NATURAL RESOURCE ECOLOGY LABORATORY

Colorado State University

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Use of Remote Observation to Verify N_2O Emissions from Land

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

USDA

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Globally important nitrous oxide emissions from croplands induced by freeze–thaw cycles

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Abstract

Seasonal freezing induces large thaw emissions of nitrous oxide, a trace gas that contributes to stratospheric ozone destruction and atmospheric warming. Cropland soils are by far the largest anthropogenic source of nitrous oxide. However, the global contribution of seasonal freezing to nitrous oxide emissions from croplands is poorly quantified, mostly due to the lack of year-round measurements and difficulty in capturing short-lived pulses of nitrous oxide with traditional measurement methods. Here we present measurements collected with half-hourly resolution at two contrasting cropland sites in Ontario and Manitoba, Canada, over 14 and 9 years, respectively. We find that the magnitude of freeze–thaw-induced nitrous oxide emissions is related to the number of days with soil temperatures below 0 °C, and we validate these findings with emissions data from 11 additional sites from cold climates around the globe. Based on an estimate of cropland area experiencing seasonal freezing, reanalysis model estimates of soil temperature, and the relationship between cumulative soil freezing days and emissions that we derived from the cropland sites, we estimate that seasonally frozen cropland contributes 1.07 ± 0.59 Tg of nitrogen as nitrous oxide annually. We conclude that neglecting freeze–thaw emissions would lead to an underestimation of global agricultural nitrous oxide emissions by 17 to 28%.

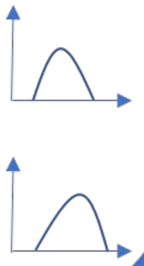
Tier 3 DayCent Ecosystem Modeling Platform

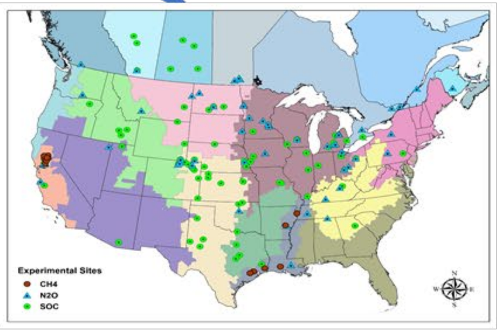
Model Development/ Calibration

Parameter Sensitivity Analysis

Sampling Importance Resampling

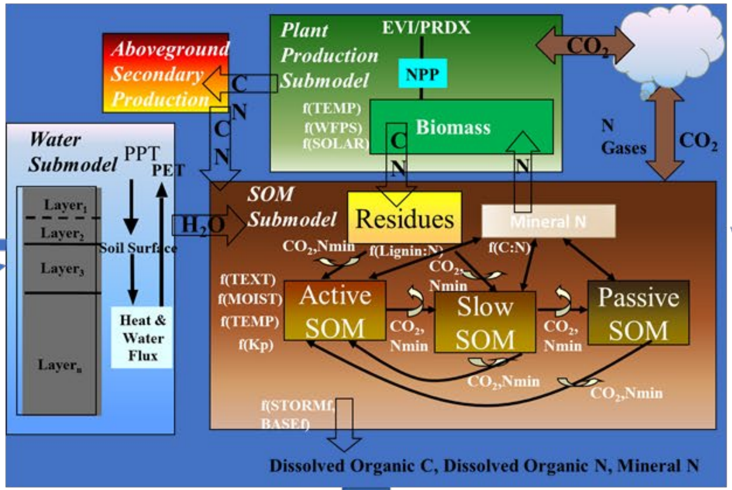
Posterior Parameter Distributions



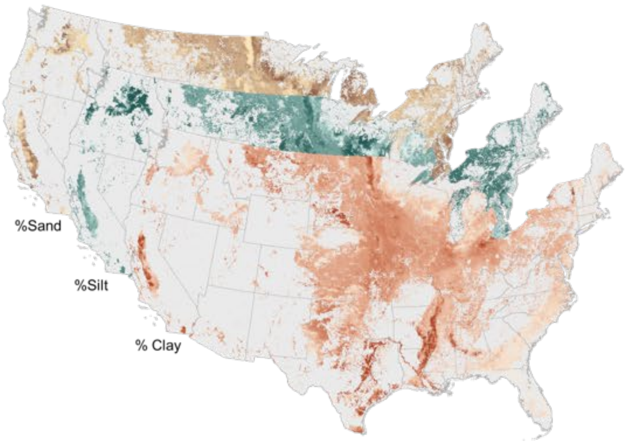


Observations

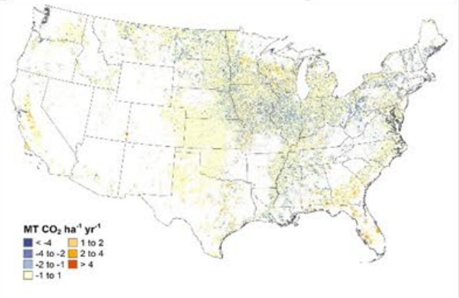
DayCent Ecosystem Model



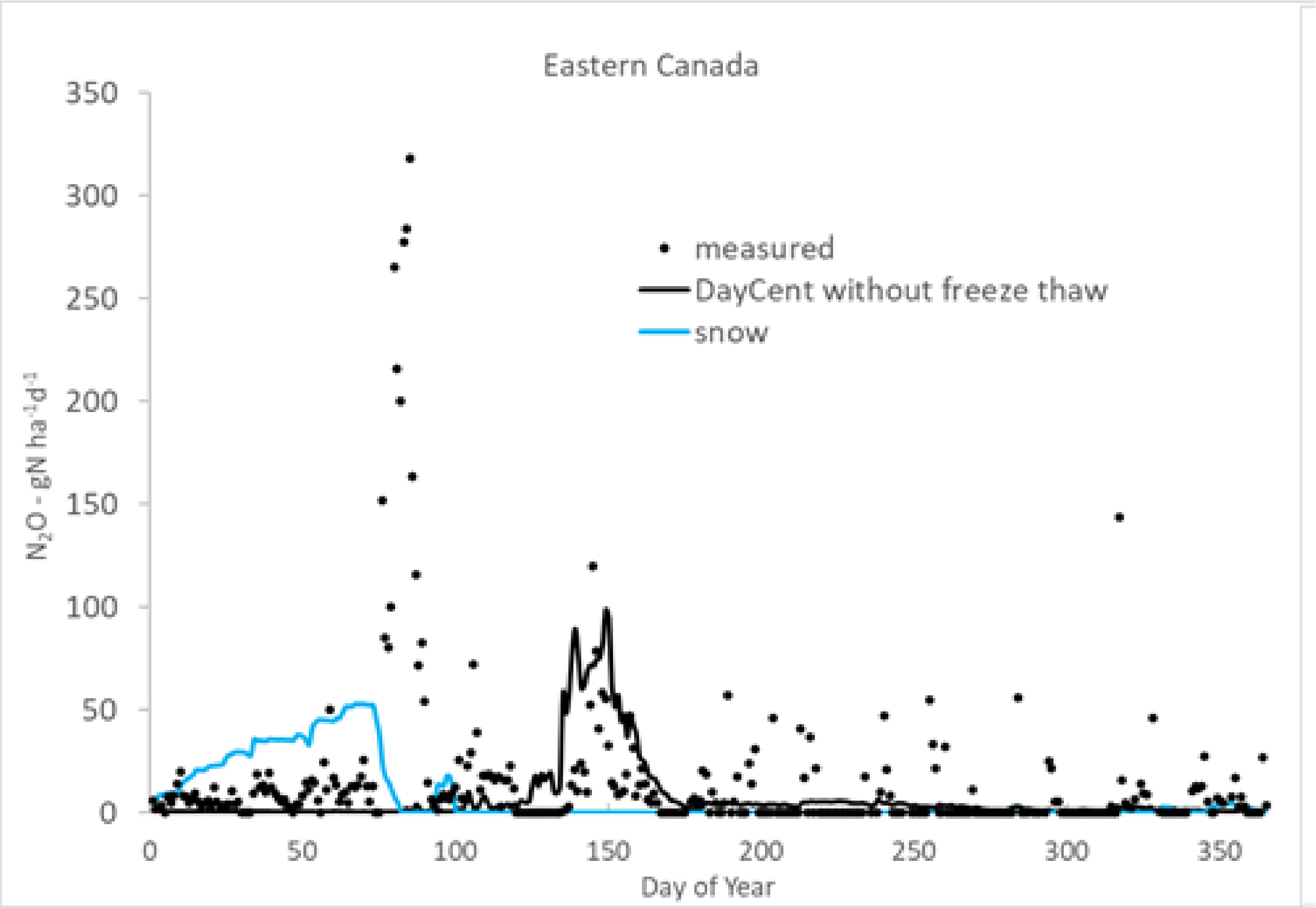
Input Data: Geospatial Datasets/Surveys (e.g., soil texture)



