disturbance

Photo: James O'Neil

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AIR RESOURCES BOARD

Natural and Working Lands Carbon Inventory 2025 Update
Developed Lands

February 7, 2025

Dr. Tara Seely

CARB

Carbon Neutrality by 2045

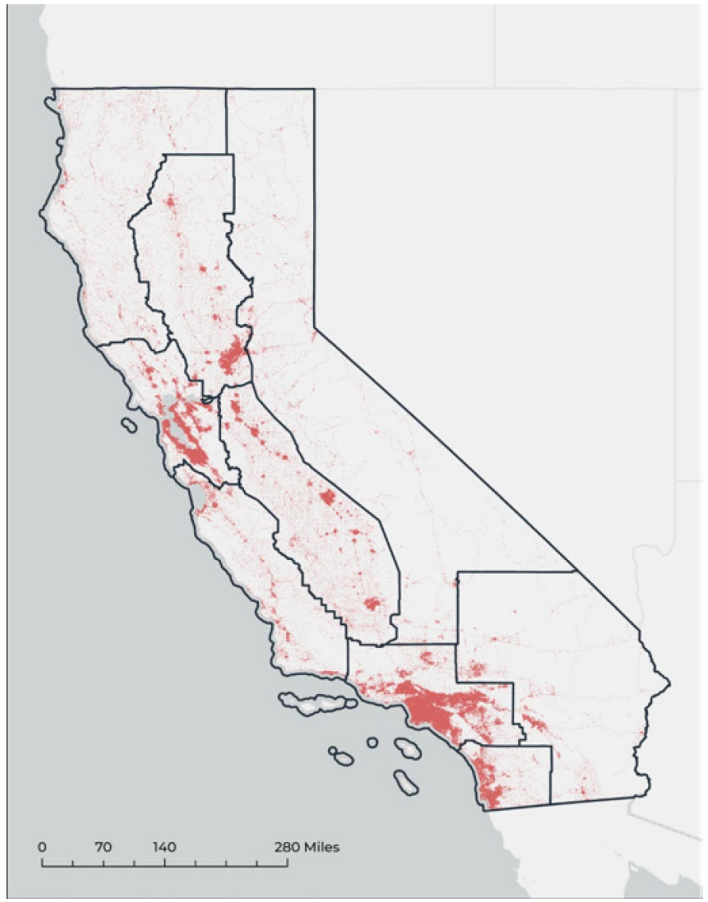
AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

Natural and Working Lands (NWL)

Other Carbon Removal

CARB

Developed Lands



NWL Climate Smart Strategy

Photo credits: Renee Schiavone/Patch Photo Archive, Hollywood Blvd/Getty Images, Bob White/CC BY-NC-ND 2.0, Josh Edelson/AFP via Getty Images, socalurbangardens.com

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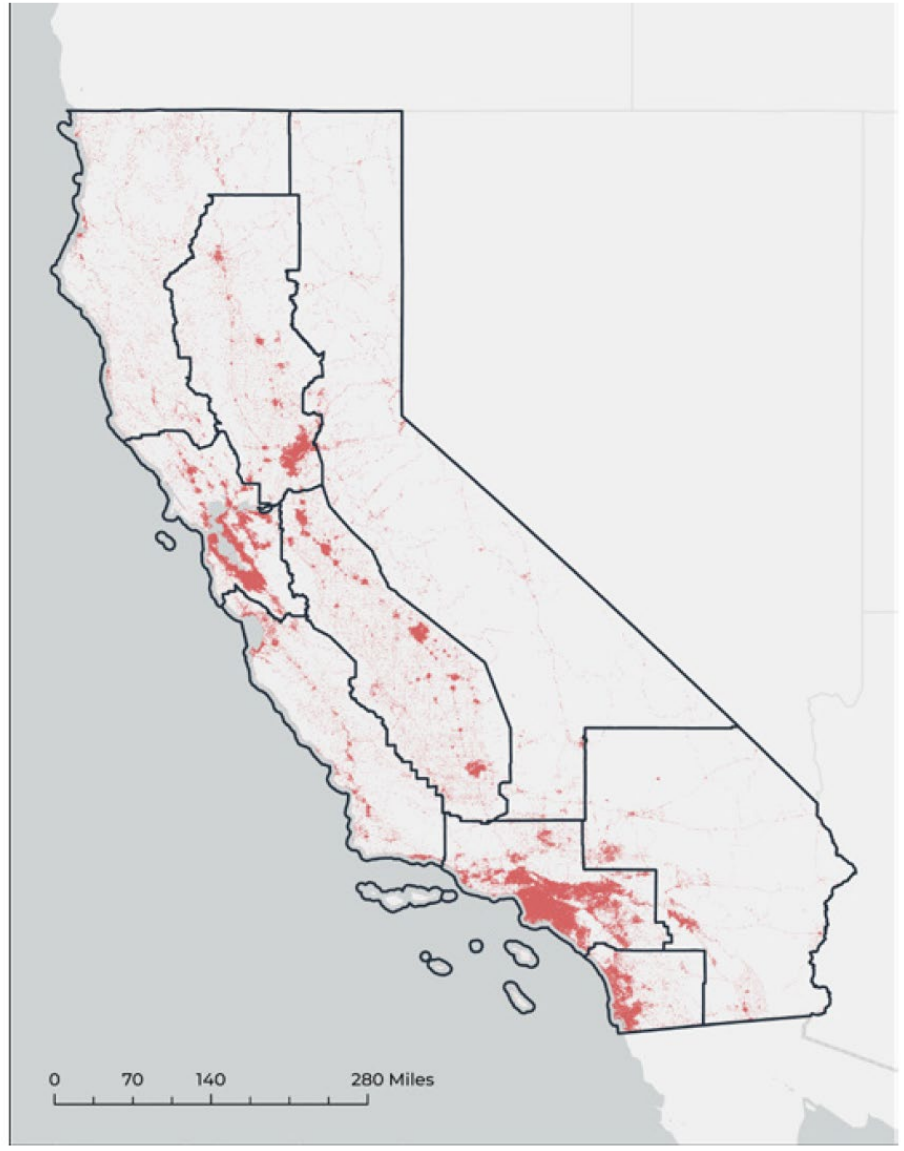
Key New Feature: Delineating Developed Lands

- "Developed Lands" encompass energy, transportation, residential, commercial, and production infrastructure of any size
- Join spatial data on energy infrastructure, roads, night time lights, building footprints
- Quantifying carbon may require methods from other land types but carbon will still be attributed to developed lands



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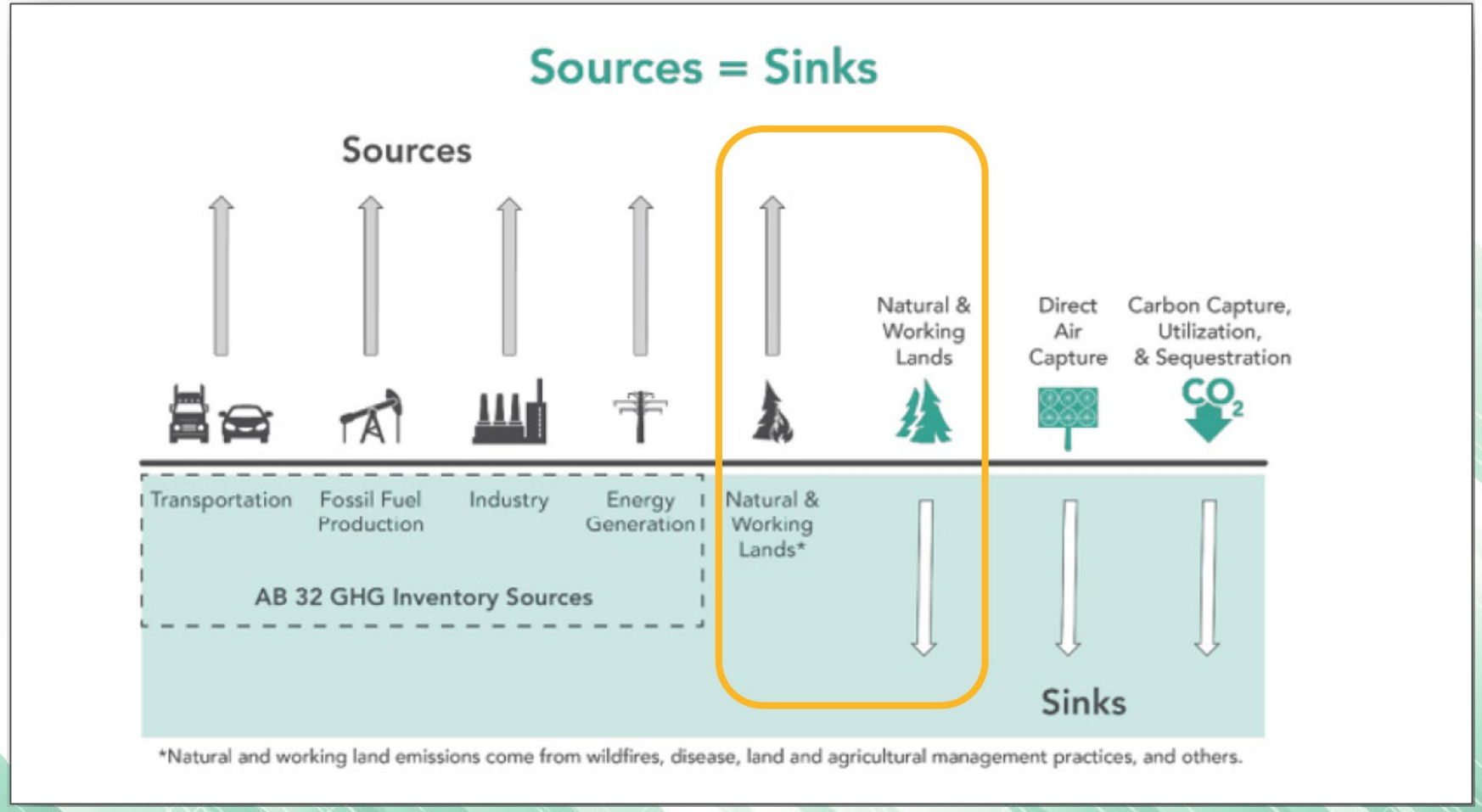
NWL Carbon Sinks and Sources



