Rangeland Carbon Fluxes in the Northern Great Plains

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US Geological Survey

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Objectives

- ✓ Exhaustively model and map Carbon fluxes in rangelands to quantify the fluxes and
- ✓ Investigate temporal and patterns to understand climate and environmental influences.

METHODS: Develop Empirical Model Tree Algorithms to Predict Flux Tower Carbon Observations From Spatial Data

Localized
Detailed
Measurements

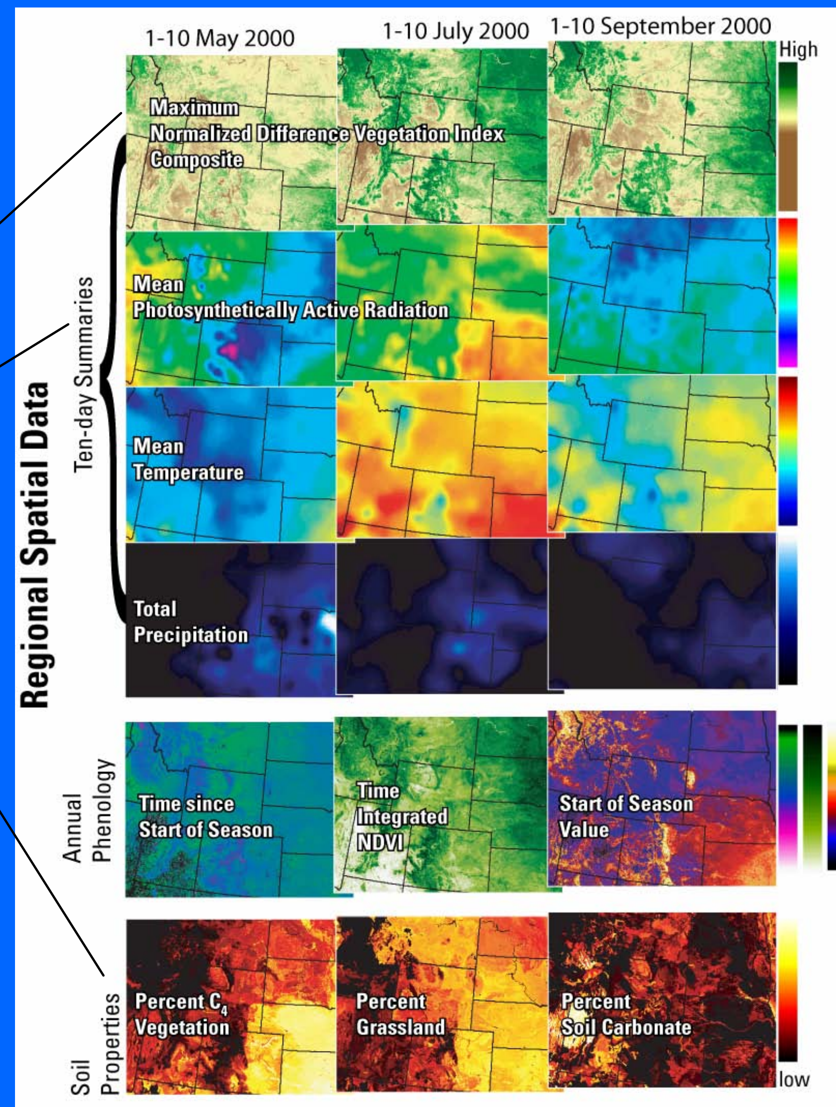
C Flux Mapping
Model Tree

If NDVI < 0.40
C fluxes = f(X1, X2, X4)
If NDVI >= 0.40
C fluxes = f(X1, X4, X6)

