Modeling Terrestrial Methane Biogeochemistry in CLM4Me

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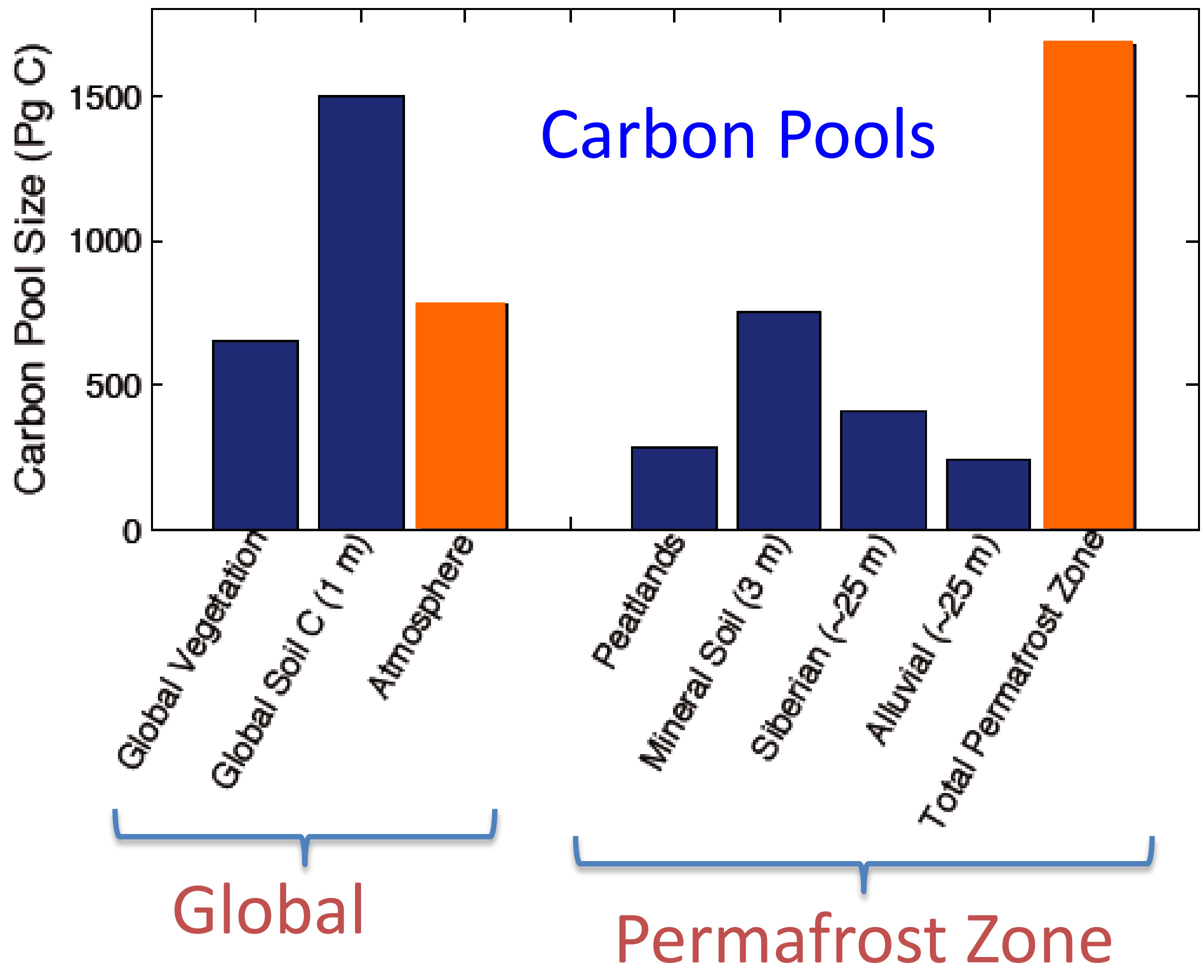
Motivation for Modeling High-Latitude BGC

- Biogeochemical climate feedbacks include C loss from veg. and soil.
- Wet conditions release CH_4 as well as CO_2.