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NWL Carbon in Developed Lands

- Pools include: soils, herbaceous perennials, trees, gardens, etc.
- Durable, more resilient carbon
- Proximity to people = co-benefits

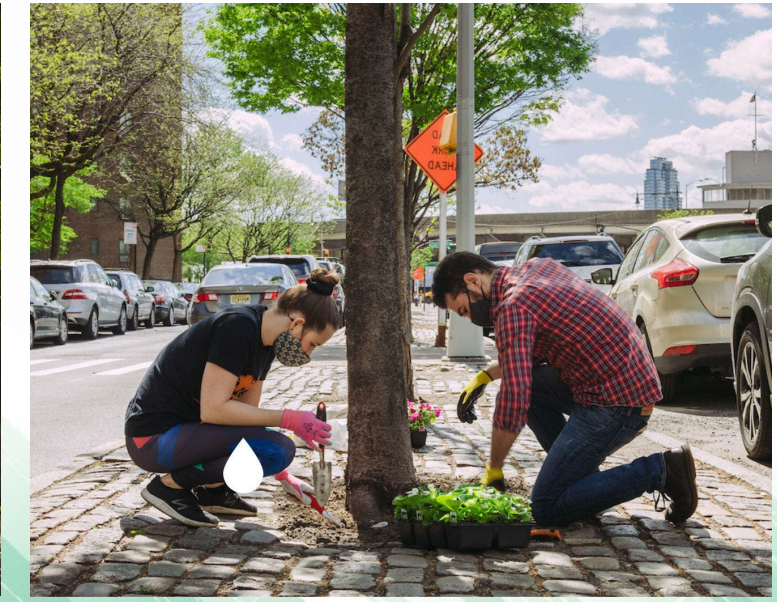

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Photo credits: Pernell Quilon, Buzzfeed; onetreeplanted.org; Paige Green, © Green Schoolyards America

Nature Based Solutions in Developed Lands

AB 1757 Nature-Based Solution (NBS) in Developed Lands	2045 Target
Acreage targets	**(acres/year)**
Afforestation between communities and croplands	230K
Conservation	17.3K
Urban and community greening and forestry	34.7K
Reducing community wildfire risks	11K
Percentage targets	**(percentage)**
Decrease wildfire ignition caused by vehicles	30%
Treat priority roads that function as evacuation routes	100%
Tree targets	**(trees/year)**
Urban and community greening and forestry	200K

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Current Carbon Quantification Methods

(Shutterstock)

- Emphasizes carbon in census-designated urban areas
- Separate quantification for tree biomass and soil carbon

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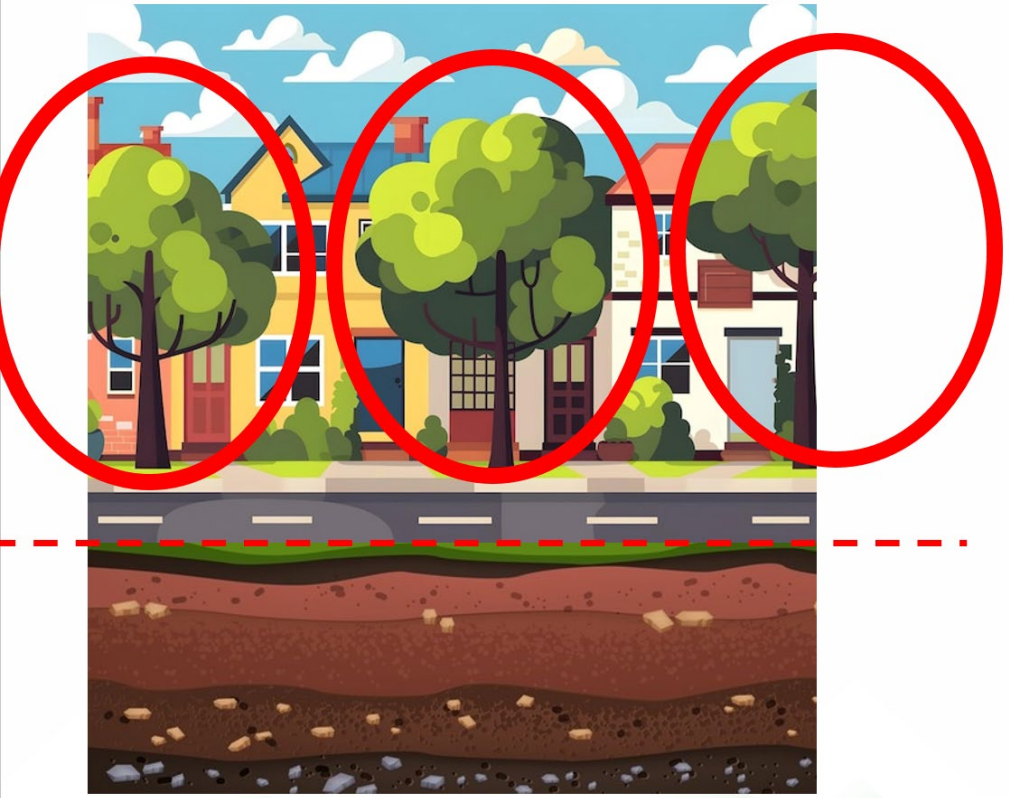
Tree Biomass Carbon Quantification



(Shutterstock)

- Tree biomass: species inventory + tree cover
- Previously: Random point samples represent tree cover
- Update: Remote-sensing derived tree cover map

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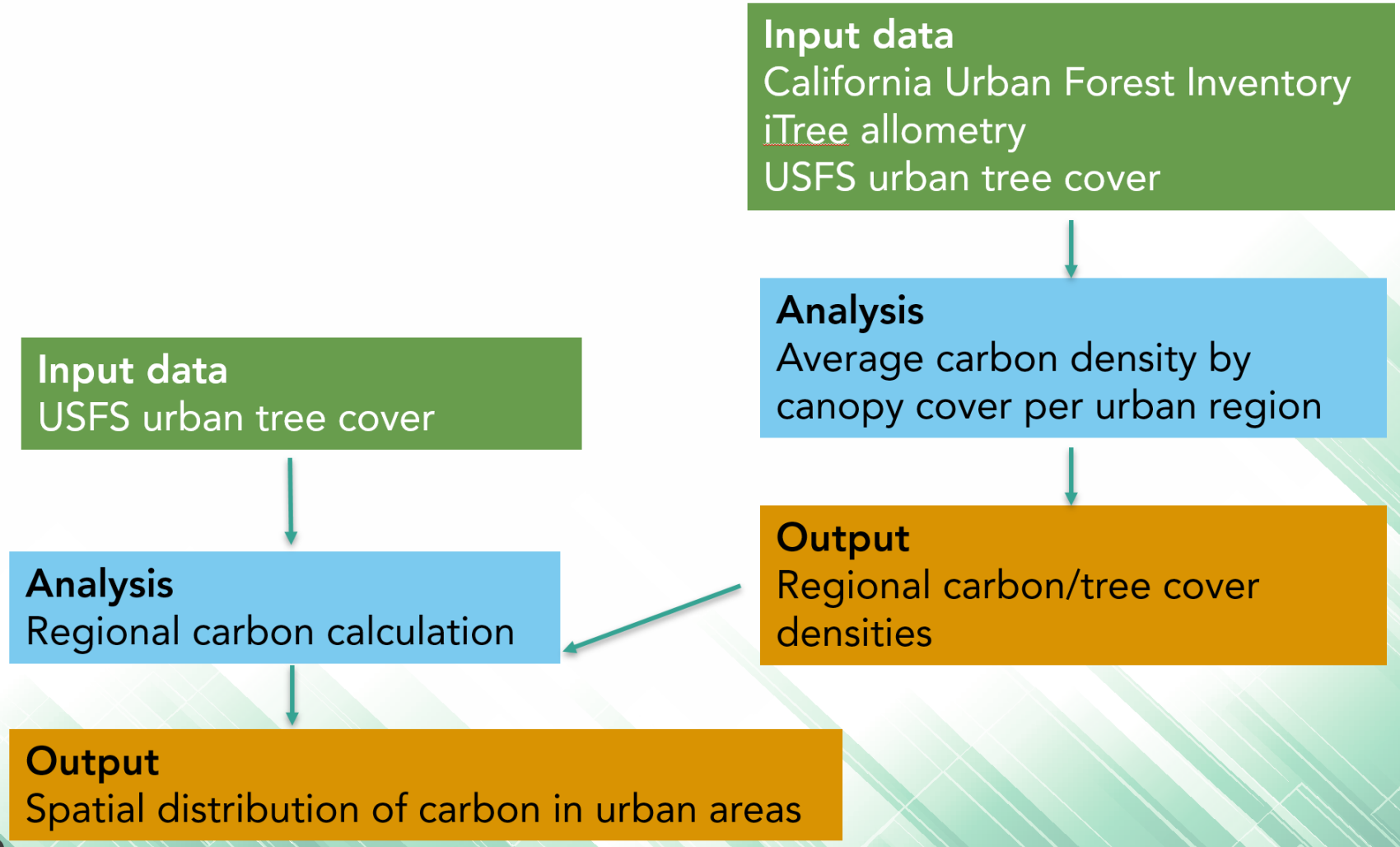
Proposed Tree Biomass Carbon Quantification



