Coastal wetland carbon accounting: using U.S. syntheses to build up the baseline

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Acknowledgements to MANY colleagues:
* NASA Carbon Monitoring System (18 PI’s, >60 collaborators)
* SOCCR-2: Tidal Wetlands and Estuaries (Chapter 15)
* USGS LandCarbon Program and CEC
Future Methane Soil Biomass Maps Big Picture

cec.org
Terrestrial:Aquatic Interfaces (TAIs)
Small but spatially extensive
Terrestrial:Aquatic Interfaces (TAIs)
complex coupling of land and ocean
SOCCR-2: Coastal zones are net sinks of carbon

Tidal wetlands are small but significant sinks
A brief history of research on tidal wetland C fluxes e.g. Positive influence of SLR on C sequestration until tipping point

Also see Morris et al, AGU Earths Future (2016)
“Blue” Carbon Monitoring System
Leveraging field and remotely sensed data to reduce uncertainty in national inventories of coastal wetland carbon fluxes

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“Blue” Carbon Monitoring System
Can we get beyond Tier 1 using national datasets?

Annual estimated CO₂eq emissions and removals for wetlands remaining wetlands (98%

3 Tg C burial per year
0.2 Tg CH₄ per year

*Biomas C assumed = 0
Goal: Reduce Uncertainty

1. How uncertain are these national layers? (High, Medium, Low)

2. How much better do they need to be to improve GHG accounting?

3. Where are the biggest data gaps?

4. Is the uncertainty with monitoring (quality, coverage) or modeling (process-based understanding)?

5. Tidal Zone

6. Land Cover Change

7. Biomass

8. Soil Carbon Density

9. C Accretion

10. Methane Flux
Land Cover: 2.8M ha mapped tidal wetlands
- NOAA’s Coastal Change Analysis Program (CCAP)
- USFWS National Wetland Inventory (NWI)

Of the 45 Mha of U.S. wetlands (lower 48), 50% are coastal (CCAP) & 6% are tidal (CCAP+NWI).

Of tidal wetlands, 80% are saline and 20% are freshwater.
Land Cover Change: very little wetland loss 1996-2010

Conversions are dominantly Emergent Marsh to Open Water

Conversions are 94% in Louisiana
Summary of Conversions (CCAP 1996-2010):
80% of loss (0.08Mha) = saltmarsh to open-water
75% of gain (0.02Mha) = open-water to saltmarsh
Better maps needed:

- **Tidal zone/connectivity**
- **Salinity** (fresh, mixed, saline)
- **Elevation**

e.g. NWI hydrology modifiers are not consistent with LiDAR or field observations
N=6 sentinel sites

Biomass plots (>2600)
Biomass:
Tidal Marsh

Kristin Byrd, USGS

Modeled: Observed (no bias)

 Fraction Green Veg, of 30m pixel (1mNAIP)
Biomass: Byrd et al (in review)

Universal model for annually reproducible maps at 30m resolution for tidal marsh peak biomass based on LandSat and automated 1m NAIP water/soil/vegetation classification (RMSE = 311, $R^2 = 0.58$)

<table>
<thead>
<tr>
<th>Random Forest Ranger Variable</th>
<th>Relative Importance</th>
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<tbody>
<tr>
<td>Soil-adjusted Veg Index</td>
<td>100</td>
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<tr>
<td>Norm.Diff.Red.Green</td>
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<td>Wide Dynamic Range Veg Index</td>
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<td>Norm.Diff.Green.Blue</td>
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<td>Norm.Diff.SWIR2.Red</td>
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<td>Norm.Diff.SWIR2.NearIR</td>
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<td>Site.Chesapeake</td>
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<td>Site.Everglades</td>
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<td>Site.SanFrancisco Freshwater</td>
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<tr>
<td>Site.San Francisco Bay</td>
<td>4</td>
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<tr>
<td>Site.Louisiana</td>
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<tr>
<td>Site.Puget Sound</td>
<td>0</td>
</tr>
<tr>
<td>Site.CapeCod</td>
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</table>
Tidal Marsh Biomass Model:

- Works across all 6 sites
- Works across all plant forms
Biomass - Mean C Mg/Ha: EEM = 1.8, PEM = 2.0