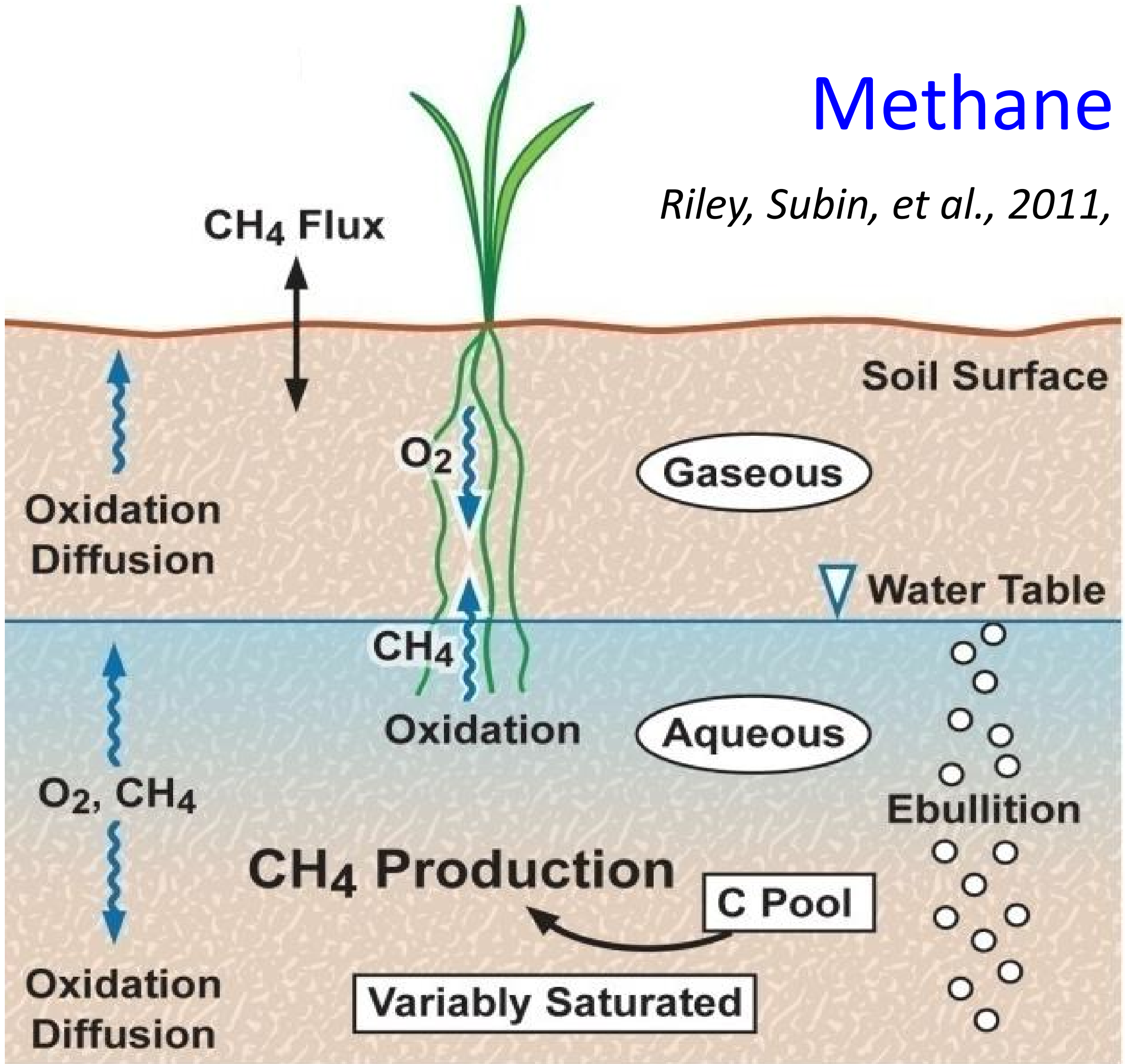
[Jobaggy 2000, Field et al. 2007, Zimov et al. 2006, Tarnocai et al. 2009, Schuur et al. 2008]

LBNL Subsurface Modeling

- Mechanistic process representations
  - Explicit vertical resolution
  - Transport of chemical species
- Required to accurately estimate feedbacks
  - Without correct mechanisms for preserving soil C, models cannot accurately predict its release.
- CLM4Me starts this approach for methane
  - First terrestrial methane model integrated into CESM1
  - To be released in CLM4.5 in 2012