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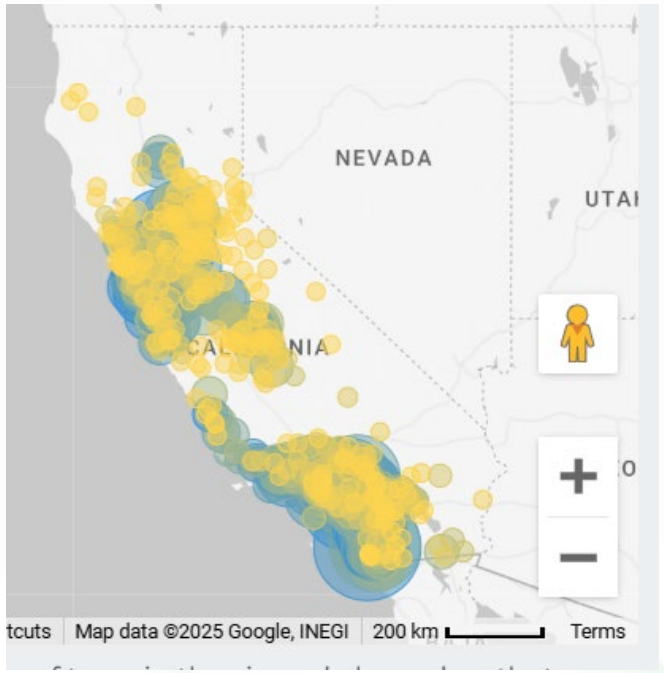
Key New Feature: Urban Forest Inventory and Allometric Equations



Input data
California Urban Forest Inventory
iTree allometry
USFS urban tree cover

Step 1:

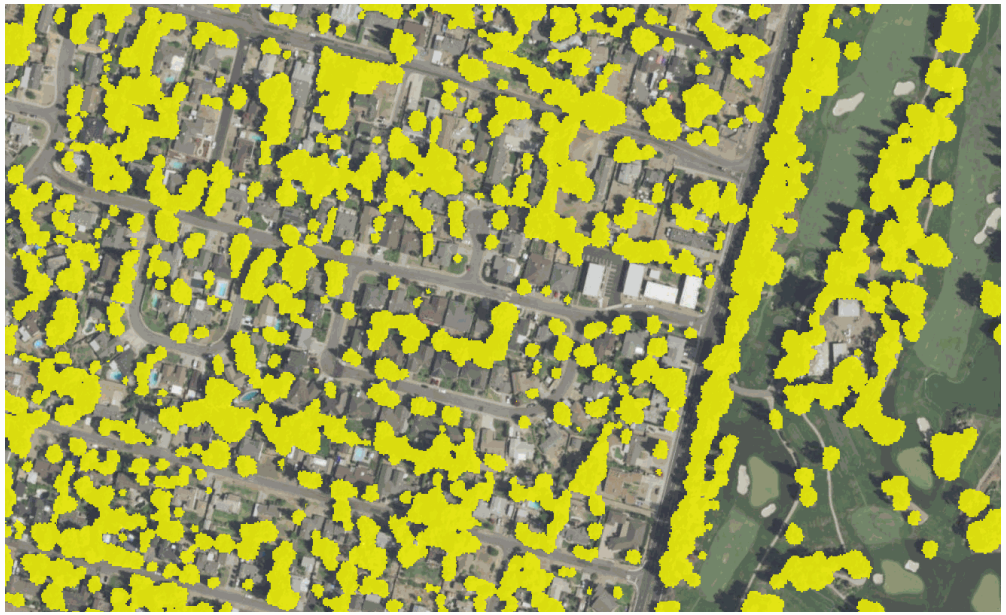
Analysis
Average carbon density by canopy cover per urban region

~8 million trees in California Urban Forest Inventory;

Updated species-specific carbon allometric equations

CARB

Key New Feature: Tree Biomass Carbon Quantification



Input data
USFS urban tree cover

Step 2:

Analysis
Regional carbon calculation

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Carbon Quantification

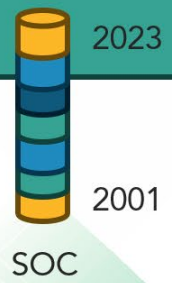
(Shutterstock)

- Soil Carbon: carbon stored in top 30cm of soil
- Drivers: soil type, climate, vegetation, sealing, land use history

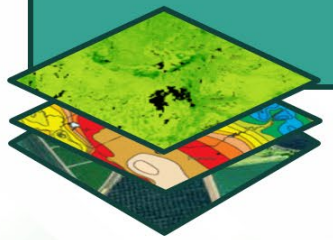
CARB

Soil Organic Carbon: A Unified Framework

Generate a time-series training dataset (Empirical measurements + Process-based modeling)



Scale the time-series data wall-to-wall (Digital soil mapping with covariates)

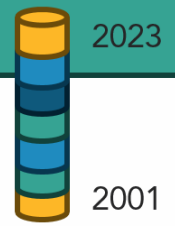


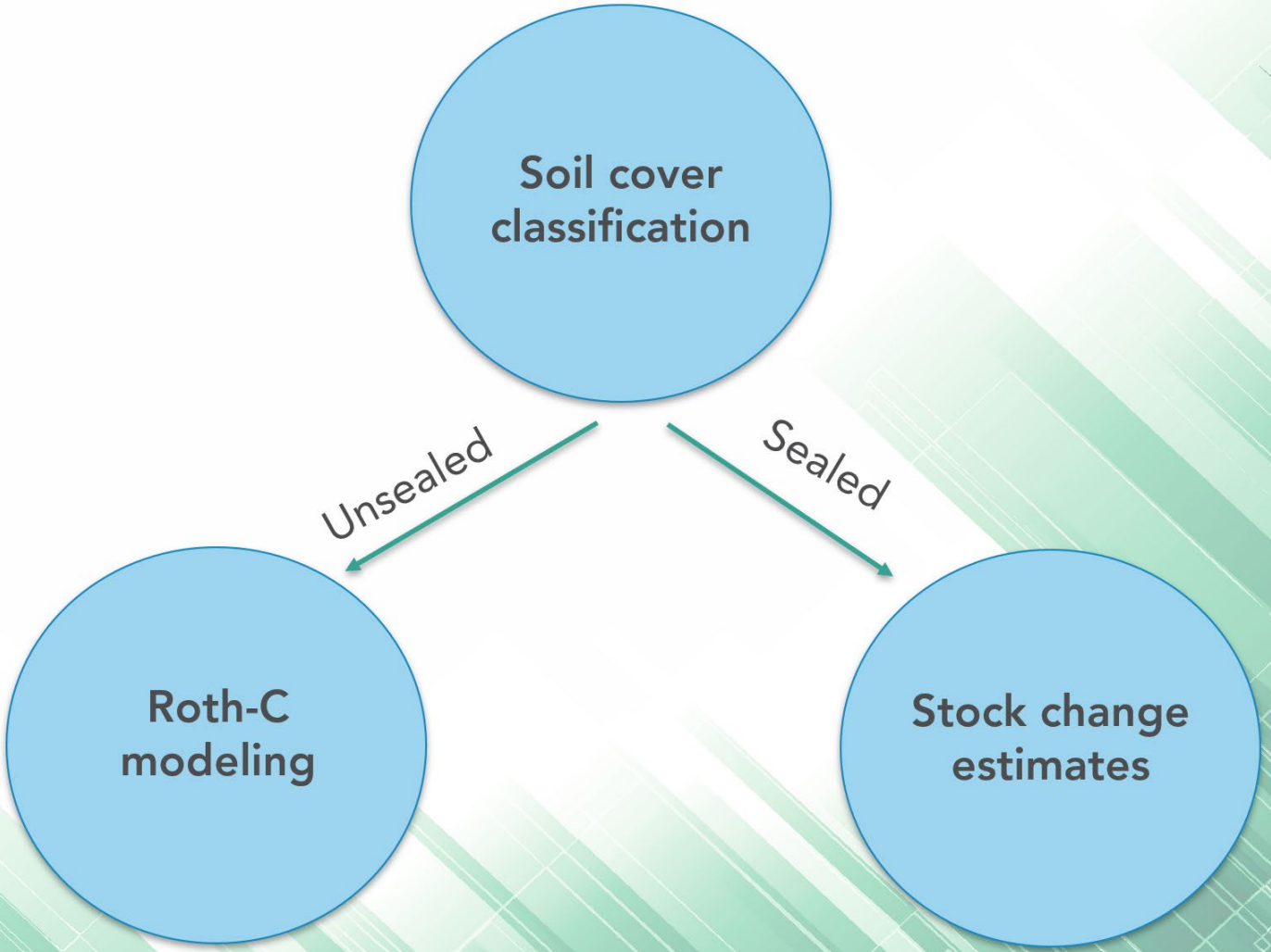
Produce statewide maps of soil carbon over time