Output Data: SOC Stock Changes, N_2O emissions, CH_4 emissions

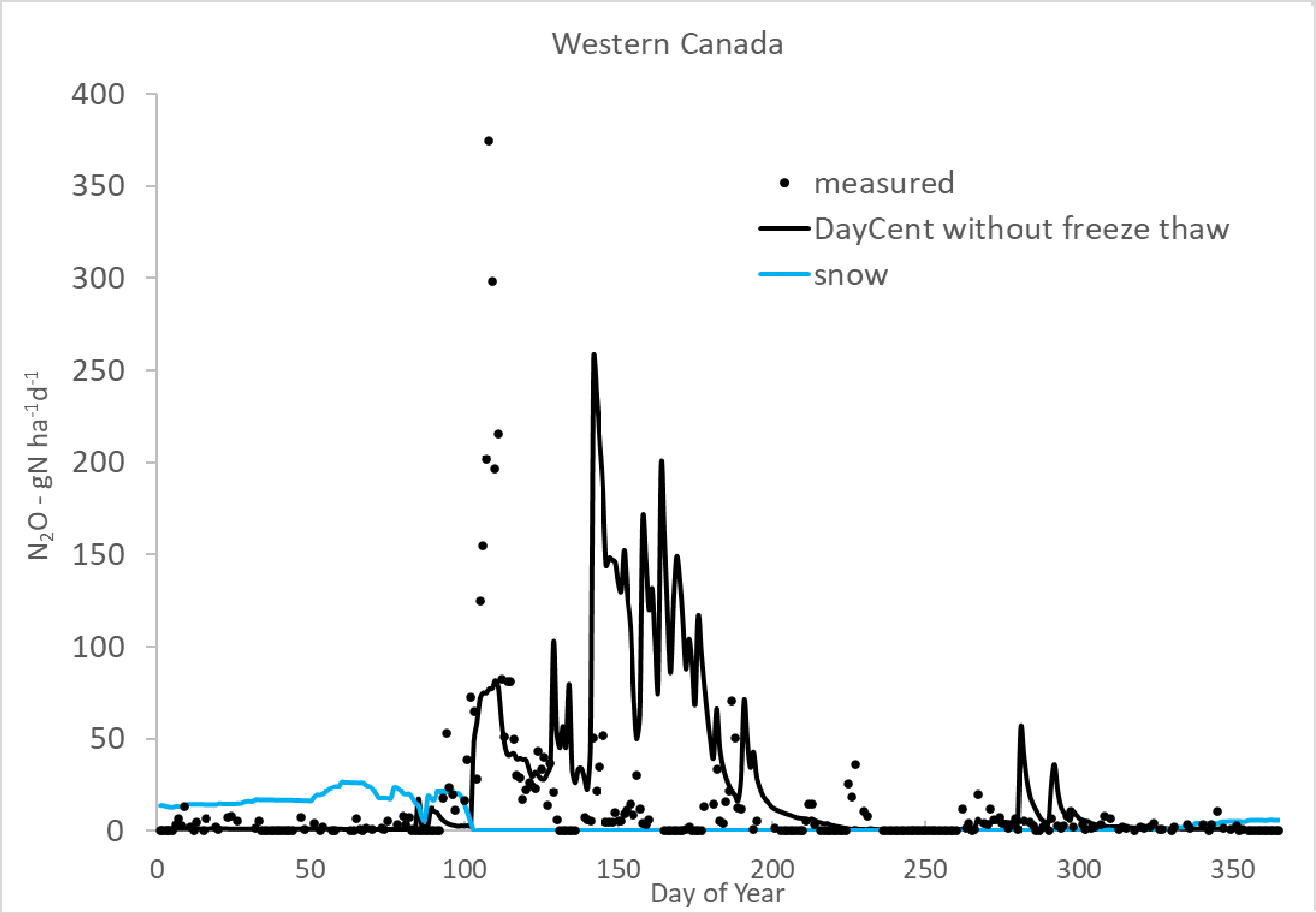


Eastern Canada (Elora Experiment)



Del Grosso et al. , 2022, PNAS

Western Canada (Glenlea Experiment)



Del Grosso et al. , 2022, PNAS

Objectives

- Represent the impact of freeze-thaw cycles on pulses of soil N_2O emission in the DayCent Ecosystem Model
  - Model development, testing and evaluation
  - Used ground-based flux data and atmospheric inversion data
- Recalculate direct soil N_2O emissions for the US National GHG Inventory Reporting to the UNFCCC

Developing Freeze Thaw Routines

Atmospheric Inversion

Tier 3 Inventory Analysis

Evaluating Inventory with Inversion

Freeze-Thaw Cycles

- Denitrification is enhanced during freeze-thaw events (Groffman et al. 2009; Kim et al. 2012; Risk et al. 2013)
- Labile organic matter accumulates when soils are frozen during the winter due to greater root senescence and microbial death in frozen soils
- Thawing increases moisture levels in the soil and limits O_2 diffusivity, creating more anaerobic conditions
- Differing temperature sensitivities of the enzymatic processes that control the amounts of N_2 and N_2O from denitrification

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Modeling Freeze-Thaw Events

- Event Trigger
  - Snow melt or thawing in the upper soil profile
- Drivers
  - Remove respiration constraints and/or shift in water-filled pore space constraints
  - Cumulative Freezing Degree Days (Wagner-Riddle et al. 2017)
    - Magnitude of event, minimum threshold for event to occur, and/or maximum threshold with no further enhancement

Model Parameterization

- **Optimization routine with latin hypercube sampling from parameter distributions**
  - **RMSE =** $\sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}}$
  - **Relative Bias =** $\frac{\sum_{i=1}^{n}(O_i - P_i)/O_i}{n}$
  - **Correlation coefficient**

Modeling Freeze-Thaw Events

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- Drivers
  - Remove respiration constraints
  - Shift in water-filled pore space constraints
  - Cumulative Freezing Degree Days (Wagner-Riddle et al. 2017)
    - Magnitude of event

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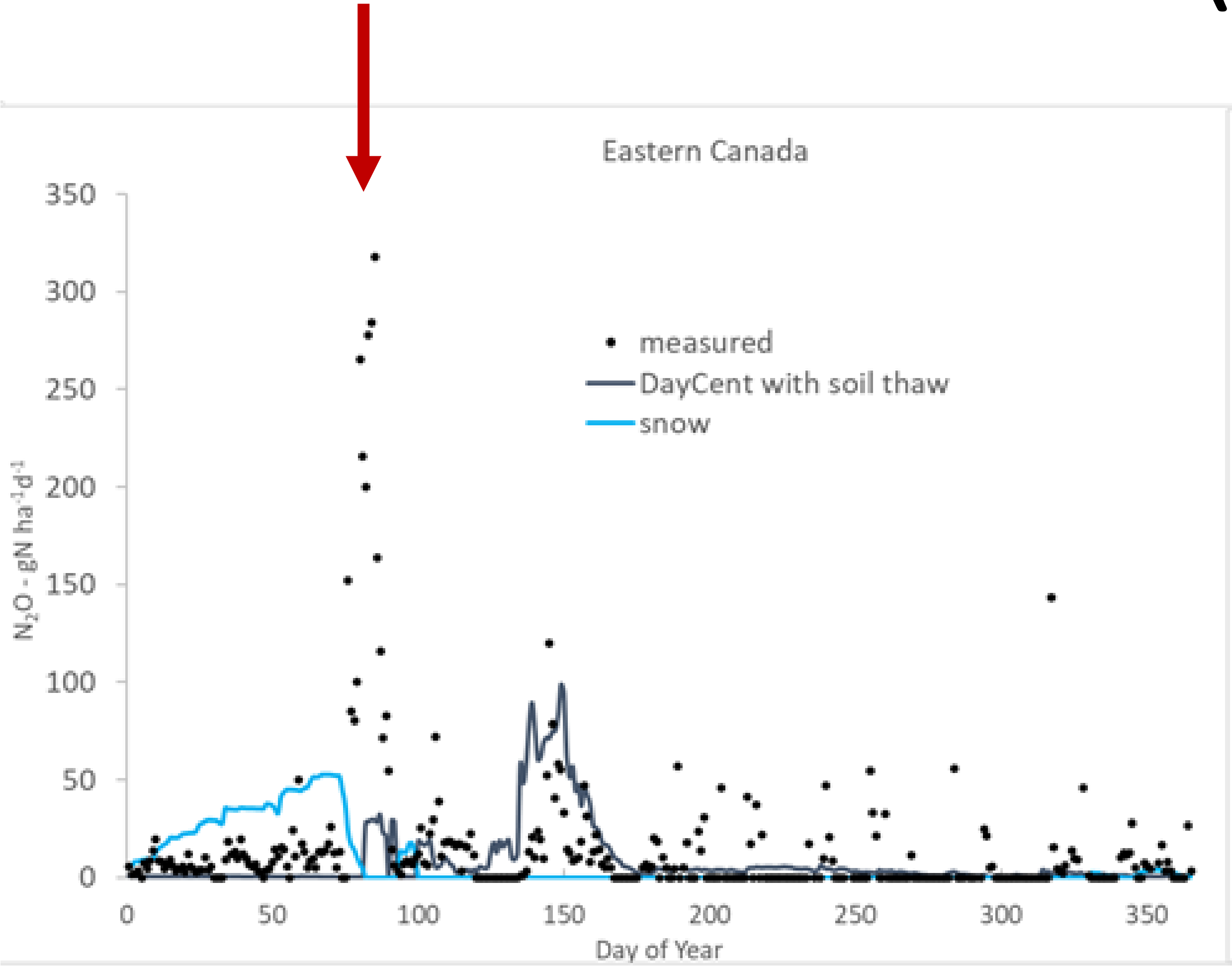
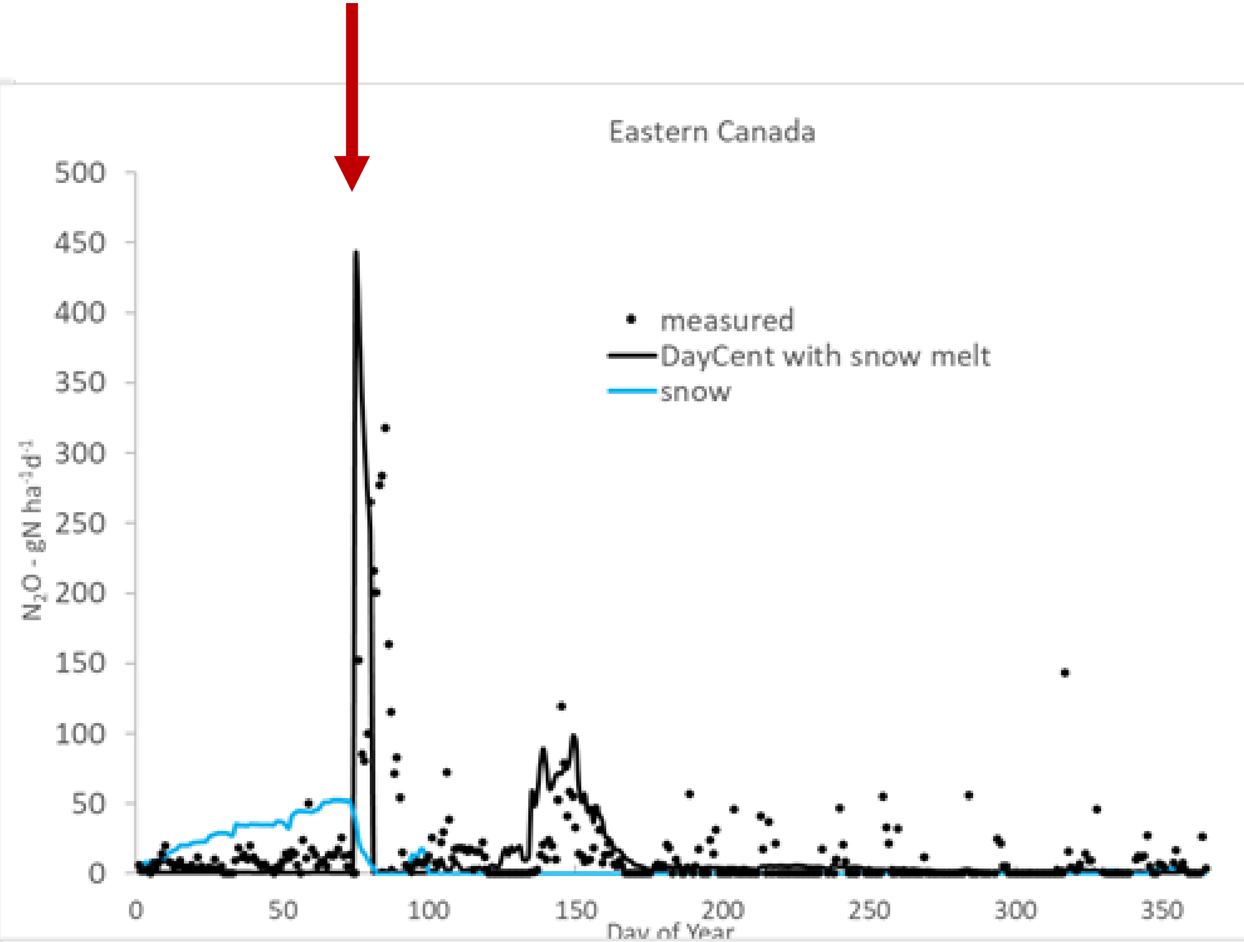
Eastern Canada (Elora Experiment)