Methane Cycling

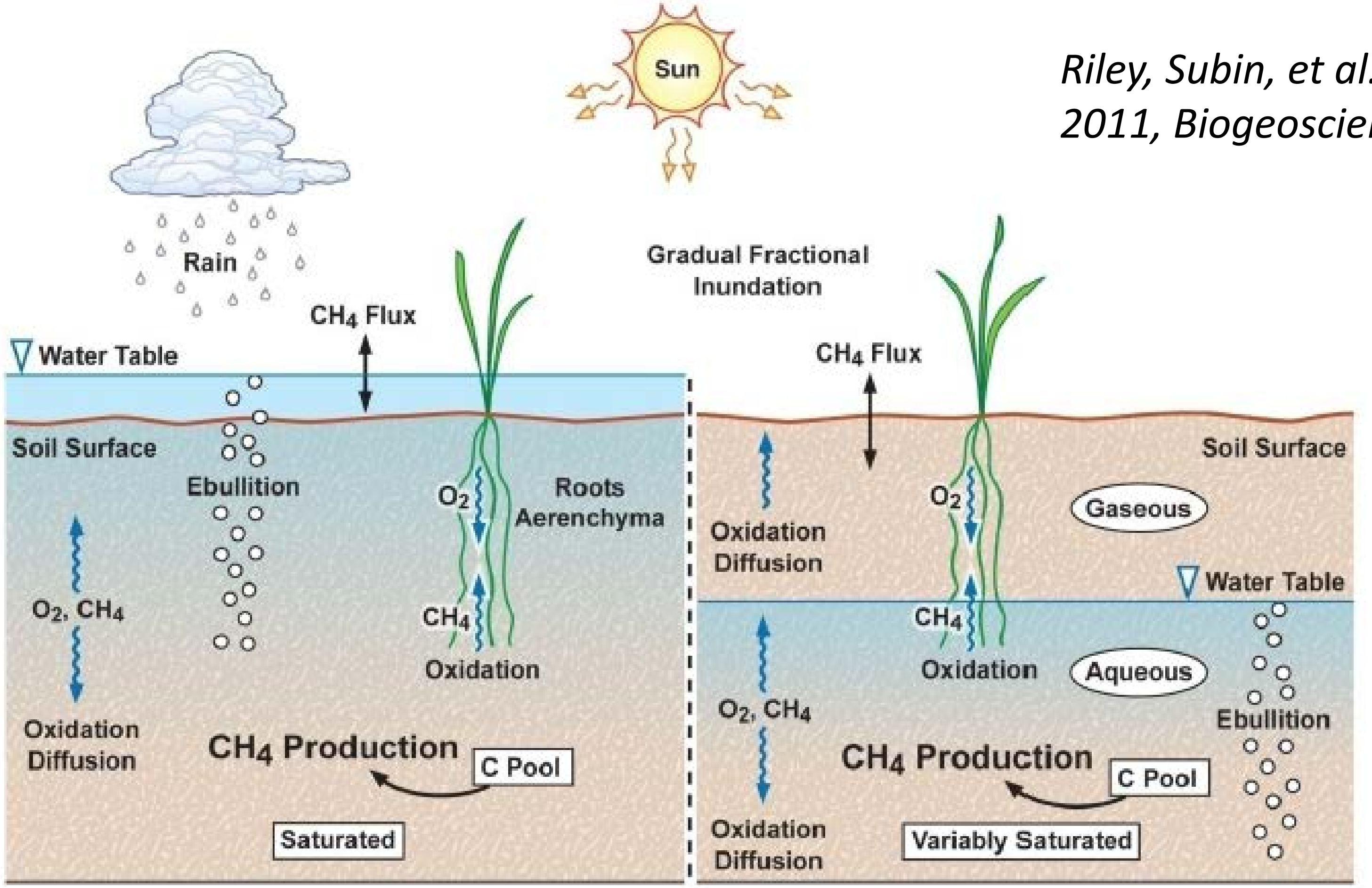
Riley, Subin, et al., 2011, Biogeosciences



- Net emissions are often a small difference between large gross fluxes with different large environmental sensitivities.
- Aqueous chemistry limits production but is difficult to predict at a GCM scale.