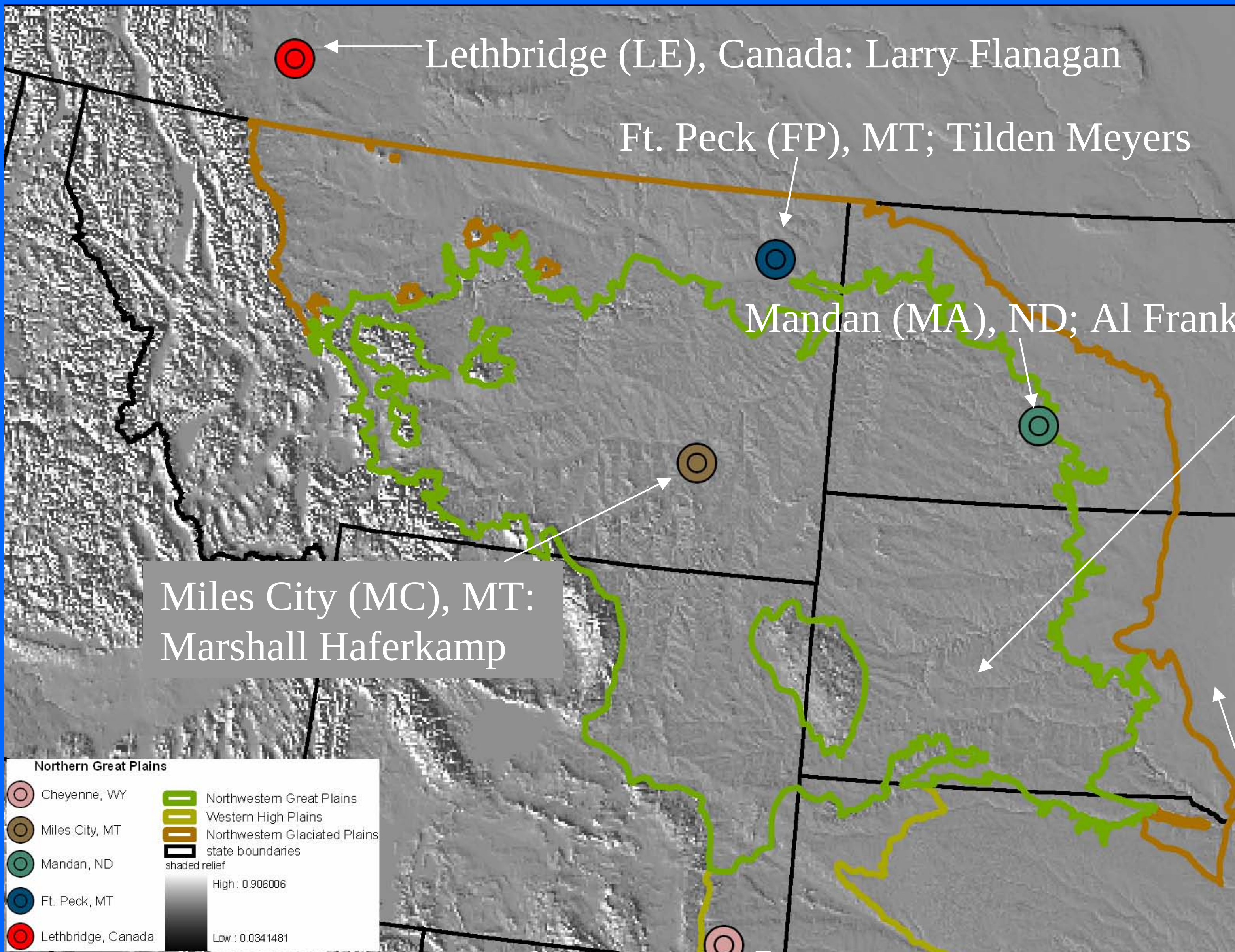
C Flux Maps

Northern
Great
Plains

Spatial Variables Through Time



Flux Tower Data is used to Develop Models for the Mapping of 10-day Carbon Dynamics on Rangelands



Cheyenne (CN), WY: Jack Morgan

New Towers

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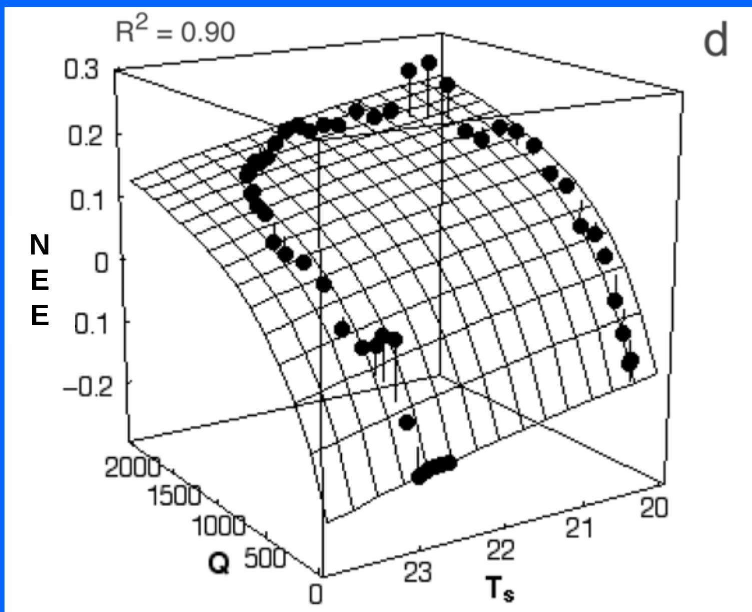
METHODS: Tower C Fluxes Associated with Basic Ecosystem Functions of Gross Primary Production (Pg) and Total Ecosystem Respiration (Re) are Derived From Light Response Curves on 30 min. Datasets.