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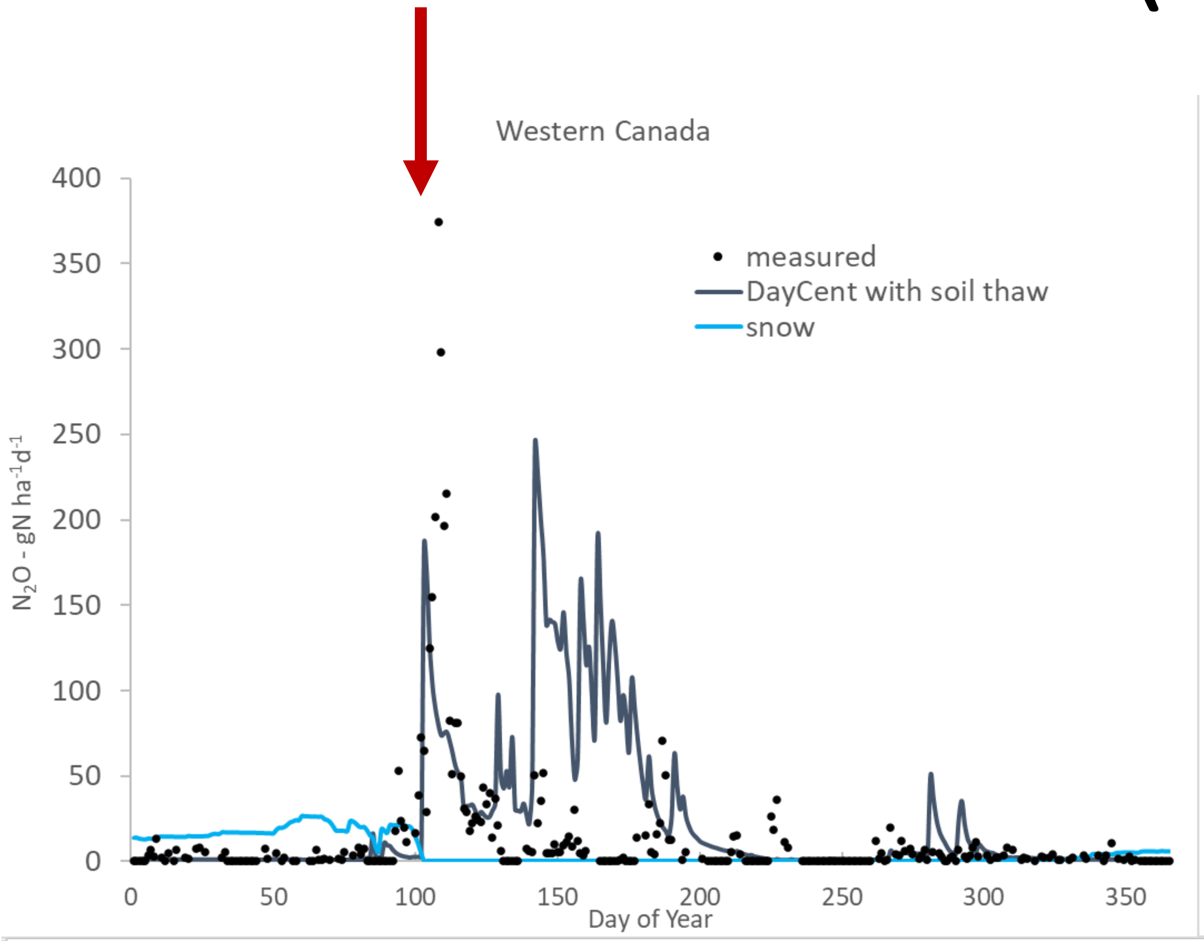

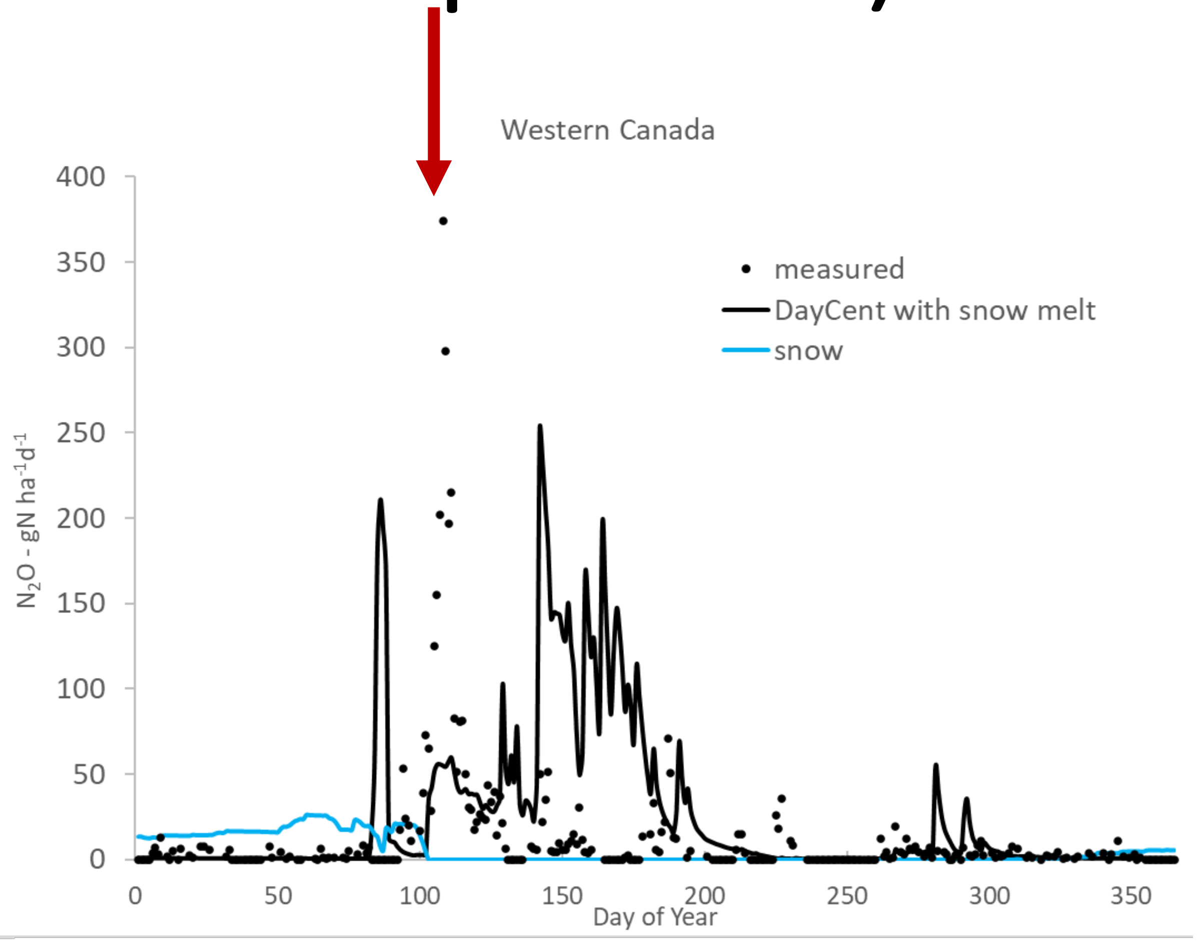

Del Grosso et al. , 2022, PNAS

Developing Freeze Thaw Routines

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CarbonTracker-Lagrange (CT-L) regional N_2O Inversion