CLM4Me

Riley, Subin, et al., 2011, Biogeosciences



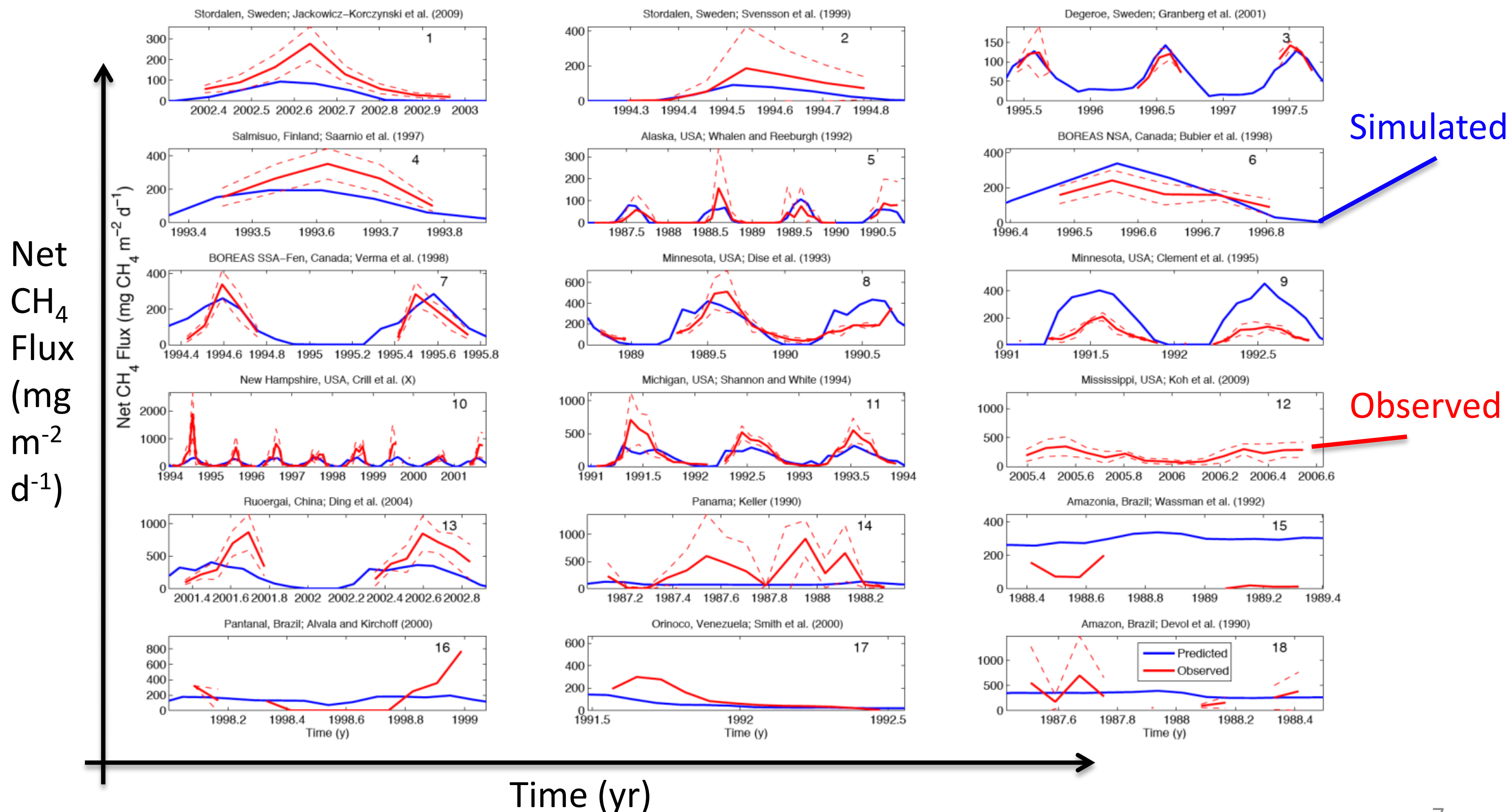
- 2 reactions + 3 transport mechanisms
- Fractional inundation based on model-satellite hybrid
  - Model runs twice in each gridcell for inundated and “upland” fraction

CLM4Me Modeling Philosophy

- Directly measureable processes (when possible): not parameterization of site-scale net fluxes
  - Large spatial heterogeneity in system properties
  - Tuning can be under-determined with sparse data on gross fluxes
- Self-consistent 1D ecosystem patches
  - Energy, water, and chemical species satisfy 1D reaction-transport equations

Comparison to Site Observations

- Inconsistent site performance indicates spatially explicit parametric uncertainty and/or missing processes