Tagir Gilmanov, SDSU, coordinator of the FLUXNET WORLDGRASSFLUX working group



$$P(Q,T_s;\ \alpha,\beta,\gamma_0,\theta,\kappa)=\frac{1}{2\theta}\left(\alpha Q+\beta-\sqrt{(\alpha Q+\beta)^2-4\alpha\beta\theta Q}\right)-\gamma_0 e^{\kappa T_s},$$

Derives estimates of daytime respiration independent of nighttime flux data

(others often use relationships derived from nighttime fluxes and apply them to daytime observations)

PROVIDES:

1) Tower Pg, Re, and NEE
2) Facilitates flux tower data gap filling
3) Quantifies ecophysiological parameters

(quantum yield (α), maximum gross photosynthesis (β), & daytime respiration (γ))

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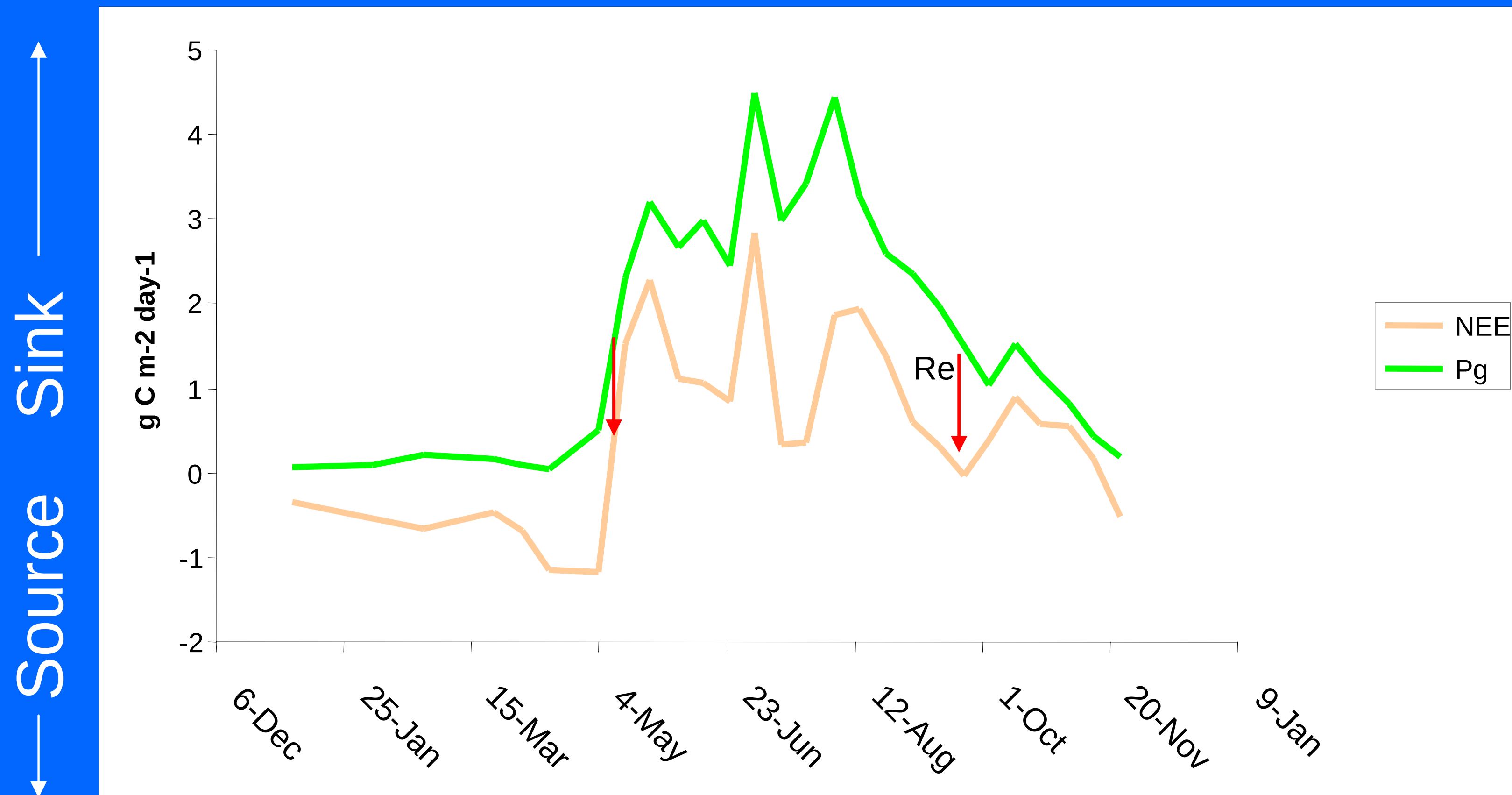
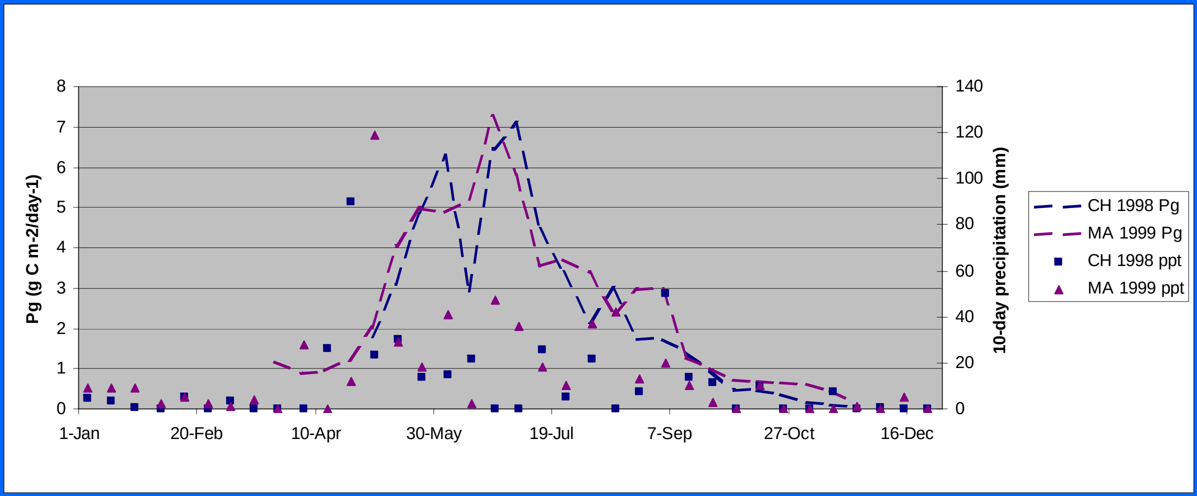
Ecosystem Process Carbon Partitioning: Added Value