- North American domain with a 1°x1° spatial resolution
- Jan 2007-Dec 2020, daily time step
- Transport using WRF-STILT and NAMS-HYSPLIT particle back trajectories
- Ground and aircraft N_2O data from NOAA GGGRN
- Bayesian inversion framework
  - Minimize cost function and solve for optimized N_2O flux

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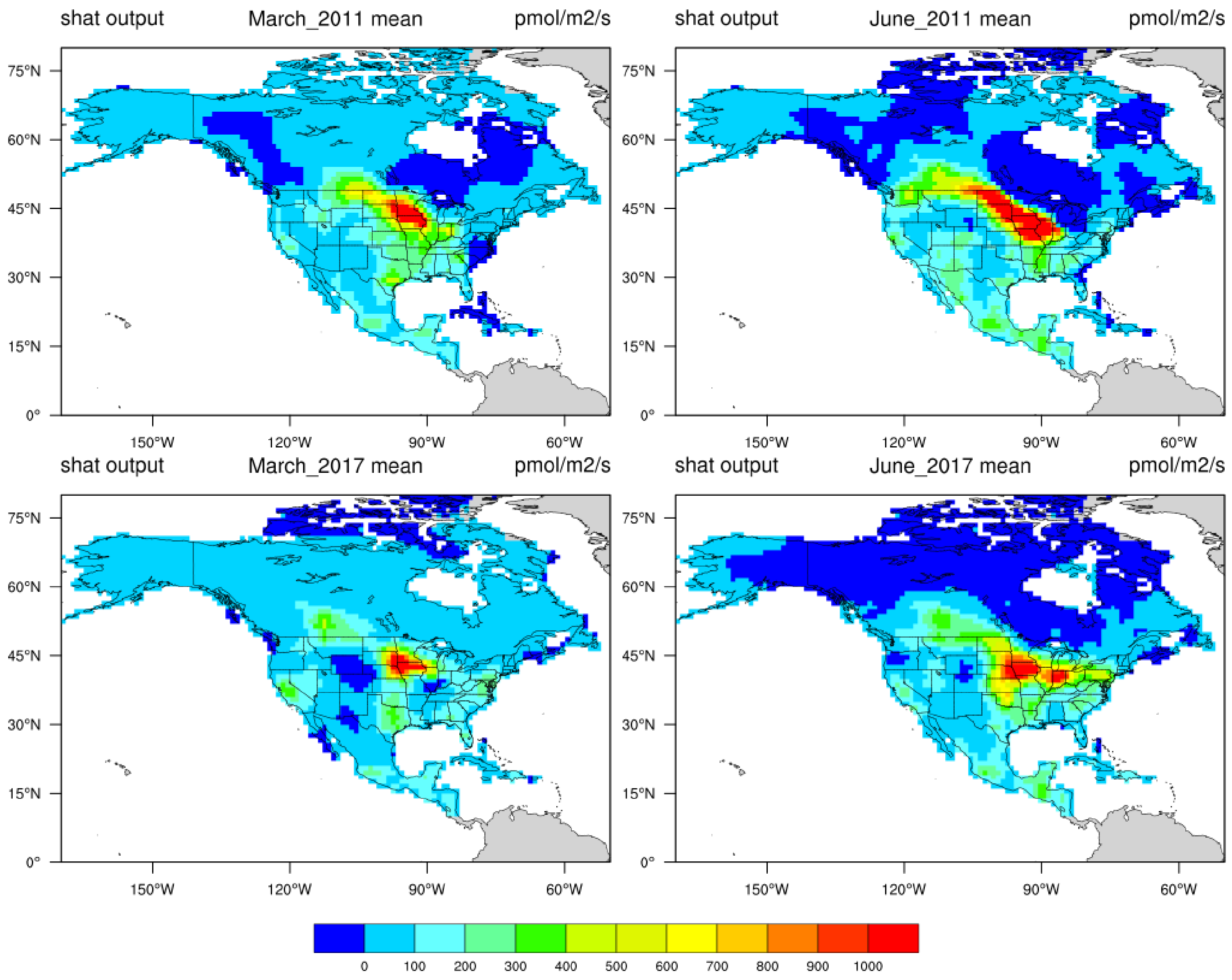
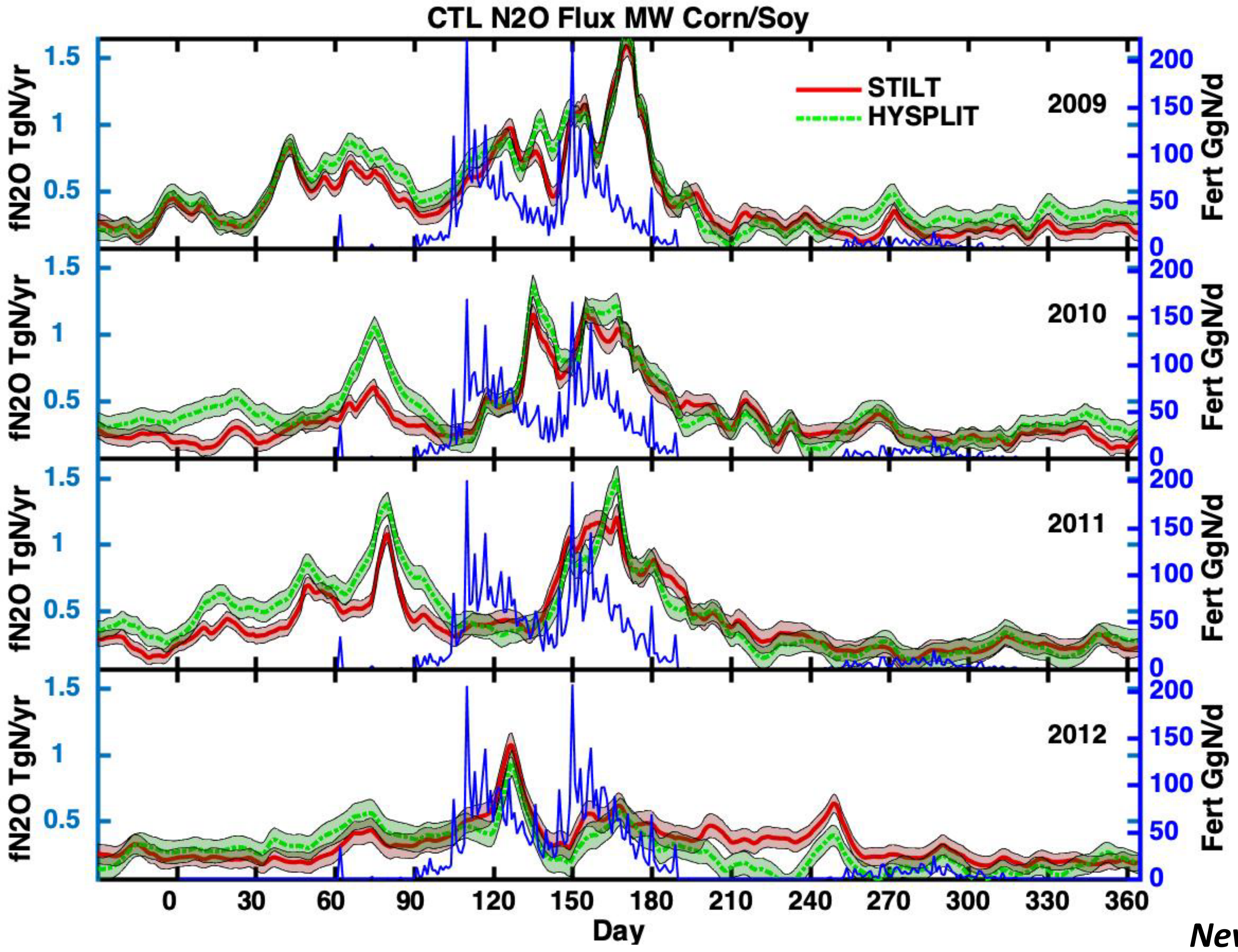
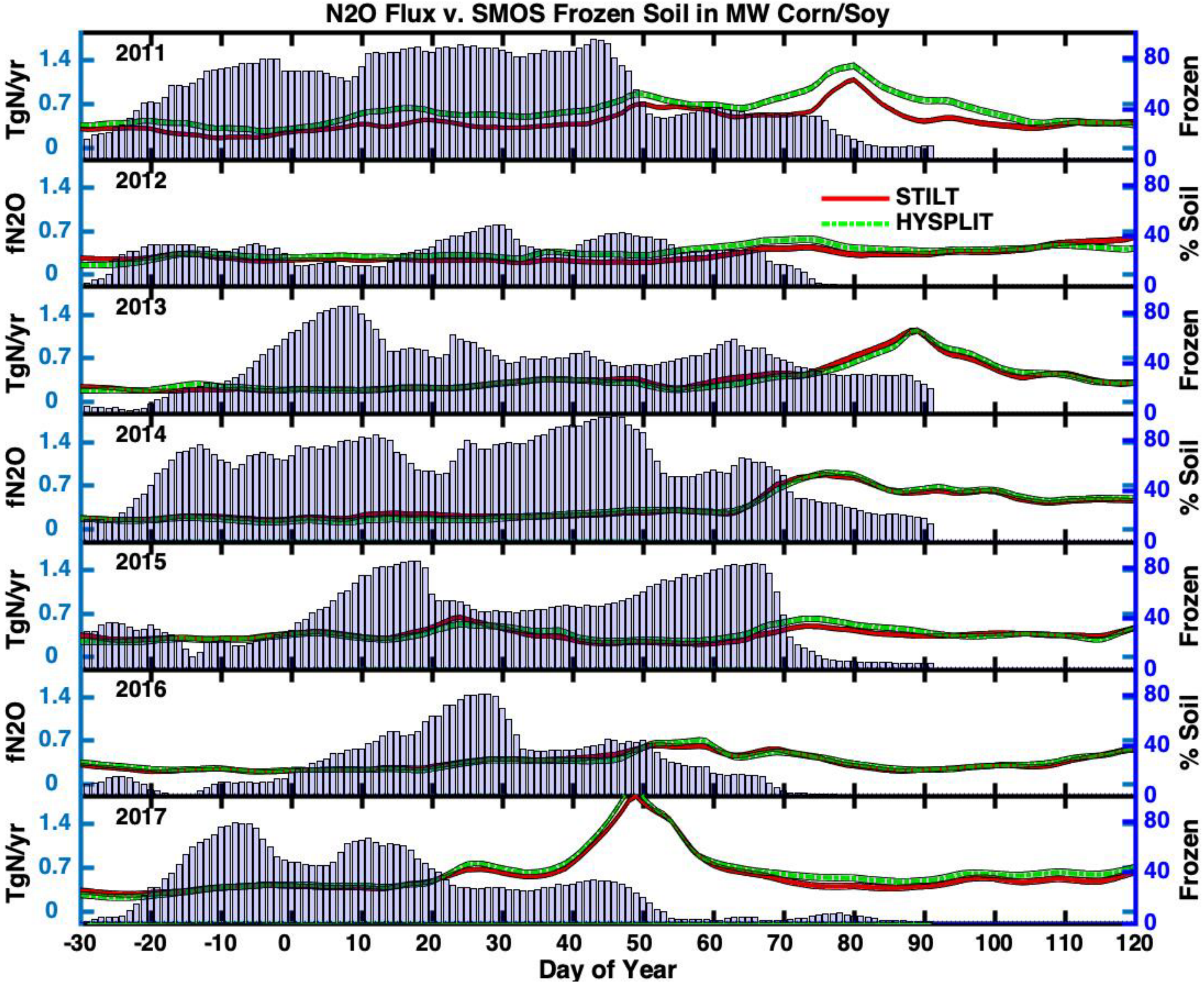
Is there evidence of N_2O pulse events during freeze thaw periods in late winter/early spring?