- Similar stocks across all sites and salinities
- Similar %C tissue conversion (mean 44.1%, n=1384)
Soil C Stock: Community Effort

James Holmquist, SERC

NCSS Pedon Database
Calibration-Validation Dataset
Coastal Conus States

Big Picture Maps Biomass Soil Methane Future

Shimon Anisfeld
Don Barber
Leah Beckett
Thomas Bianchi
Brandon Boyd
Andrew Breithaupt
Lauren Brown
Grace Brush
Kevin Buffington
John Callaway
Kirk Cochran
Chris Craft
Ron DeLaune
Katherine Drake
Judy Drexler
Troy Hill
David Johnson
Michael Kearny
Andrew Kemp
Conrad Kirby
Leper
Glen MacDonald
Helaine Markewich
Nathan McTigue
Patrick Megenigal
Scott Neubauer
Greg Noe
Andy Nyman
Rich Orson
Thomas Quirk
Sarai Piazza
Katrina Poppe
Willy Reay
John Rybysyck
Donny Smoak
Karen Thorne
Tiffany Troxler
USGS-NWRC CRMS
David Walters
Lisa Windham-Myers
Soil C stock is 26.44 g C m$^{-3}$ (SE=1, SD=14)

- similar spatially and downcore

![Graph showing bulk density and carbon mass vs depth and organic matter fraction](image-url)
Soil C density saturates above 0.03
• Similar to EPA NWCA (0.028 g C cm\(^{-3}\))
• Mineral soil < 13.4% Organic matter
C Accretion = f (RSLR)

Redfield, 1965
C Accretion = f (RSLR) but, is it mappable?

Redfield, 1965

https://tidesandcurrents.noaa.gov/sltrends

(-0.2 to 9.7 mm y⁻¹), 92 longterm tidegauges >50y
C Accretion = f (RSLR)  
but, is it mappable?  
Not by 2 tidegauges in LA

Vertical accretion from CRMS dataset  
Jankowski et al 2016, Nature Communications

GSA Today, v. 27, doi: 10.1130/GSATG337GW.1, 2017  
Nienhuis, Tornquist, Jankowski, Fernandez, and Keough

"A New Subsidence Map for Louisiana"
C Accretion = includes allochthonous and labile C Sequestration = direct and longterm C sink

cquest=Bmax*0.084 * SLR/(SLR + ks*0.084*Bmax/(0.085*0.042*10000))

best fit of this equation to the MEM calculations gives ks=0.43, r^2=0.88

~40-200 g C m^-2 y^-1
Methane Flux: > 18 ppt is negligible

CH$_4$ Flux (g CH$_4$ m$^{-2}$ yr$^{-1}$) vs. Salinity (ppt)

- Grey circles: Poffenbarger et al. (2011)
- Black circles: Since 2011 SC
- Black triangles: Since 2011 EC

Poffenbarger et al. (2011)
Since 2011 SC
Since 2011 EC

△ USGS, San Francisco Bay, CA 2014-17

Sara Knox, USGS
Methane Flux – Eddy Covariance Approach

draft data (Anderson, Knox)

Low Emissions (~ 1.2 g CH$_4$ m$^{-2}$ y$^{-1}$) No clear f(salinity) or f(NEE)

Rush Ranch, CA

Suisun Marsh CH$_4$ Flux vs. Salinity (2014)
# Future – what does this mean C Accounting in tidal wetlands?

<table>
<thead>
<tr>
<th></th>
<th>Mg CO(_2)eq/ha</th>
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<th>Mg CO(_2)eq/ha</th>
<th>Mg CO(_2)eq/ha</th>
<th>Mg CO(_2)eq/ha</th>
<th>Mg CO(_2)eq/ha</th>
<th>Mg CO(_2)eq/ha</th>
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<td>70% EEM-EEM</td>
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<td>+981</td>
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<td>0</td>
<td>0</td>
<td>+7.4</td>
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<td>10% PFO-PFO</td>
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<td>0</td>
<td>0</td>
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<td>2% EEM-OW</td>
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<td>1% PEM-EEM</td>
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<td>1% PSS/FO-EEM</td>
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</tbody>
</table>

1. **Biomass Stocks and Soil Stocks:**
   - Regional variation is minor
   - Remaining variation is salinity and relative elevation (high/low marsh)
2. **Accretion is difficult to model due to within-basin variability**
3. **Key uncertainties are tidal zone map and methane variability**
Future – what does this mean C Accounting in tidal wetlands?