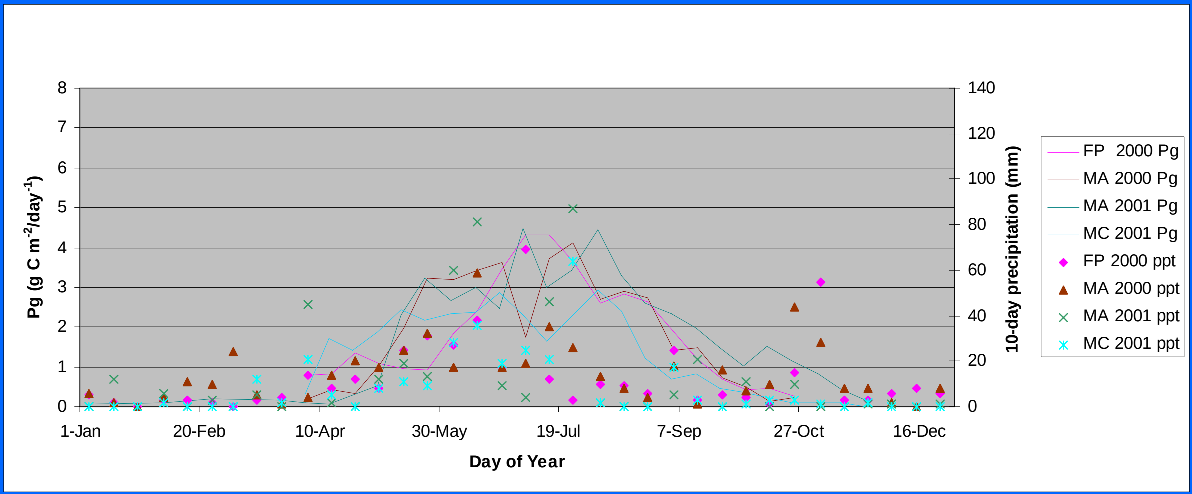


Bkwd_finalGPP_RE_NEEmodel4c.xls

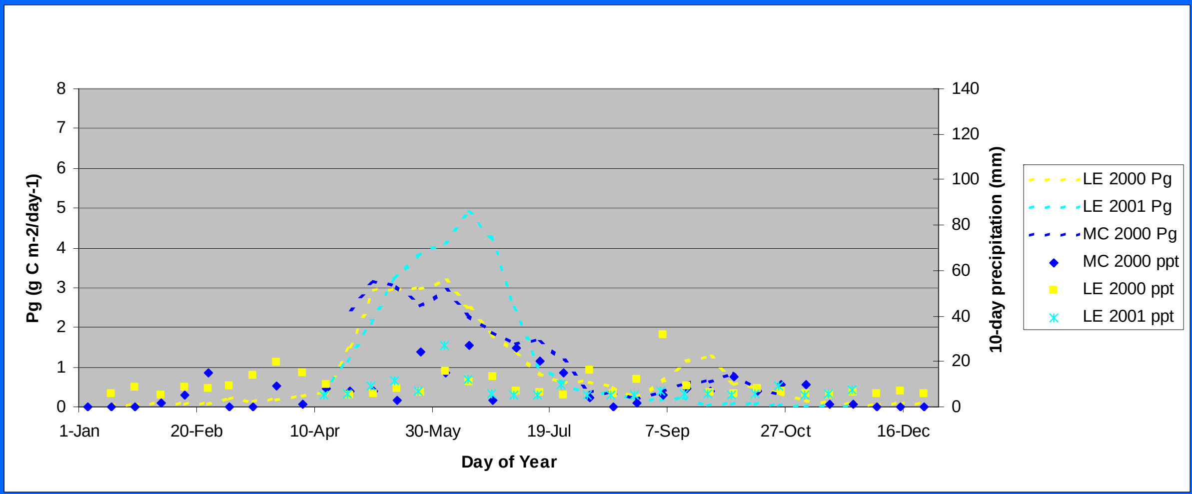
Flux Tower Pg Group: Significant Early Rain, High Pg



Flux Tower Pg Group: Moderate Rain, Moderate Pg