Nevison et al. , 2018, GBC



Nevison et al. , in prep



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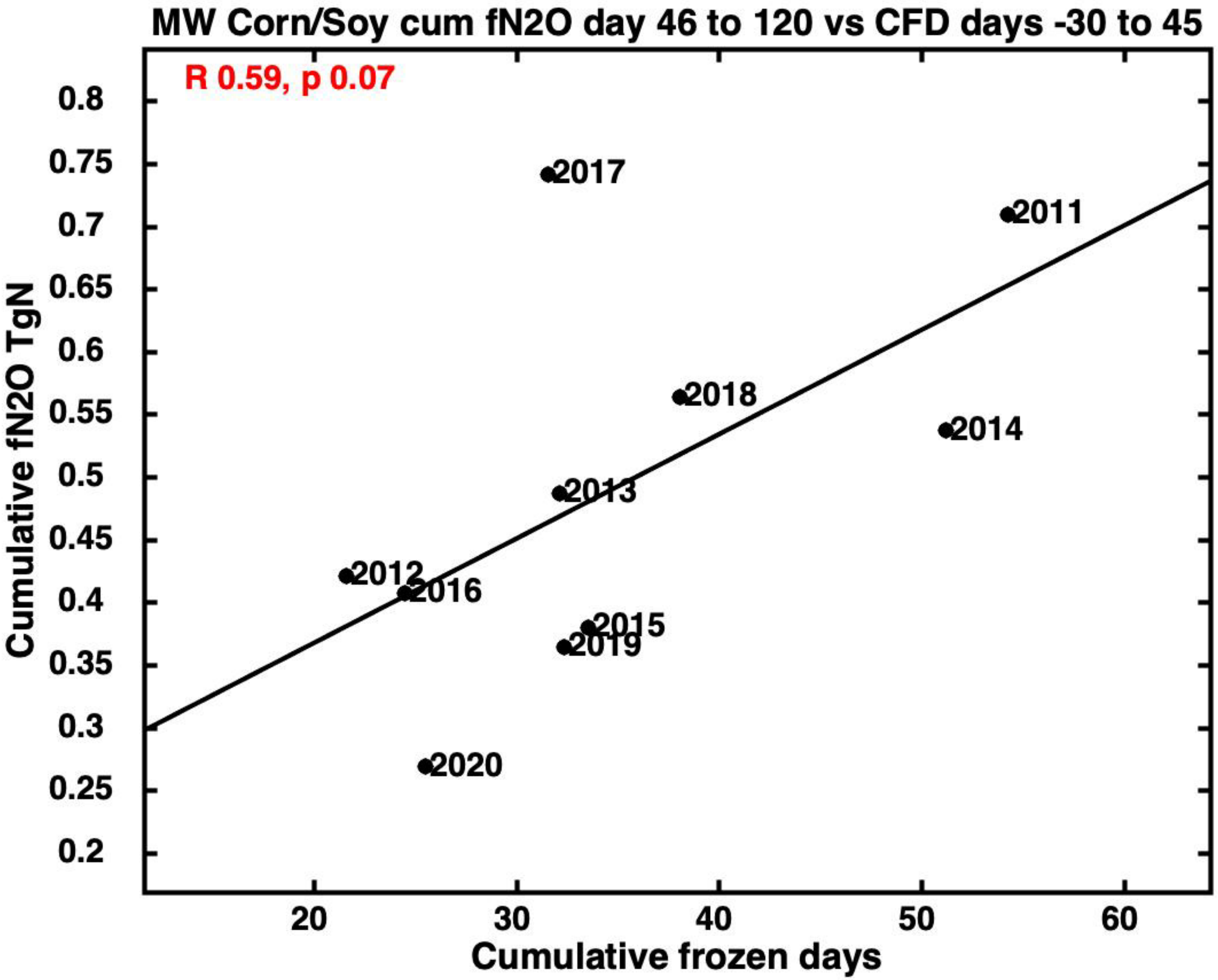
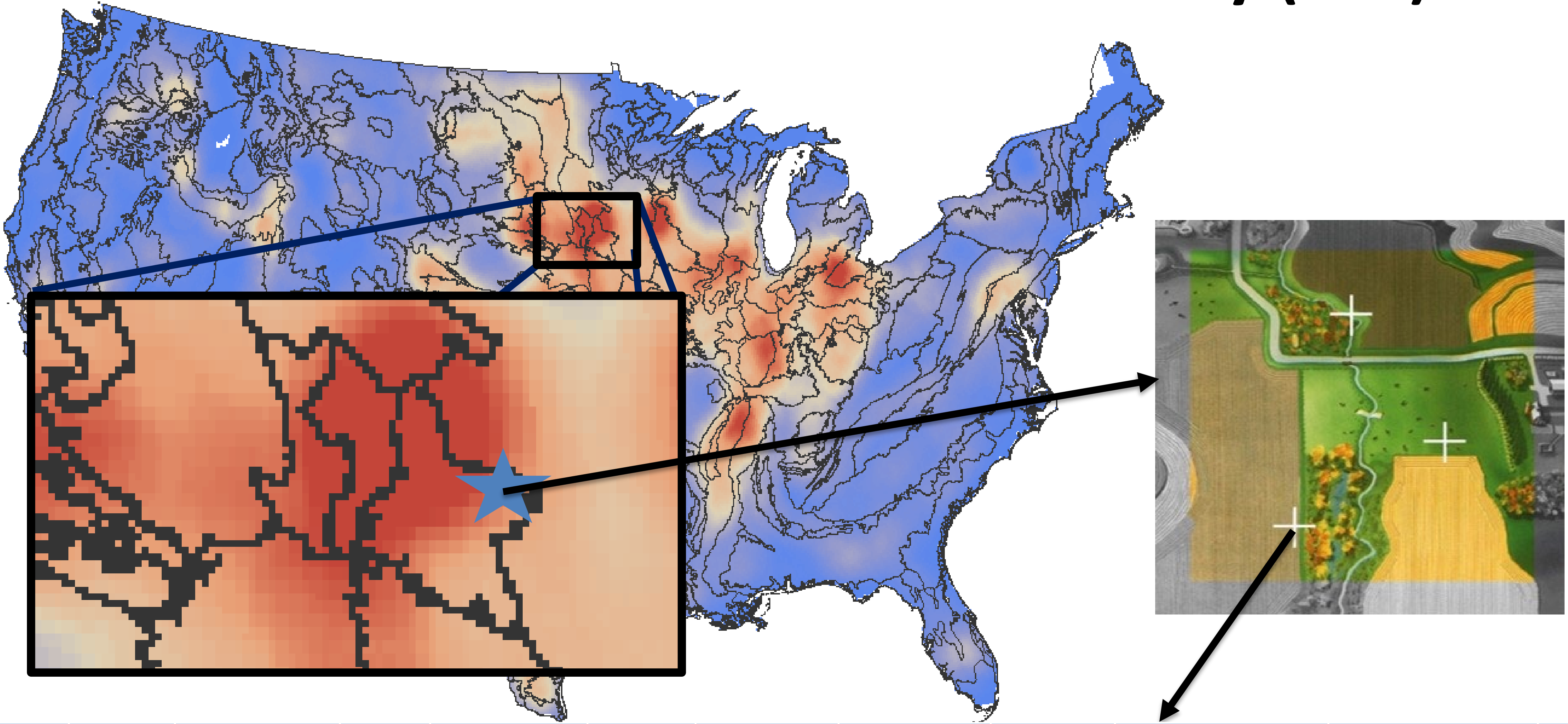