CARB

Proposed Soil Carbon Quantification

Generate a time-series training dataset (Empirical measurements + Process-based modeling)





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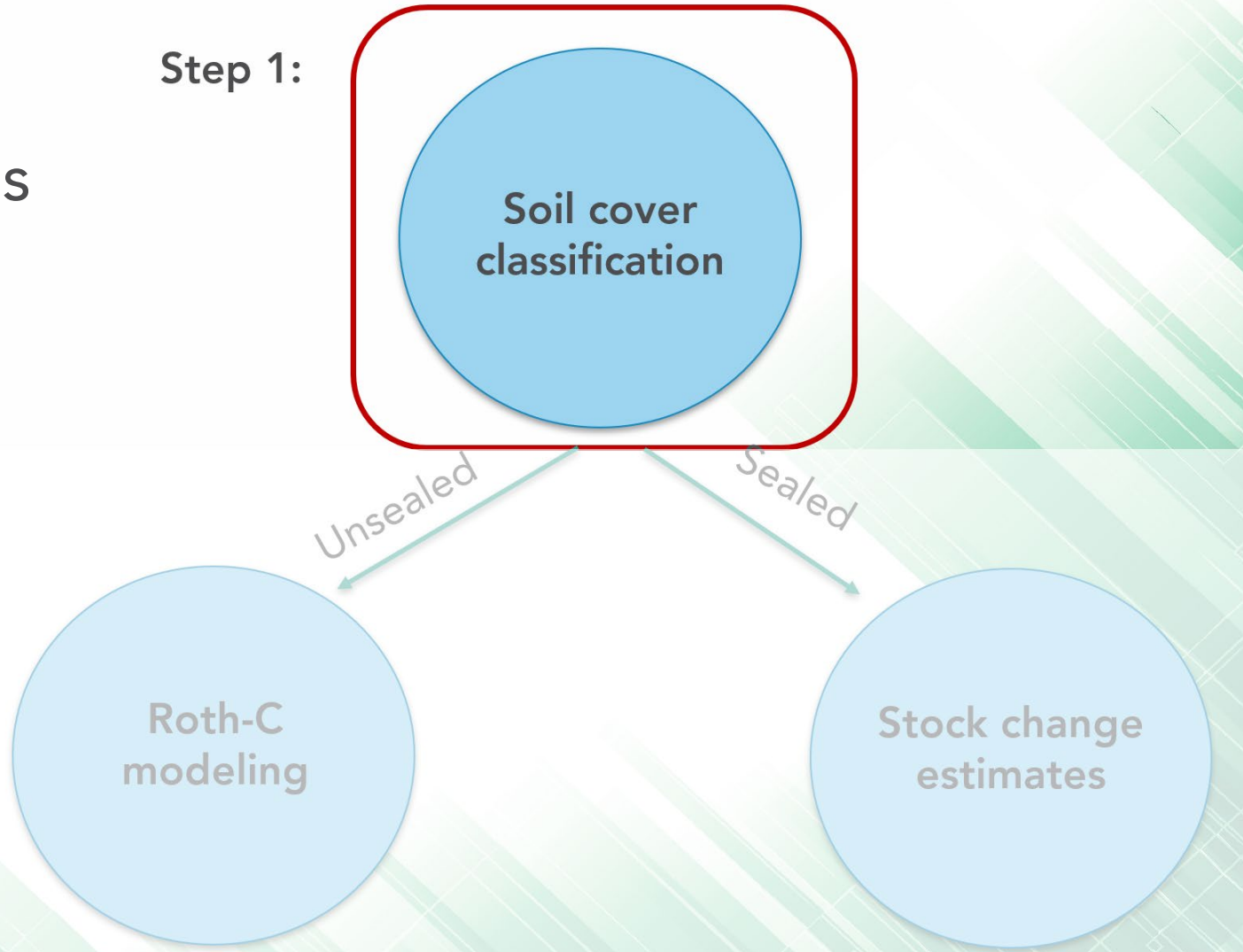
Step 1 of Proposed Soil Carbon Quantification

- **Input data:**
  - NLCD percent impervious
  - USFS tree cover
  - NAIP imagery