Flux Tower Pg Group: Low Rain, Low Pg



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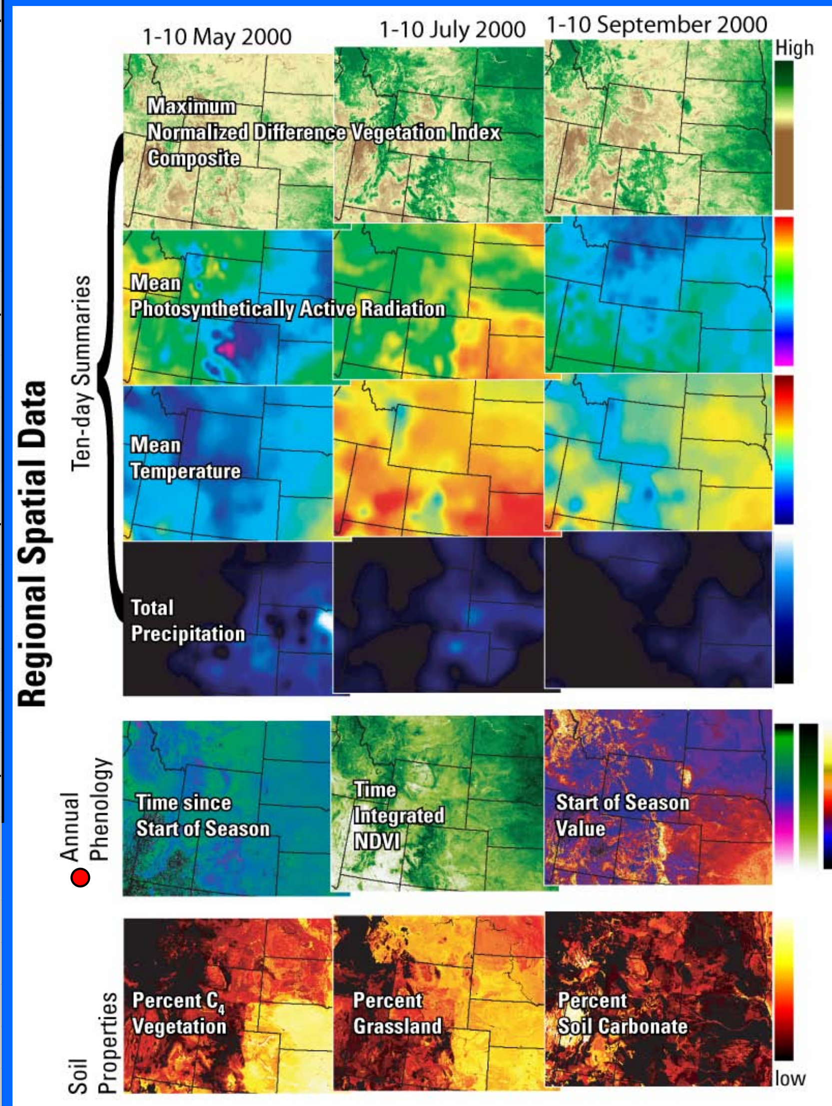
Model Development Data Set Consists of Flux Tower Pg, Re, and NEE Combined With Spatial Variables from Remote Sensing and GIS