Relevant elevation (cm scale) by merging remotely sensed (LiDAR, spectral) and ground data is a critical modeling and monitoring need for C fluxes.
Vertical Errors Prior To Correction by Community (Training Points)

- Correction Factors / Mean Vertical Errors

Holmquist, Riera et al., In Prep.
Vertical Errors Distribution Prior To Correction (Training Points)

Mean = 0.192m
Std. Dev. = 0.114m
N = 413

Holmquist, Riera et al., In Prep.
Vertical Errors After Correction (Validation Points)

- Validation Points
  - Vertical Error (m)
  - Frequency

Mean = 0.019m
Std. Dev. = 0.088m
N = 137

Holmquist, Riera et al., In Prep.
2011 Anne Arundel County DEM (MD)

Holmquist, Riera et al., In Prep.
Corrected 2011 Anne Arundel County DEM

Holmquist, Riera et al., In Prep.
Model Validation with Biomass

Holmquist, Byrd, Megonigal, In Prep.
MEM projections (draft) – to illustrate elevation sensitivity

Corrected

Not Corrected

Holmquist, Riera et al., In Prep.
<table>
<thead>
<tr>
<th>Site</th>
<th>Cit</th>
<th>n</th>
<th>RMSE</th>
<th>ME</th>
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<tbody>
<tr>
<td>GCREW - before</td>
<td>Holmquist, Reiera, et al., In Prep</td>
<td>413</td>
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<tr>
<td>Grays Harbor</td>
<td>Buffington et al., 2016</td>
<td>1166</td>
<td>0.466</td>
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<td>Willapa</td>
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<td>1465</td>
<td>0.155</td>
<td>0.154</td>
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<td>3208</td>
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<td>0.147</td>
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<td>Newport</td>
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<td>962</td>
<td>0.183</td>
<td>0.14</td>
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<td>Tijuana</td>
<td>Buffington et al., 2016</td>
<td>896</td>
<td>0.113</td>
<td>0.084</td>
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<tr>
<td>Sapelo Island - Total</td>
<td>Hladik and Alber, 2012</td>
<td>1380</td>
<td>0.18</td>
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<td>lower Apalachicola River Marsh</td>
<td>Mederios et al., 2015</td>
<td>229</td>
<td>0.65</td>
<td>0.61</td>
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<tr>
<td><strong>SUM</strong></td>
<td></td>
<td>19762</td>
<td>Average:</td>
<td>0.2215</td>
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</tbody>
</table>

Bias Overwhelmingly Positive: Marsh DEMs are too high.
Error Propagation Varies Geographically Based on Tidal Range

- Tidal Range = High Tide (MHW) - Mean Sea-Level (MSL)
- Tidal Range varies across U.S.:
  - Small for Gulf Coast, FL, and Chesapeake Bay,
  - Large for PNW and New England.
- Bias propagates with different levels of seriousness depending on tidal range.

Vegetation-Related Error

Marsh Surface

Macro-Tidal

Micro-Tidal
Error Propagation: Microtidal Gulf Coast is most susceptible to overestimated resilience

0.222 m Error Propagation for Dimensionless Elevation

- 3.9
- 0.08
Future: What does this mean for C Science in tidal wetlands?

BIG QUESTIONS COMING OUT:
Why do soils saturate with carbon?
Why do compaction and decomposition rates appear to be connected?

PROPOSAL:
burial = constant (may be variable with annual SLR or not; suggest decadal scale)
lateral C flux IS proportional to NEE

\[ \text{Lateral flux} = \text{NEE} - \text{Burial} \]
\[ \text{Burial} = \text{NEE} - \text{Lateral} \]
\[ \text{NEE} = \text{Burial} + \text{Lateral} \]
Future – What does this mean for C scientists?
We’ve got a lot of exciting work to do and datagaps to fill.

THANK YOU!
lwindham@usgs.gov