- **Cover categories:**
  - Sealed
  - Tree
  - Other vegetation
  - Bare

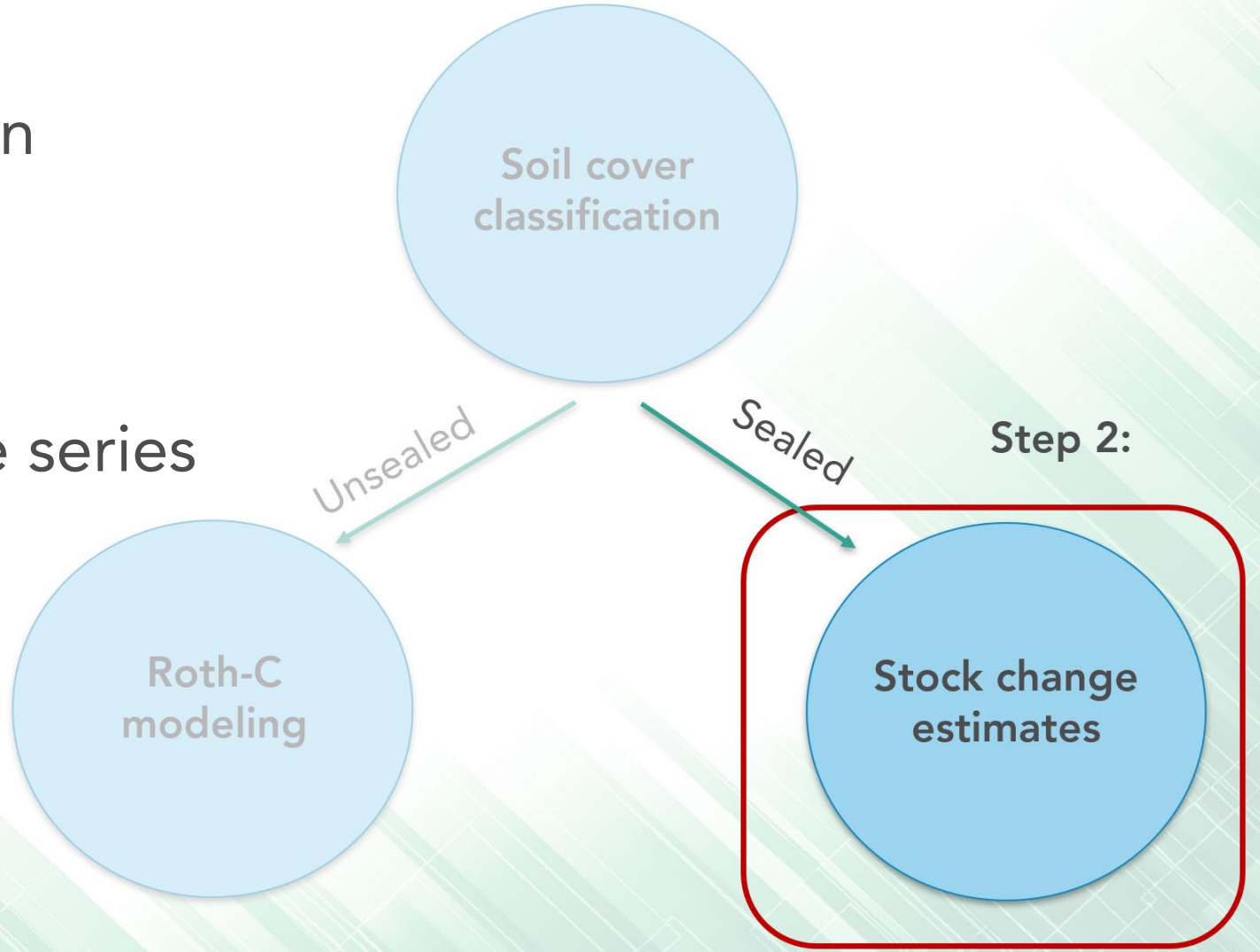


CARB

Step 2 of Proposed Soil Carbon Quantification

- **Input data:**
  Initial Soil Organic Carbon
  Sealed stock change

- **Output:**
  Soil Organic Carbon time series



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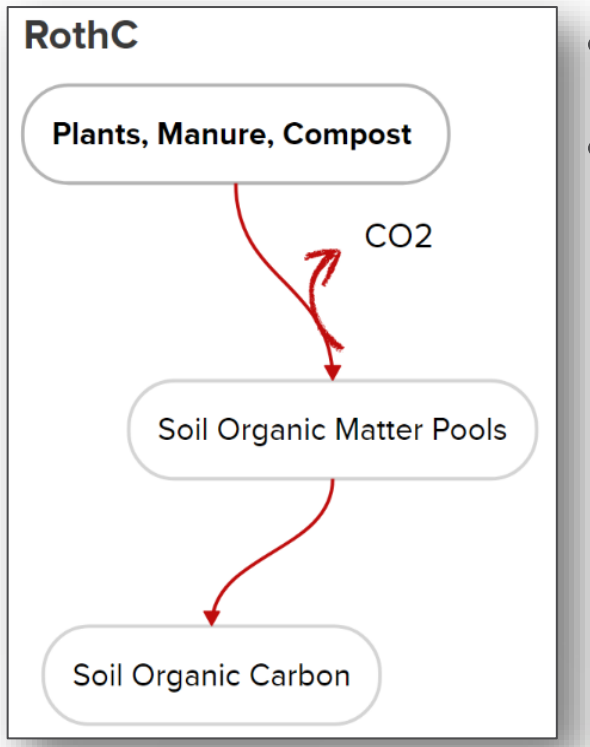
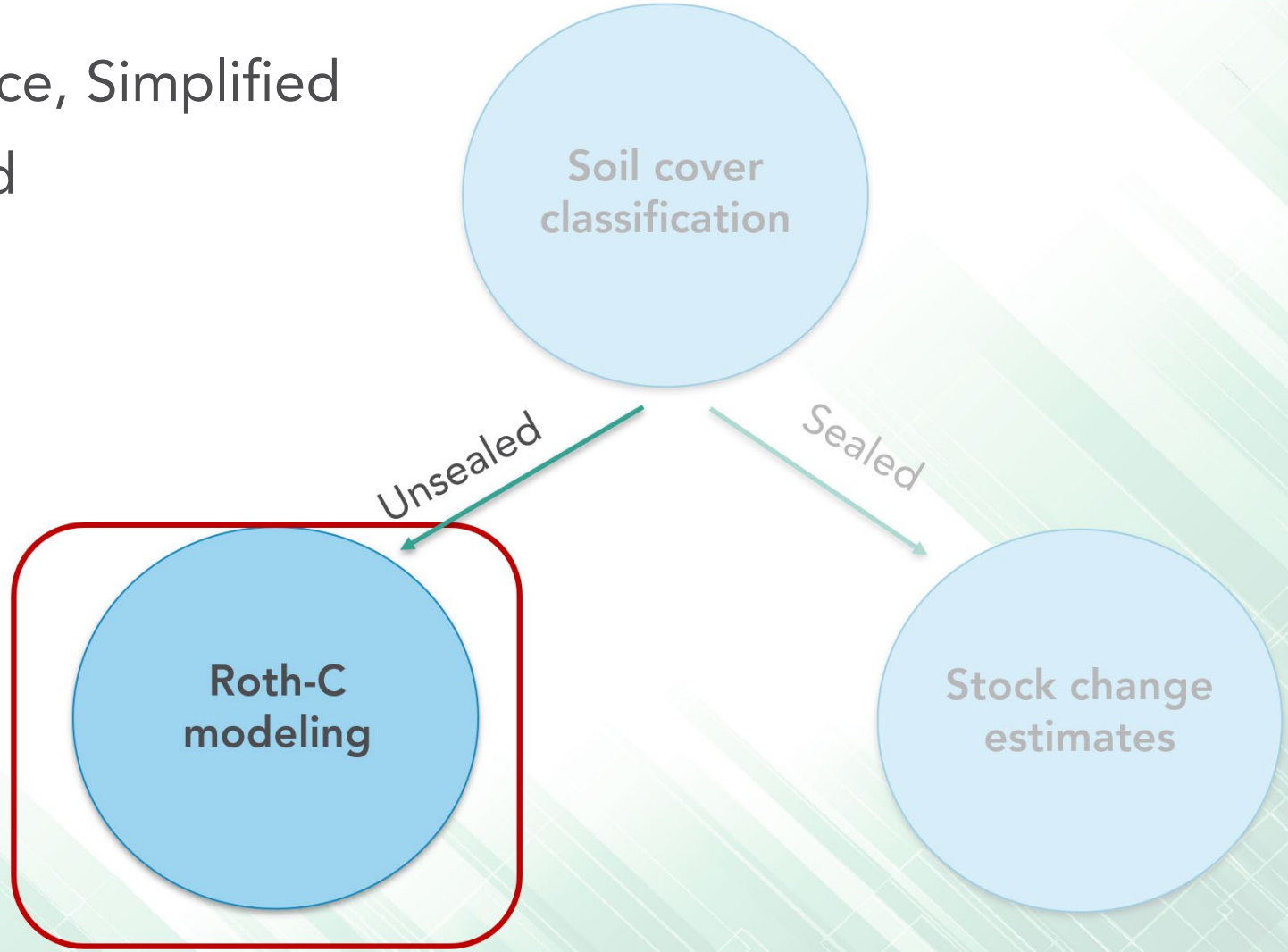
Step 3 of Proposed Soil Carbon Quantification



- Open-source, Simplified
- Well-vetted



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Developed Lands Carbon Quantification

Key new features	Needs
Delineating "Developed Lands" instead of "settlements"	Update methodology as data becomes available
Differentiating soil cover types	Soil samples for validation
Tree cover data is sensitive to NBS changes	Expand tree map beyond census-designated urban areas
Tree inventory has expanded	Balance representation of street trees with trees on private land

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AIR RESOURCES BOARD

Natural and Working Lands Carbon Inventory
2025 Update
Wetlands

February 7th, 2025

Dr. Kyle Lunneberg

Tracking California's Carbon Neutrality Goals

AB 32 Sources
Fossil Fuels/Industrial
Land fills
Dairies

Natural and Working Lands

Other Carbon Removal

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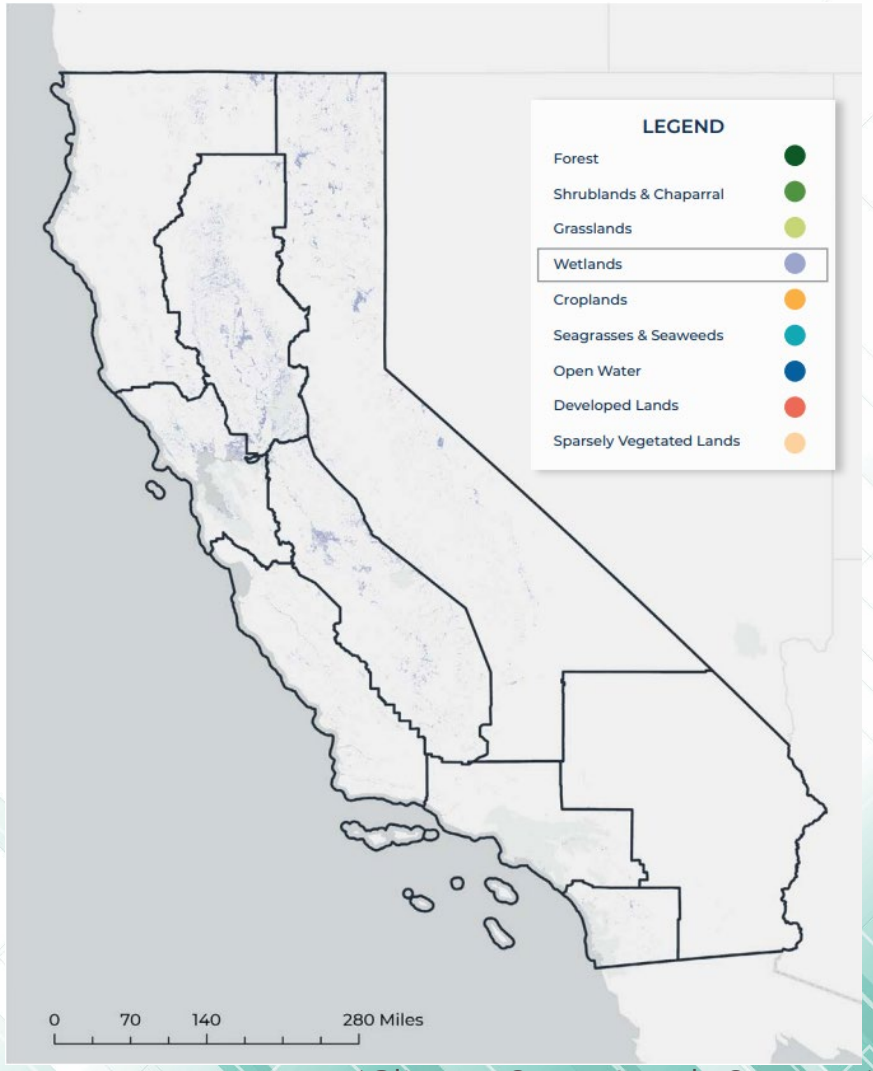
Wetlands

- Within natural and working lands, wetlands cover approximately 2% of California.