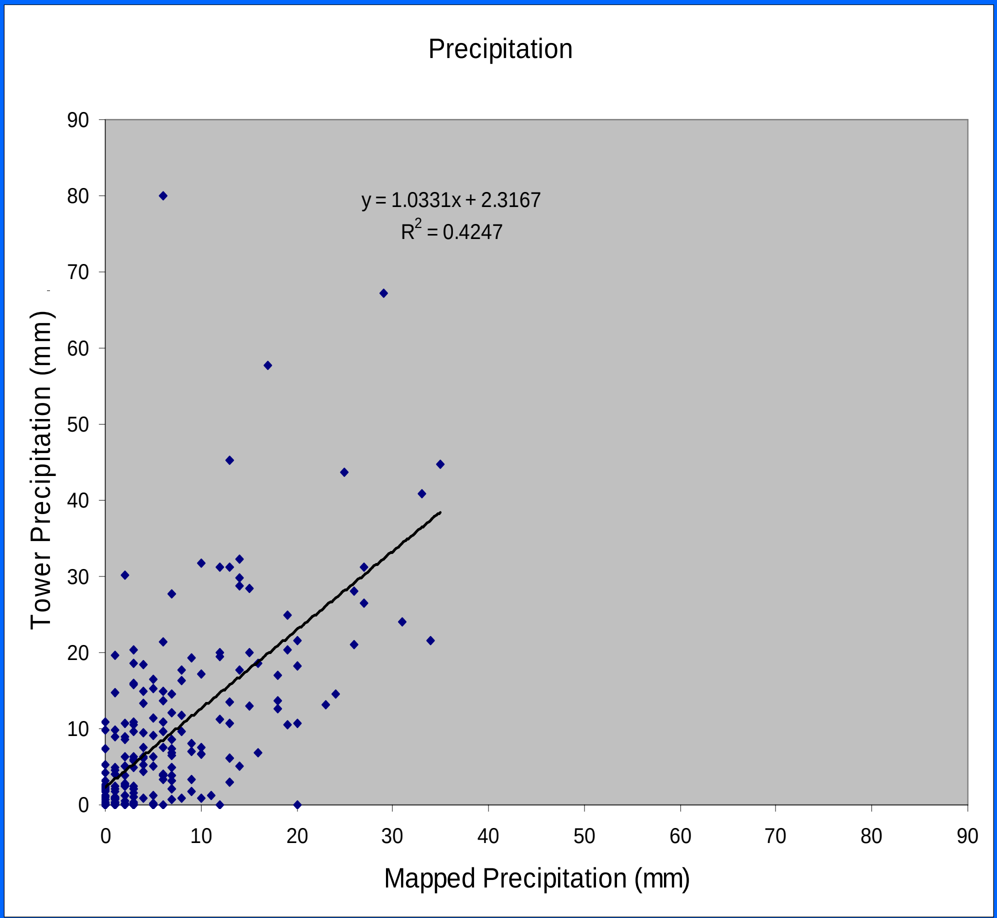
(10-day Time Step)