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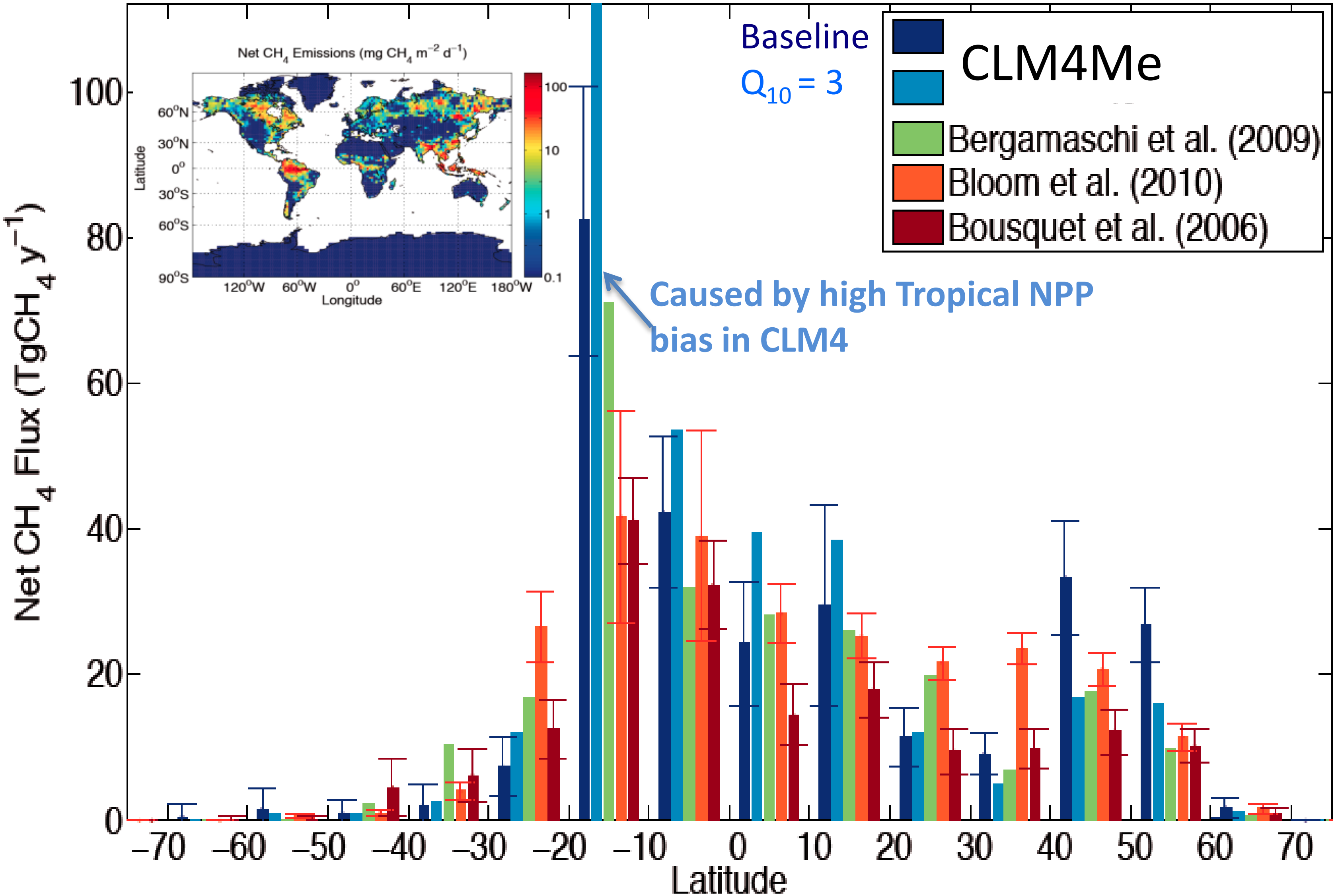
Comparison to Atmospheric Inversions