- Primary Drivers of Change include:
  - Land Use Conversion
  - Subsidence/Accretion
  - Sea Level Rise
  - Salinity
  - Management/Restoration

- In the NWL Inventory, CO2 and CH4 emissions are quantified for three IPCC-designated land types:
  - Coastal Wetlands
  - Rewetted Organic Soils
  - Inland Wetland Mineral Soils



(Climate Smart Lands Strategy)

CARB

Nature Based Solutions in Wetlands

Photo Credit: OPC

Photo Credit: OPC

AB 1757 Nature-Based Solution (NBS) in Wetlands	**2045 Target**
Acreage targets	**(acres/year)**
Conservation	1.3K
Restoration	9.2K
Sea Level Rise Protection	1.7K

CARB

(Climate Smart Lands Strategy)

Blue Carbon Ecosystem Data and Model Assessment Report

- All wetlands across the state relied on a Tier 1 IPCC quantification of GHG flux for CARB's 2018 NWL Carbon Inventory

- The California Ocean Protection Council, in collaboration with CARB and Windward Sciences, developed a report on the available models to quantify coastal wetlands at a Tier 3 level

- Investments are needed to:
  - Track restoration projects, outcomes, costs and monitoring
  - Include additional habitats such as seagrass meadows, estuaries with dynamic ocean inlets, heavily degraded wetlands, and other blue carbon ecosystems

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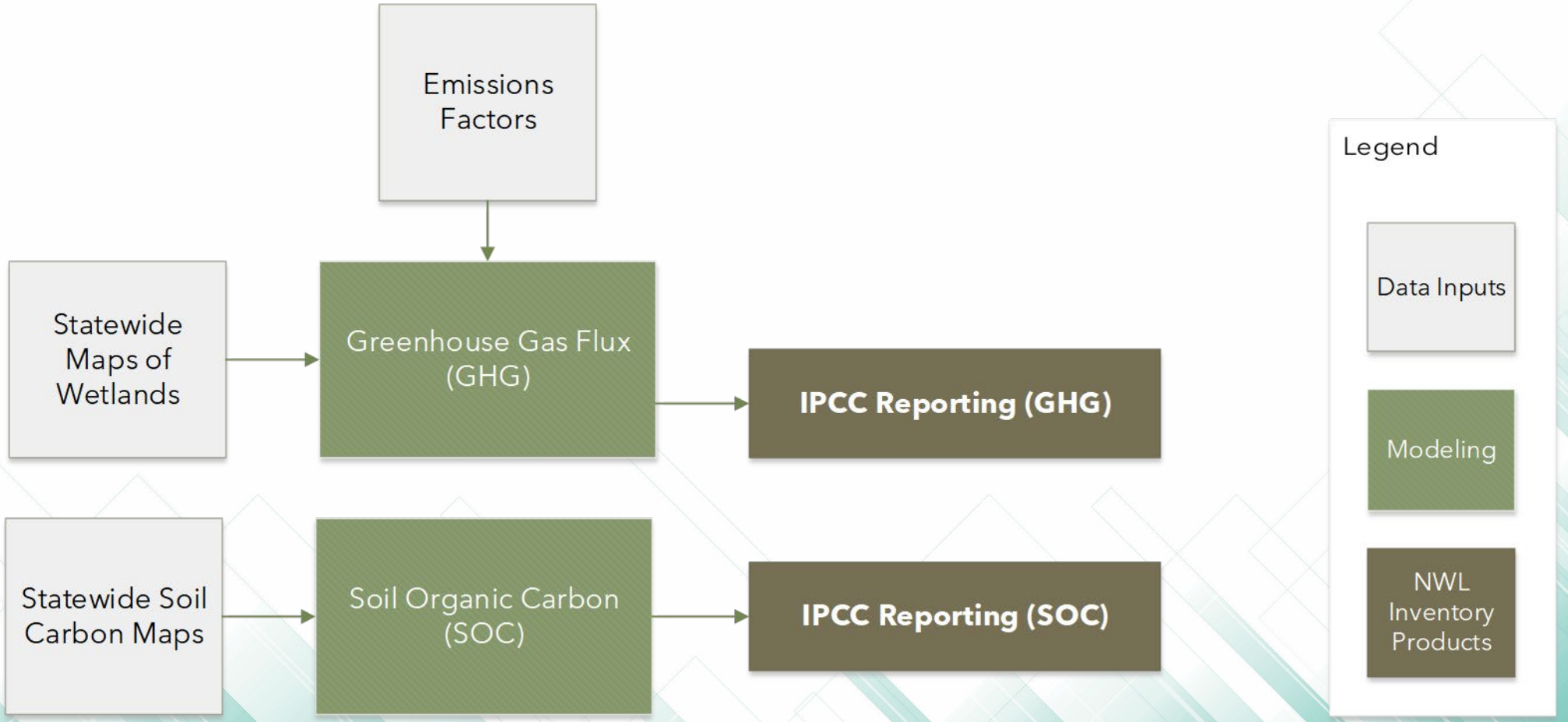
CALIFORNIA OCEAN PROTECTION COUNCIL

Previous Inventory Method



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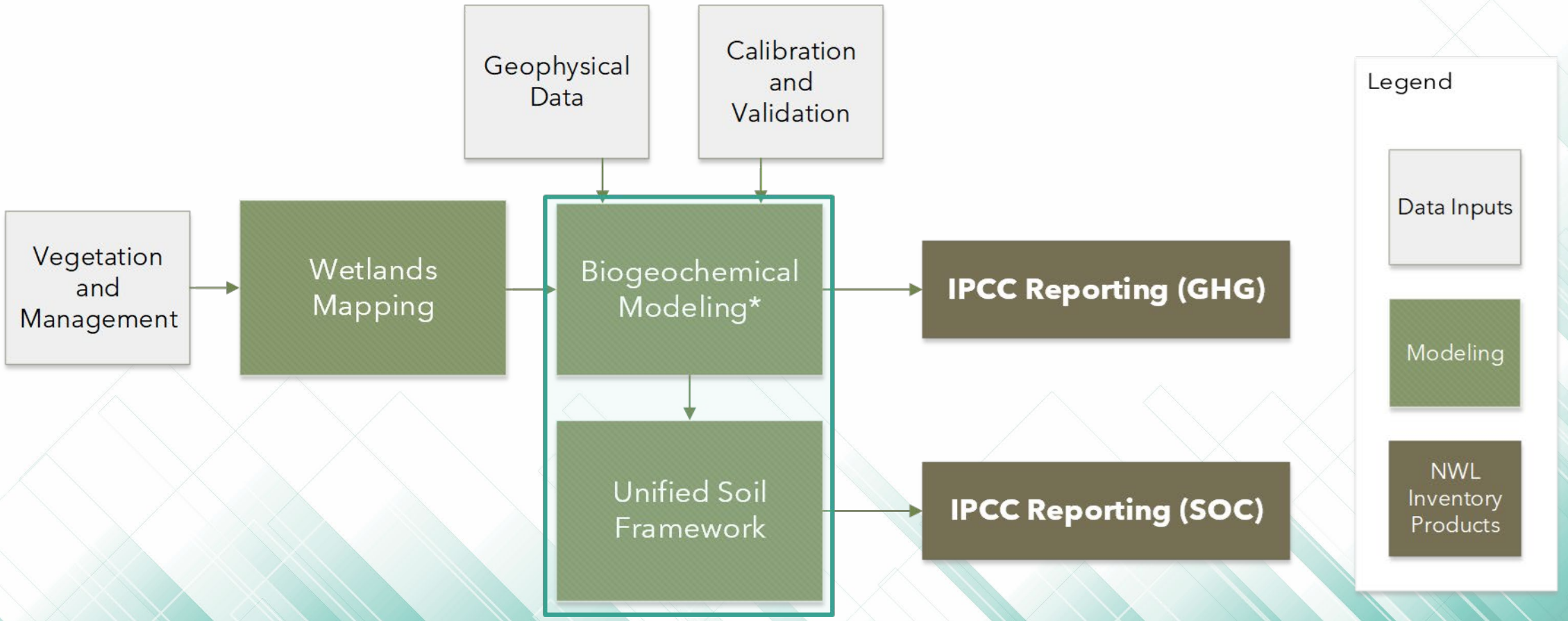
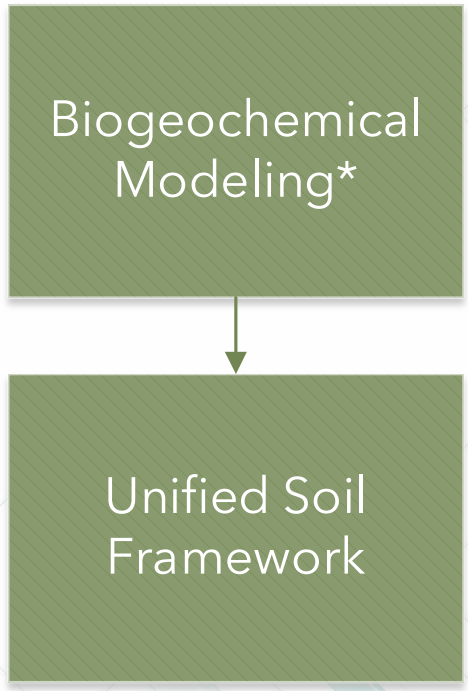
Proposed Method