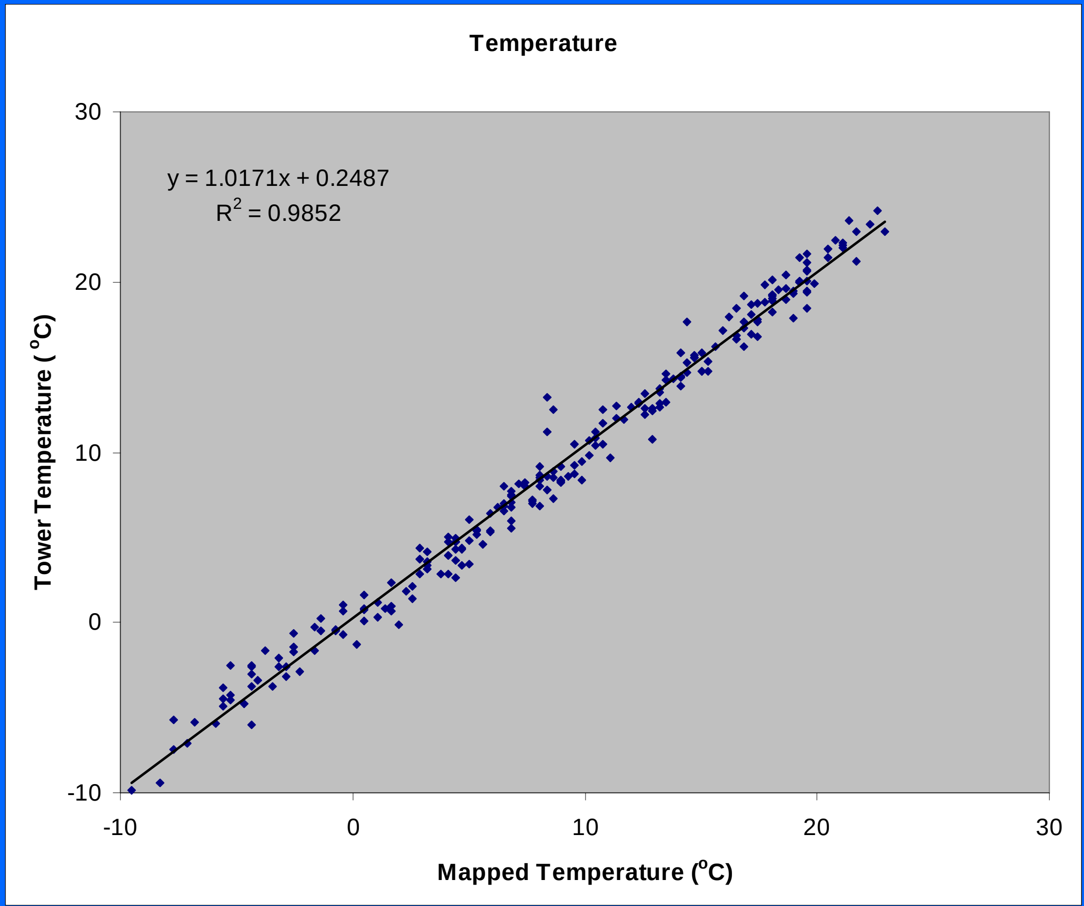
	Variable name	Definition
Seasonally Dynamic		
	Solar Radiation	function of DOY and latitude
	nd	Smoothed NDVI
	ppt	precipitation
	temp	temperature
	par	PAR
Seasonally Dynamic but dependent on time		
	sinceSost	Days since Start of Season (NDVI metric)
	DOY	day of year = photoperiodism
	solstice	days prior or post summer solstice
Annually Dynamic		
●	sosn	NDVI at Start of Season
●	sost	Start of Season DOY
●	tin	Time Integrated NDVI
	year	Categorical variable for testing year effects
Site Dynamic		
	sitecat	Categorical variable for testing site effects
	c4pct	% C4 from STATSGO
	co3surf	Surface calcium carbonates from STATSGO
	pctclaysurf	% clay in surface layer from STATSGO
	pctgrass	% grass from STATSGO
	omernick	Categorical variable for testing ecoregion effects
	Elevation	
	Aspect	



Tower versus Spatial Data

- Takes into account the accuracy of spatial data sets when developing model.
- Process-based models typically rely heavily on precipitation
- Precipitation can have high spatial and temporal variability that is difficult to map accurately.





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Distinct Model Trees

- Models that predict:
  - Net Ecosystem Exchange (NEE)
  - Gross Primary Production (Pg)
  - Respiration (Re)

Empirical Piecewise Regression Model

- Cubist
  - Parsimonious and transparent selection of variables
  - Stratification of data into homogeneous information spaces
  - Multiple regression defined for each information space

NEE Model example (g CO_2 m^{-2} day^{-1})

```
Rule 1: [98 cases, mean -1.1538022, range -6.22692 to 5.404624,
     est err 1.2296274]
  if nd <= 140 and sinceSost > 85
  then
     NEE = 6.25352 + 0.138 nd - 0.091 ppt - 0.19 sosn - 0.009 par
              - 0.01 temp - 0.0015 sinceSost

Rule 2: [21 cases, mean 0.7320258, range -3.83196 to 4.013414,
     est err 1.8628249]
  if nd > 140 and par <= 100
  then
     NEE = 1.82742 + 0.046 par - 0.04 temp + 0.033 nd - 0.03 sosn
              - 0.008 ppt - 0.0014 sinceSost

Rule 3: [60 cases, mean 0.9998901, range -4.301141 to 7.026846,
     est err 1.7766731]
  if nd <= 140 and sinceSost <= 85
  then
     NEE = 3.42815 + 0.051 par - 0.046 temp - 0.054 tin + 0.043 nd
              - 0.04 sosn - 0.012 ppt - 0.0019 sinceSost
```