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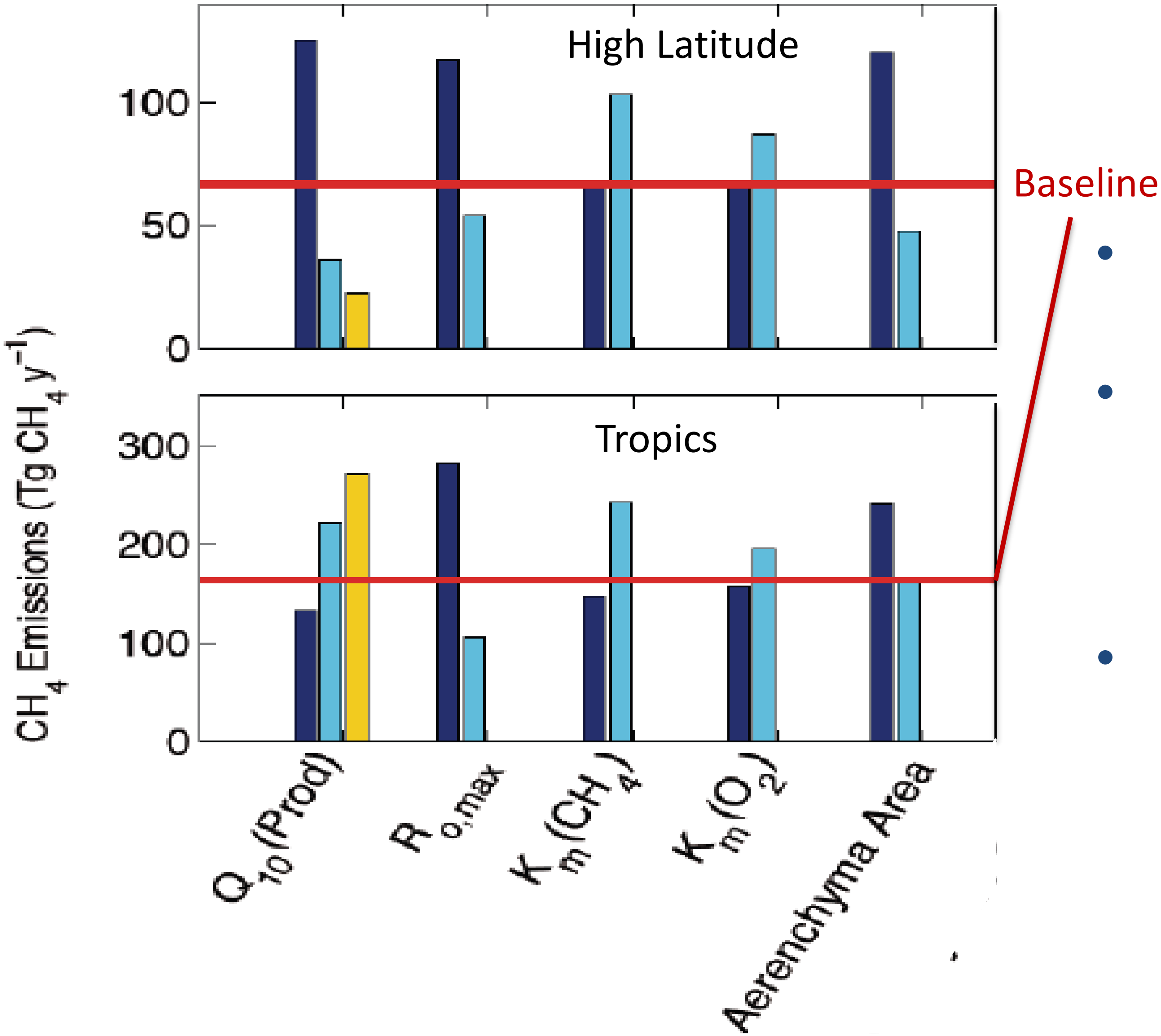
Parametric Uncertainty of Present-Day Fluxes



- Based on literature parameter ranges
- 3x global;
  5x regional;
  10x site
  flux sensitivity
- Global models not quite ready for conclusive 21st century experiments?