Nevison et al. , in prep

Is snow melt or thawing of the soil a better indicator of the timing of these events?

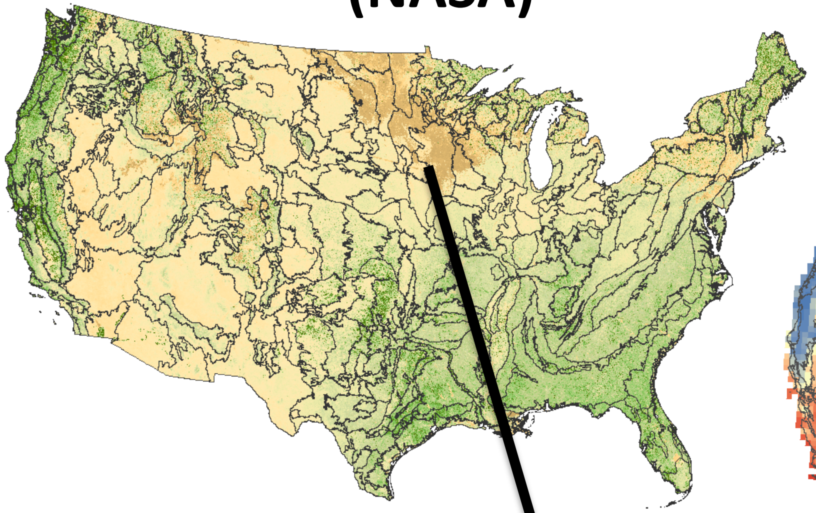
Developing Freeze Thaw Routines
Atmospheric Inversion
Tier 3 Inventory Analysis
Evaluating Inventory with Inversion

USDA-NRCS National Resources Inventory (NRI)

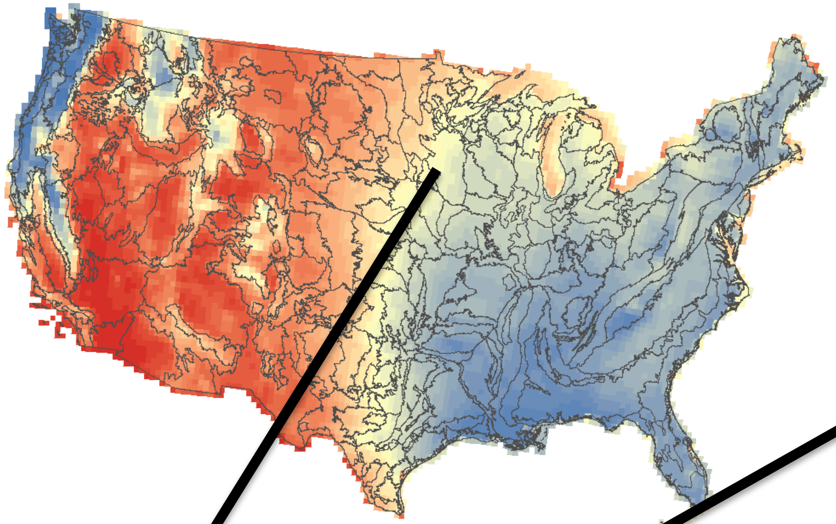


Land Use	Crop	Irrigation	EVI	Weather	Soil	Planting Date	Harvest Date	Tillage	Fertilization	Manure Amendment	Cover Crops
Cropland	Corn	Non-irrigated	?	?	?	?	?	?	?	?	?

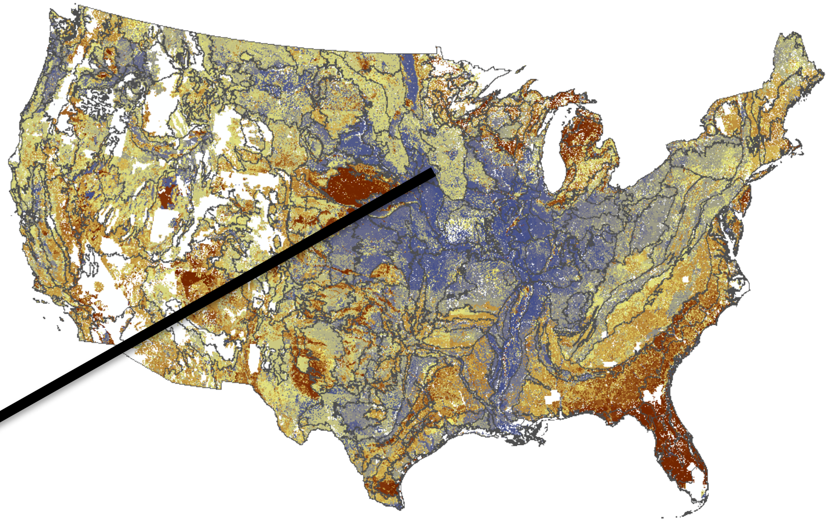
MODIS Enhanced Vegetation Index (NASA)



PRISM Daily Weather Data (Oregon State University)

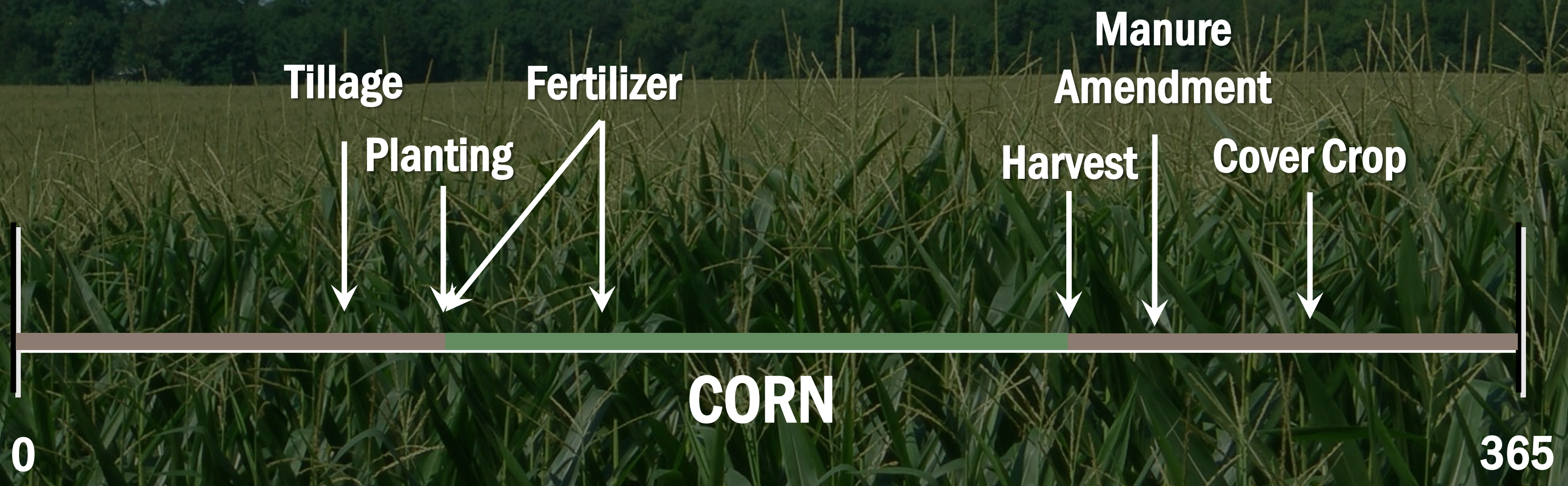


SSURGO Soils Data (USDA-NRCS)