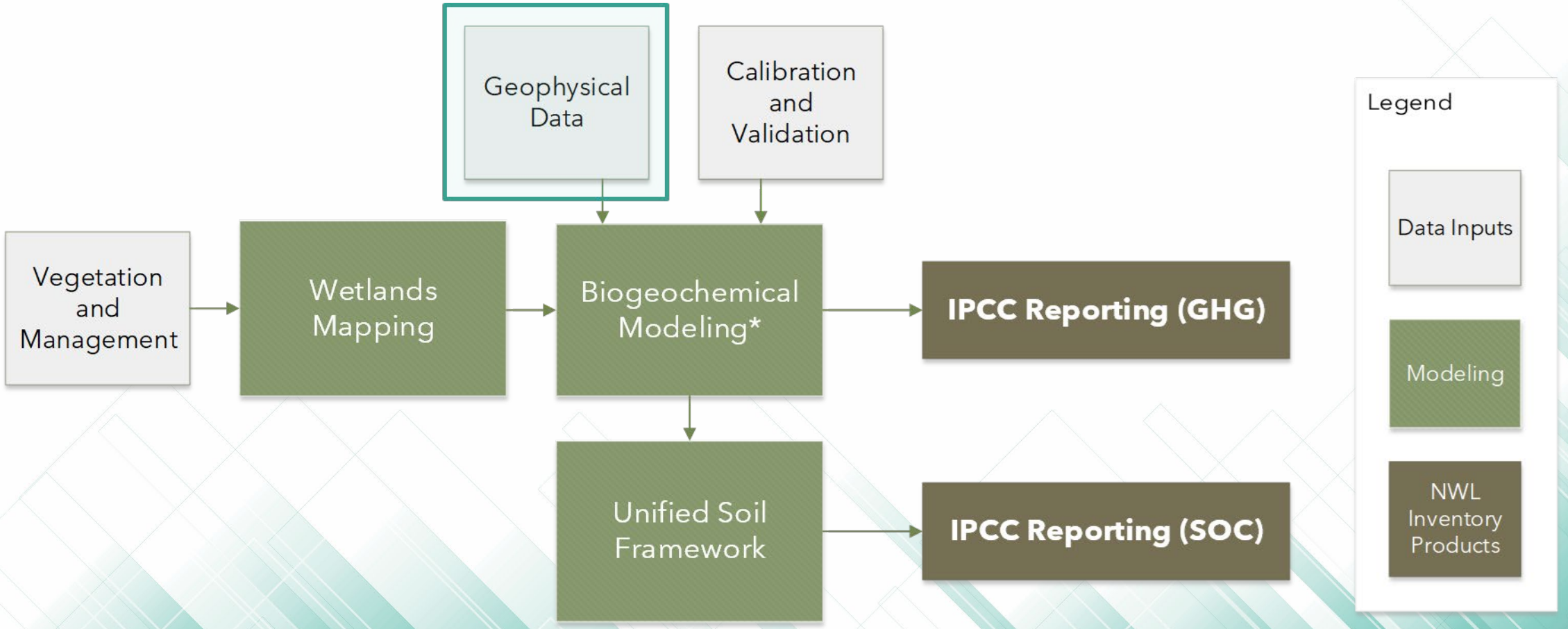
CARB

Biogeochemical Modeling

- Two process-based models will be used:
  - Cohort Wetland Equilibrium Model (Vahsen et al. 2024)
  - Peatland Ecosystem Photosynthesis, Respiration, and Methane Transport Model (Oikawa et al. 2024)
- Model outputs will be scaled through the unified soils framework.
- This will increase the sensitivity of the NWL Carbon Inventory to primary drivers of change.



Geophysical Data



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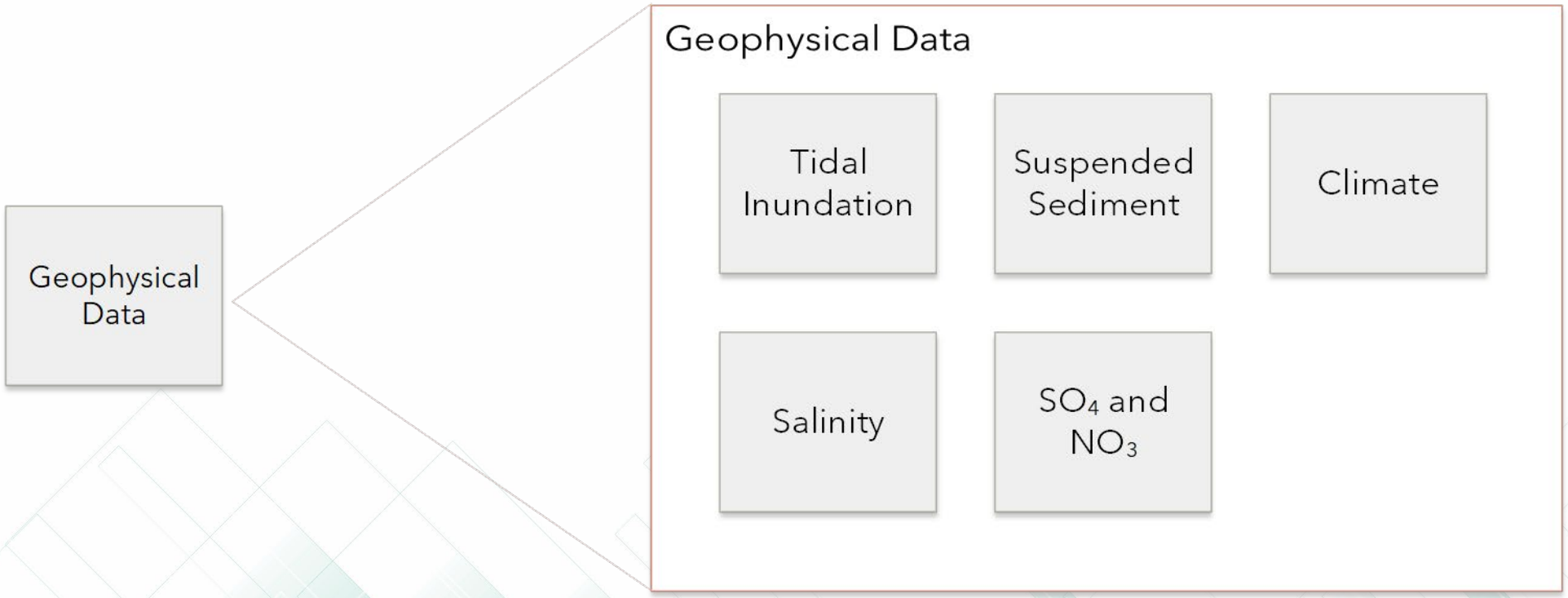
Overview of Geophysical Inputs