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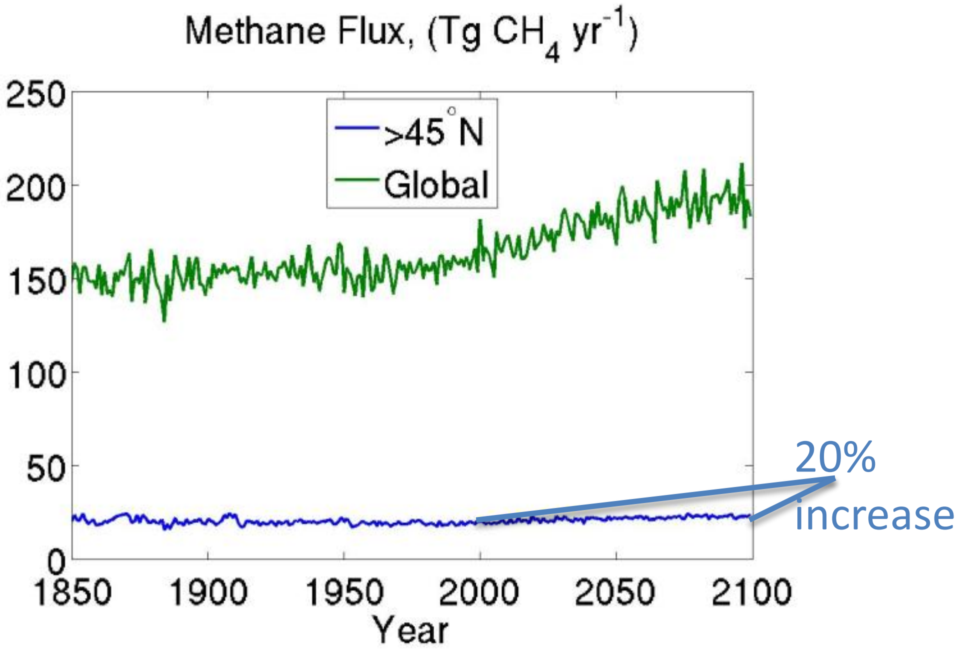
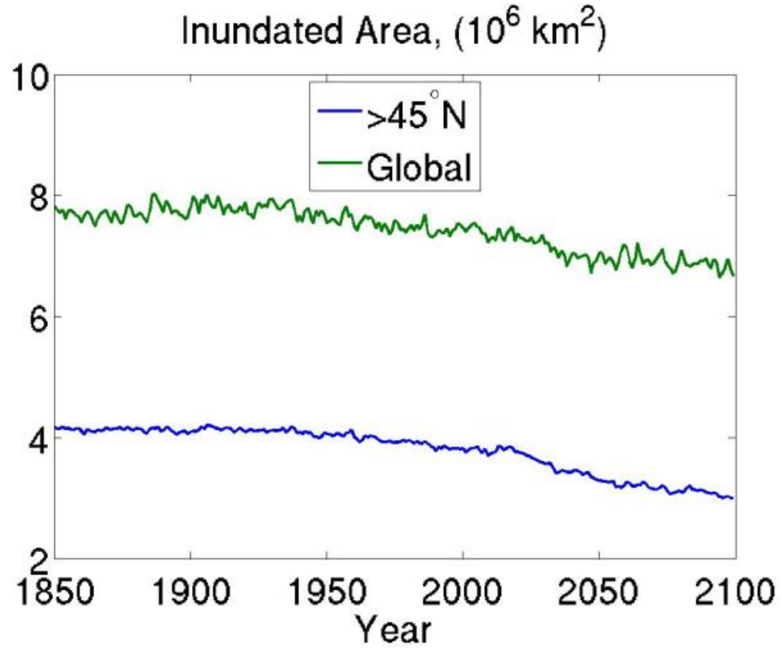
CCSM4 RCP 4.5 Scenario





- Substrate (not rate) limitation on methanogenesis
- CLM4+ hydrology predicts loss of inundated area in continuous permafrost regions
- *Model structure → little old carbon source*
  - *Atm. biases also limit tundra productivity in coupled model*

LBNL Path Forward

- Focus on predicting net C balance of wetlands and bounding plausible CH_4 scenarios
  - How will peatlands contribute to the high-latitude C feedback (200-300 Pg C)?
  - Coupling between soil physics & biochemistry
- Improving model structure
  - Vertically-resolved C & N (C.D. Koven) with permafrost preservation
  - Subgrid wetlands with anoxia, moss vegetation, and dynamic peat profile (Z.M. Subin)
  - Microbial pools and aqueous chemistry (J. Tang)

Ways NGEE Could Inform Wetland BGC Models

- Wetland type transitions (bog, fen, or lake)
- Subgrid wetness gradient
  - Scaling of ~1 m heterogeneity
- Thermokarst
- Dynamic vegetation
- Interactions of climate and aqueous chemistry

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Conclusions

- CLM4Me is the first attempt to model terrestrial CH_4 in CESM and will be released to the community.
- Coarse-scale 21st century changes in high-latitude hydrology and plant productivity may not cause a large increase in CH_4 emissions.
- Before we can have confidence in the high-latitude CH_4 feedback, more work is needed to improve model structure and use observations and fine-scale models to reduce parametric uncertainty.