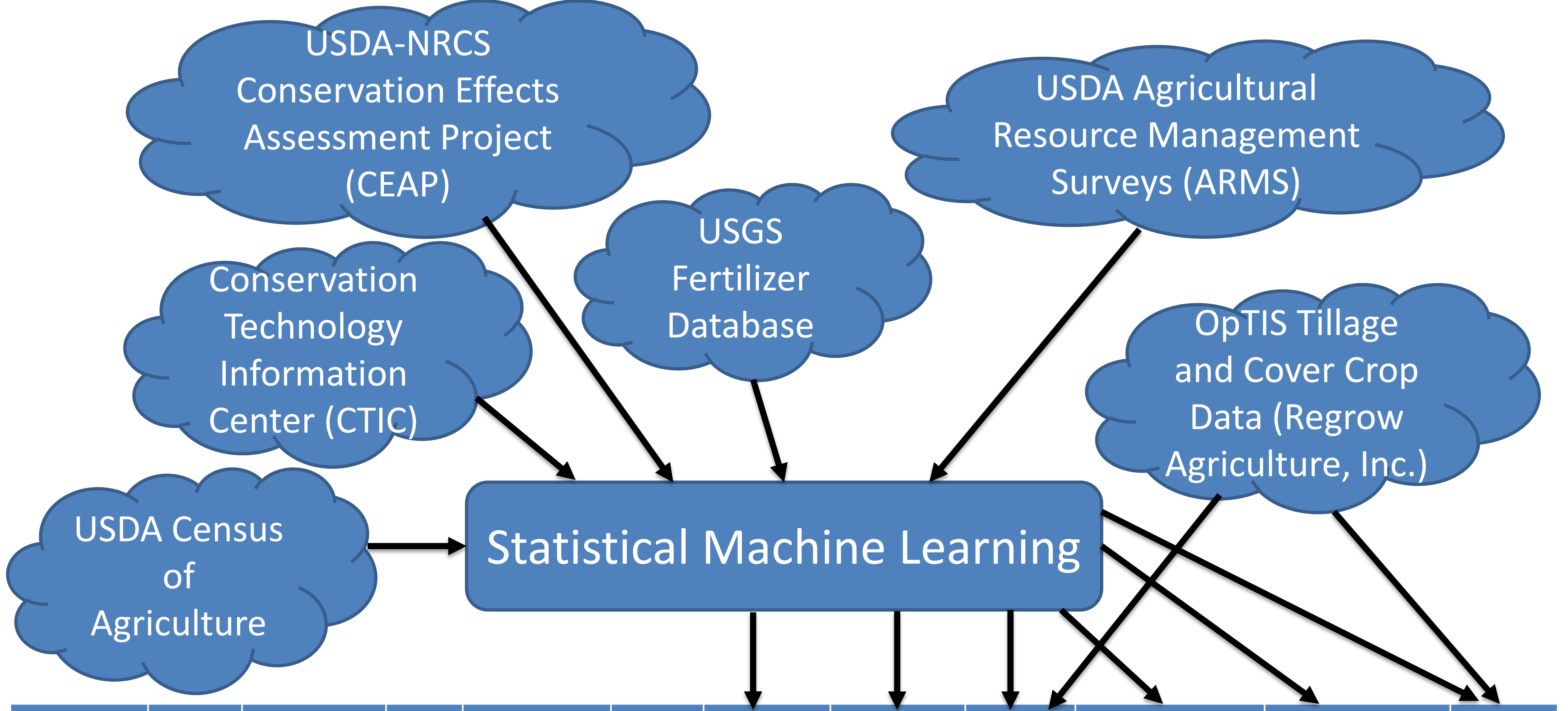


Land Use	Crop	Irrigation	EVI	Weather	Soil	Planting Date	Harvest Date	Tillage	Fertilization	Manure Amendment	Cover Crops
Cropland	Corn	Non-irrigated	0.88	15-28°C and 1.9 cm precipitation	Clay Loam	?	?	?	?	?	?

DayCent Model Simulation

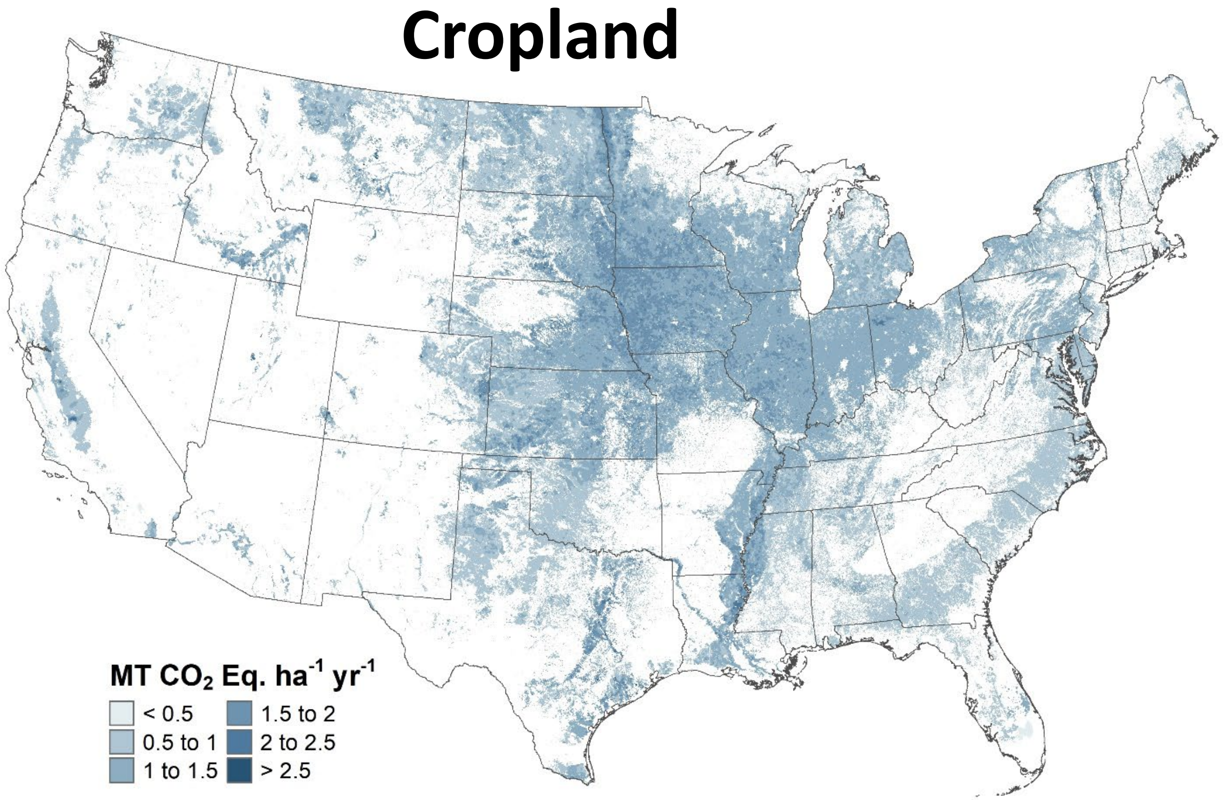


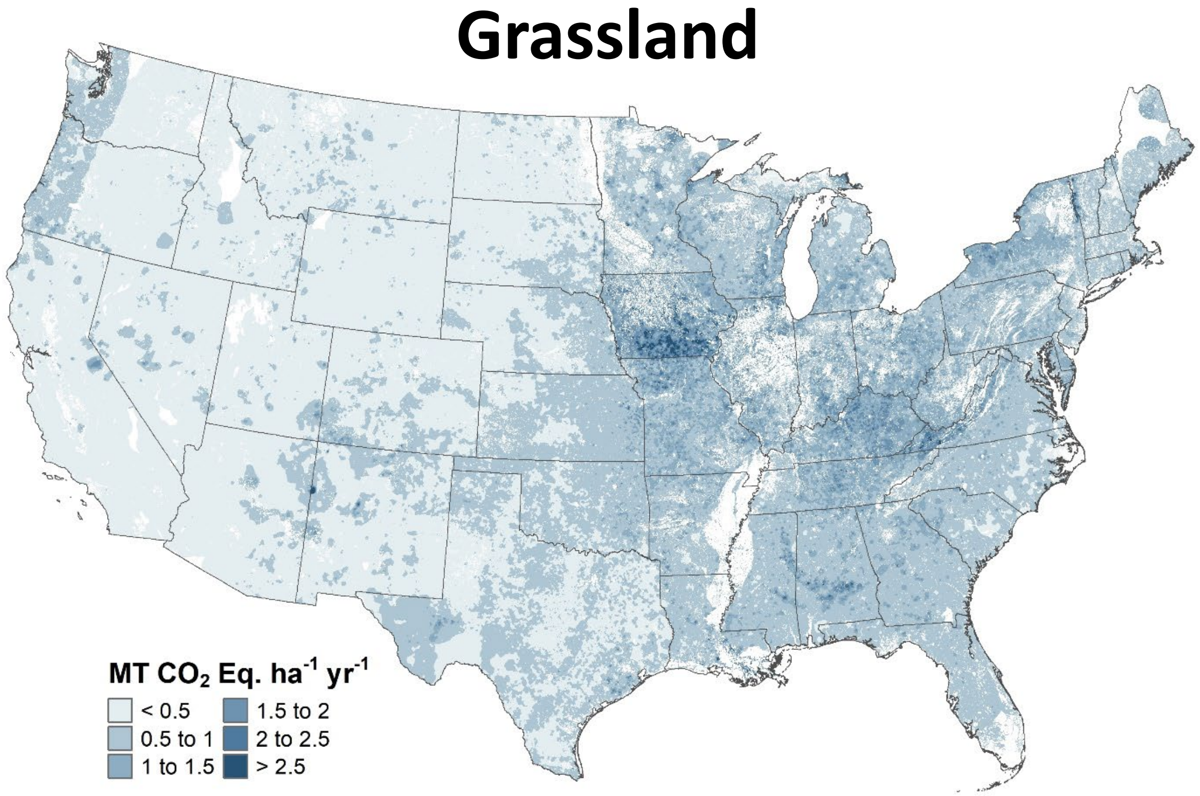
Time Series: 1979 to 2020



Land Use	Crop	Irrigation	EVI	Weather	Soil	Planting Date	Harvest Date	Tillage	Fertilization	Manure Amendment	Cover Crops
Cropland	Corn	Non-irrigated	0.88	15-28°C and 1.9 cm precipitation	Clay Loam	May 2	Oct 10	No-till	150 Kg N/ha	2 tons/ha	none