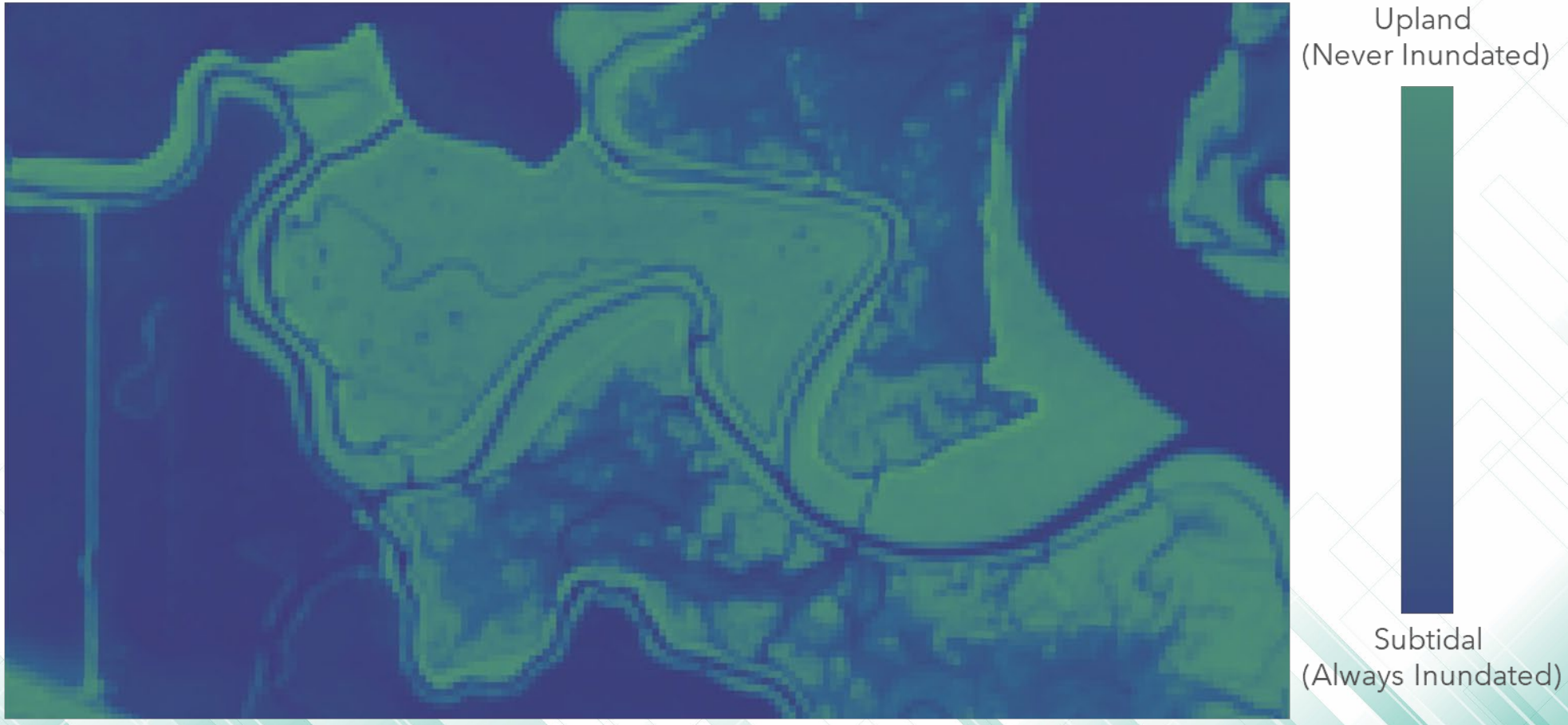
CARB

Tidal Inundation – Aerial Imagery

Aerial Imagery of the Napa Sonoma Marsh

CARB

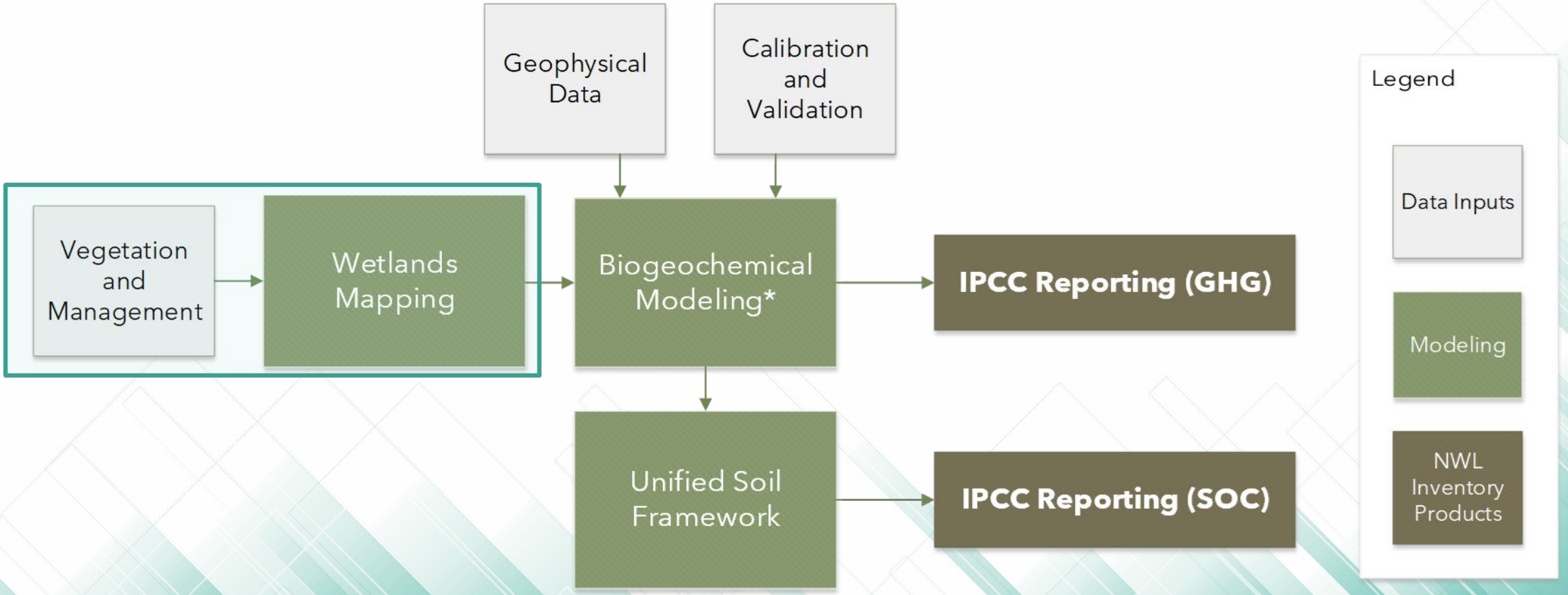
Tidal Inundation – Spectral Imagery



Remotely Sensed Tidal Inundation (Narron et al. 2022)

CARB

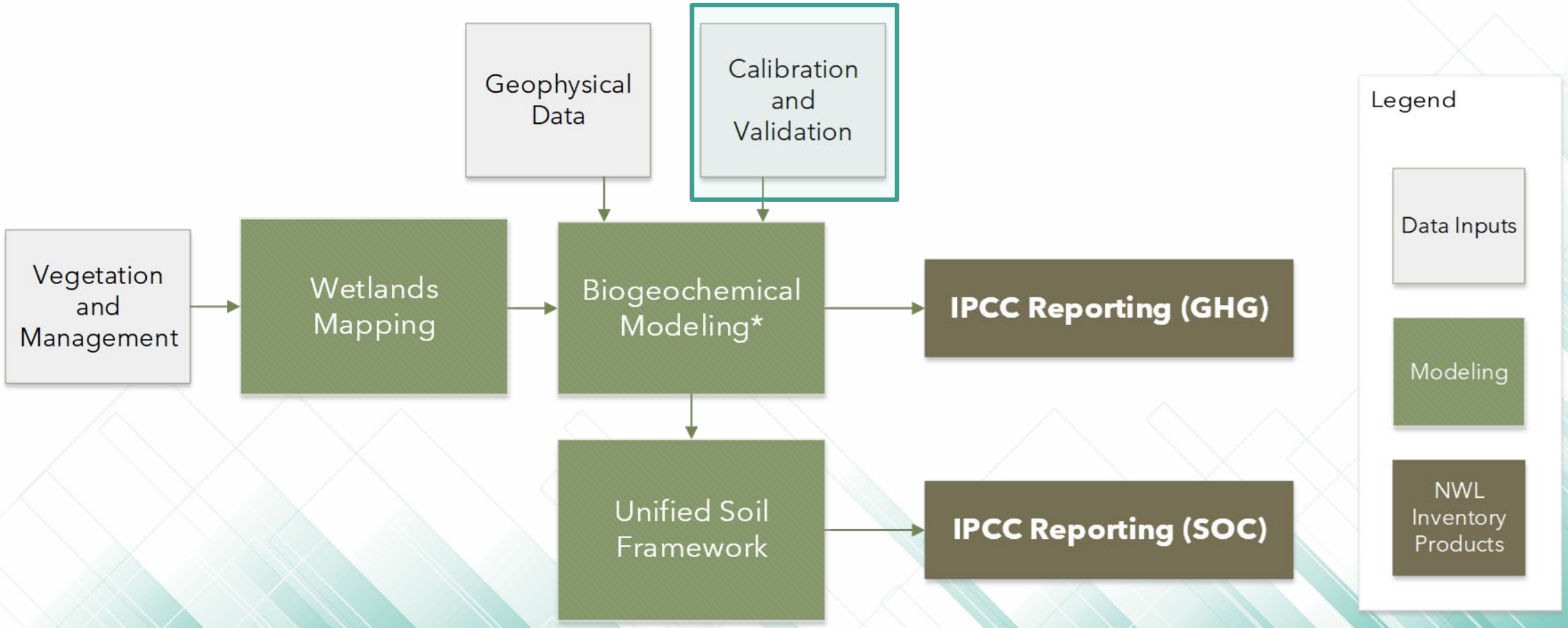
Proposed Method – Mapping



Wetlands Mapping

CARB

Proposed Method – Calibration and Validation



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Soil Carbon Calibration & Validation

- The Coastal Carbon Atlas Dataset provides approximately 350 calibration and validation soil cores across California (Holmquist et al. 2024)

- This includes coastal and Delta wetlands across the state, but does not include data for inland wetland mineral soils

Holmquist et al. 2024

CARB

GHG Calibration and Validation

- Eddy covariance (EC) towers measure landscape-scale fluxes of greenhouse gases (GHG).
- EC data can calibrate and validate GHG flux models.
- In California, eddy covariance data exists for the Delta, San Francisco estuaries, and Elkhorn Slough.

Photo Credit: Matthias Falk

Summary

- The proposed updates would include Coastal and Delta wetlands in the NWL Carbon Inventory using Tier 3 IPCC methods.

- These enhancements are more sensitive to land use change, subsidence, accretion, sea level rise, salinity, management, and restoration.

- Existing limitations and future directions:
  - Inland wetland mineral soils
  - N2O quantification
  - Specific coastal wetlands and seagrass ecosytems

CARB