Acknowledgements

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Extras

Conclusion

Riley, Subin, et al., 2011, Biogeosciences

- Large parametric uncertainty in present wetland CH_4 emissions
  - Temperature sensitivities
    - Oxidation vs. production
    - Substrate vs. rate limitation
  - CH_4 : CO_2 production
  - Oxidation microbial kinetics
  - Vegetation properties (e.g., aerenchyma)
- Sensitive to details of subgrid hydrological representation
- Additional model deficiencies and structural uncertainty

Model Development Components

- Moss vegetation
- Prognosing soil physical properties, including variable thickness peat horizon, based on soil C accumulation
- Prognostic water table in wetlands
- Anoxia, vertical C & N, ^{14}C tracer (Charlie Koven)
- Link with O_2 transport in CH_4 model

It would be really nice to have:

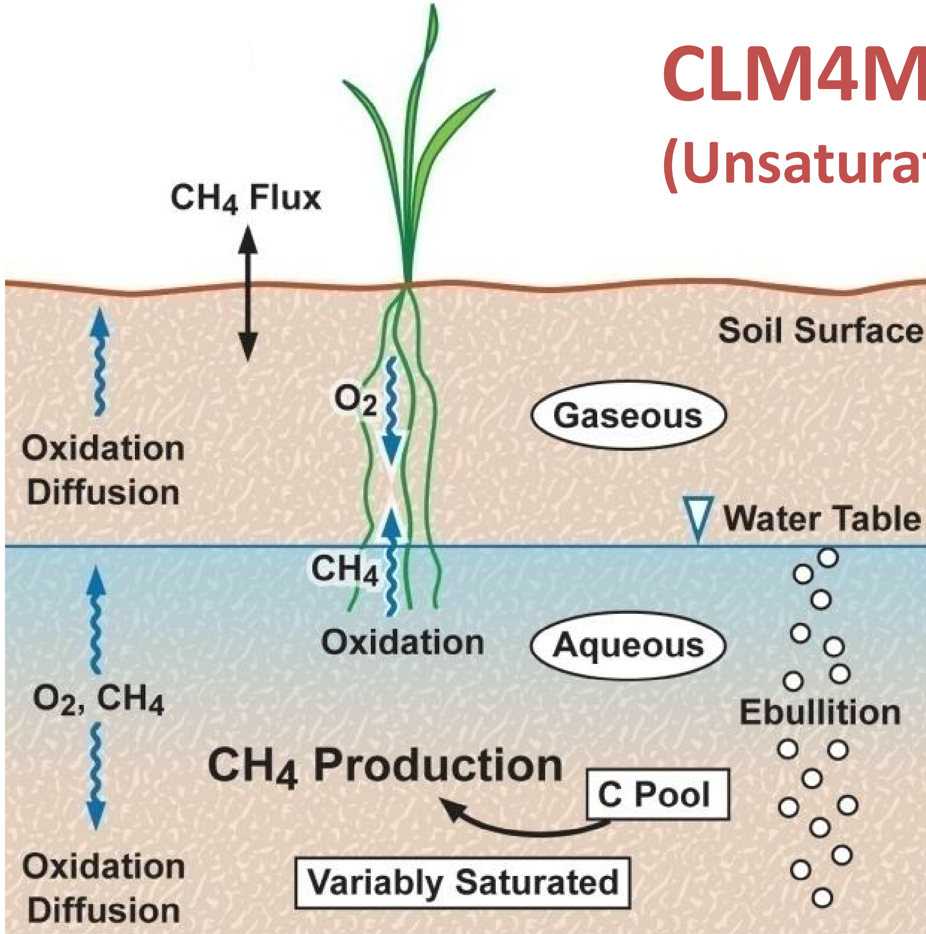
- Dynamic wetland area
- Integration with river model; DOM export (& import)
- Dynamic vegetation distribution
- Prognostic bog & fen proportions and soil chemistry

Challenges

- Model conceptual dichotomy:
  - Dynamic inundated fraction (varying sub-seasonally)
  - Separate wetland ecosystems with different belowground properties (1000+ year memory)
- Fine-scale (~1 m) variability with nonlinear effects on gridcell average C fluxes
- Horizontal hydrological interactions
- Peatland inundated fraction may not be well-predicted by topography

CLM4Me

(Unsaturated Fraction)



Solved for both CH_4 and O_2
(CH_4rxns shown here)

$$\frac{\partial (RC)}{\partial t} = \frac{\partial F_D}{\partial z} + P(z,t) - E(z,t) - A(z,t) - O(z,t)$$

Net change

Diffusion

Production

Ebullition (bubbling)

Aerenchyma (tissue)

Oxidation

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