Direct Soil N_2O Emissions





US-EPA, 2022, NIR

Developing Freeze Thaw Routines
Atmospheric Inversion
Tier 3 Inventory Analysis
Evaluating Inventory with Inversion

Challenges: Evaluating Inventory

- Comparing total fluxes from atmospheric inversion analysis to source category emissions from inventory
- Mismatch in spatial coverage
  - Inventory only includes managed land
  - DayCent is not used to estimate emissions in forest lands and settlements

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Challenges: Evaluating Inventory

- Time step differences
  - annual v. daily
- Spatial density of atmospheric observations
- Small flux associated with N_2O emissions
- Topography

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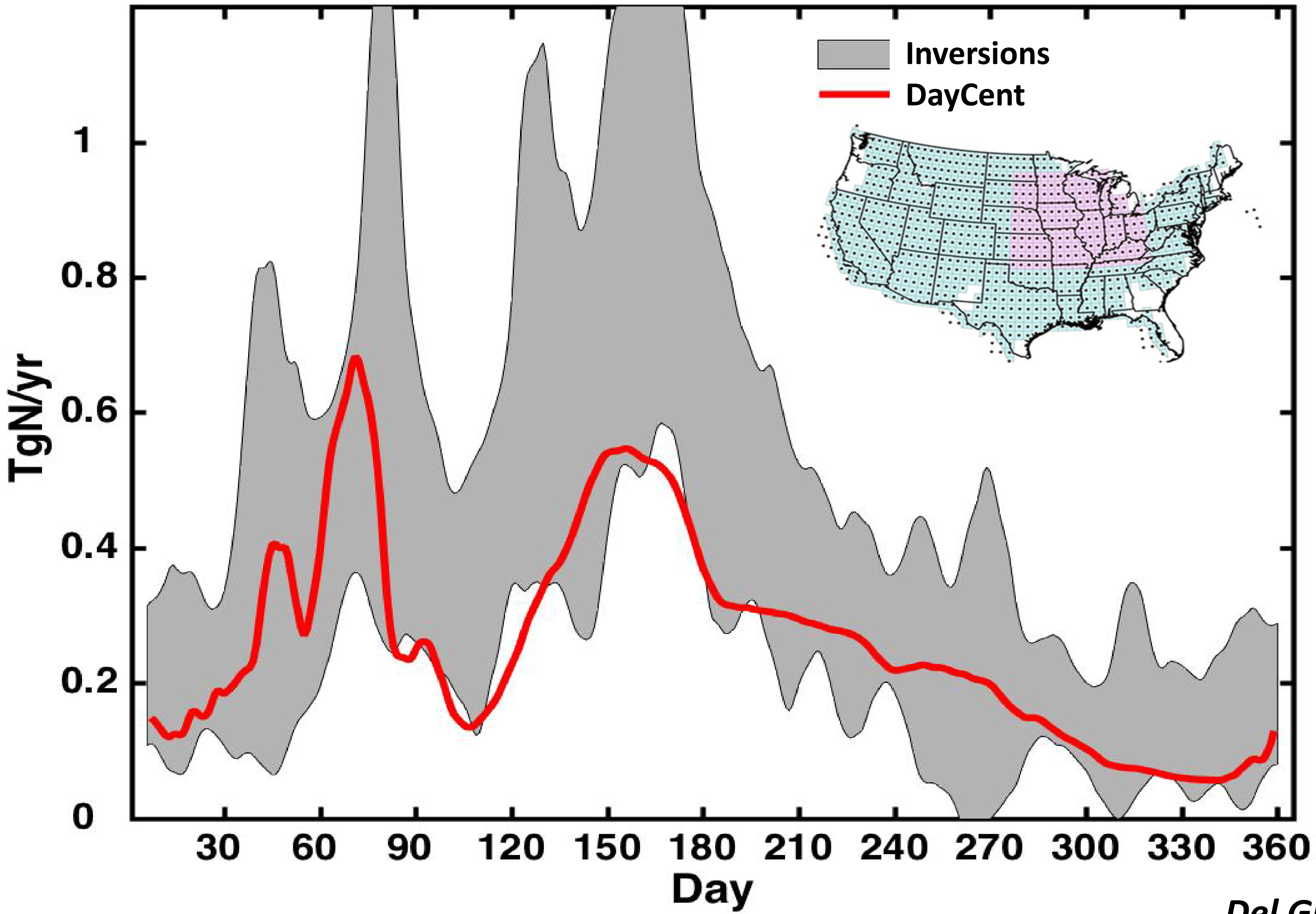

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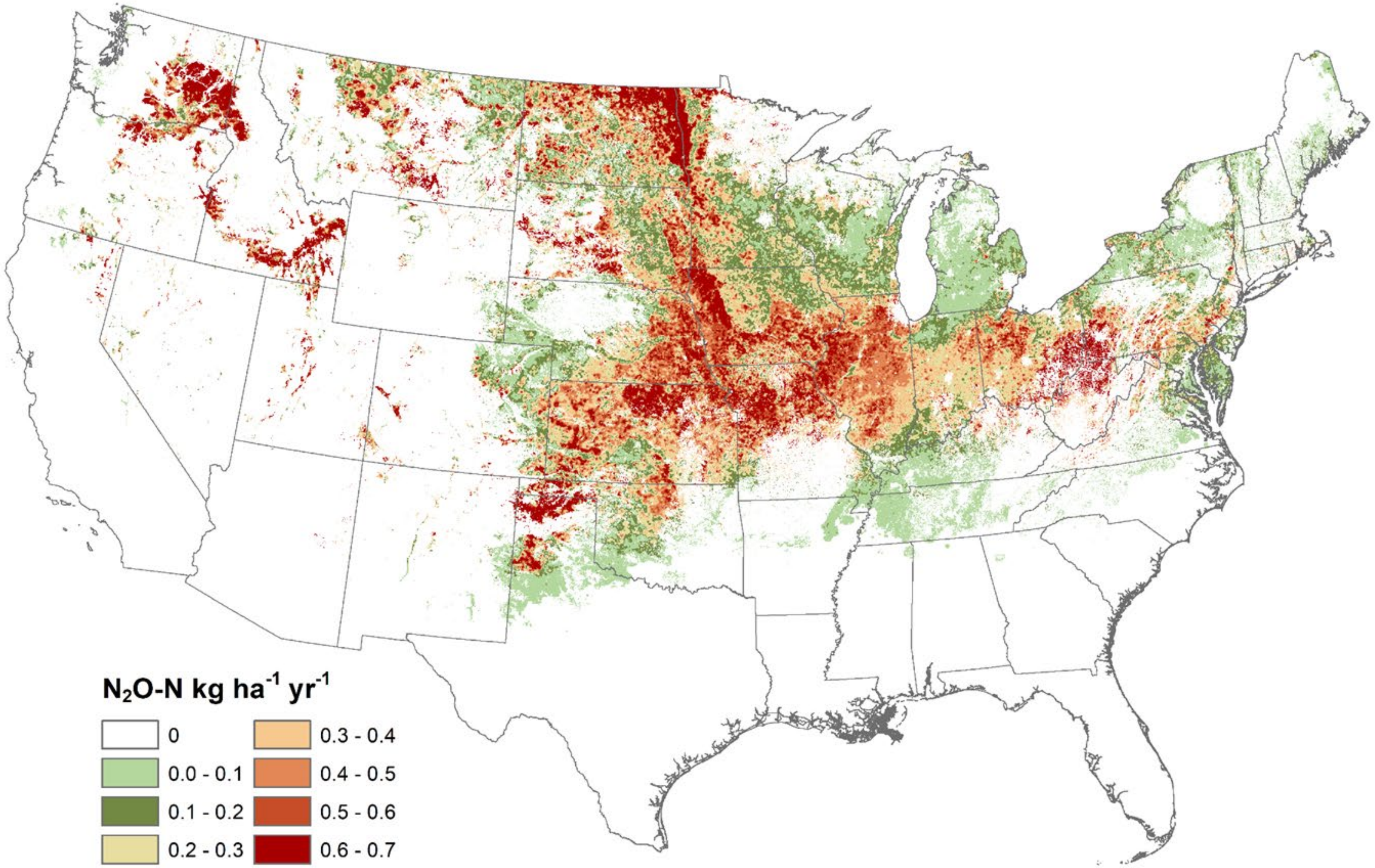
Freeze-Thaw Induced Emissions



Del Grosso et al. , 2022, PNAS

Conclusions

- Estimated fluxes from atmospheric inversion methods can be useful to confirm patterns in emissions
  - This is particularly important when there are limited observations informing the inventory
- Estimated fluxes from atmospheric inversion methods can also be used to evaluate inventory method options
    - Alternative algorithms
- Next Step: Extend analysis to evaluate magnitude of differences between inventory and atmospheric inversion

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