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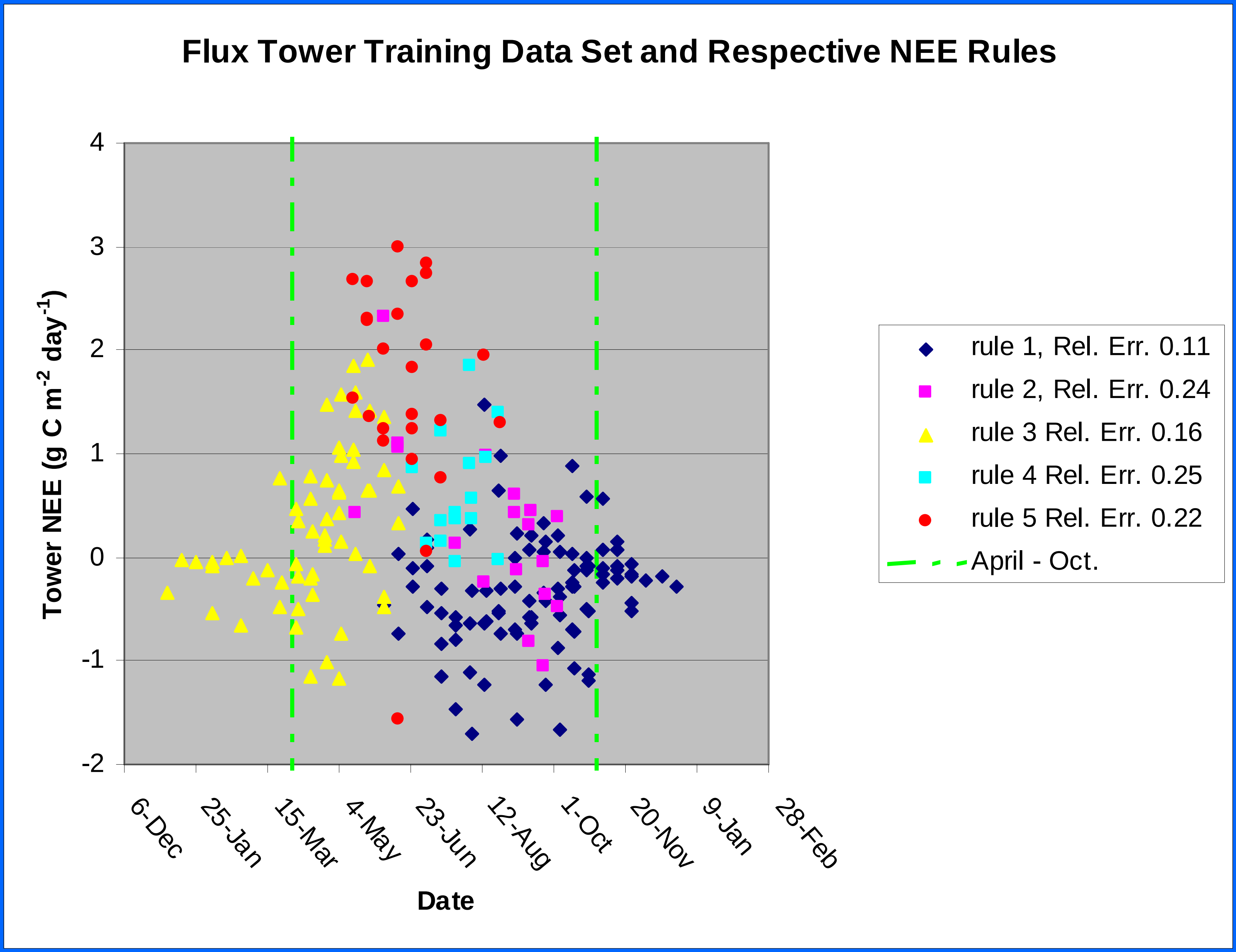
Rules or respective “information spaces”



Variables used to predict NEE

Theme	Count	Pct.	Weight	Pct.
par	429	34.3	1.712	13.2
nd	390	31.2	2.981	22.9
sinceSost	379	30.3	0.732	5.6
temp	40	3.2	3.360	25.8
ppt	11	0.9	1.636	12.6
tin	0	0.0	1.385	10.7
sosn	0	0.0	1.193	9.2

Variables used to predict P_g

Theme	Count	Pct.	Weight	Pct.
nd	683	37.8	7.031	33.5
par	508	28.1	5.322	25.3
doy	177	9.8	2.231	10.6
temp	136	7.5	2.222	10.6
sinceSost	132	7.3	1.437	6.8
c4pct	111	6.1	0.448	2.1
sost	60	3.3	0.827	3.9
tin	0	0.0	1.482	7.1

Variables used to predict R_e

Theme	Count	Pct.	Weight	Pct.
temp	2848	40.4	3.540	4.0
nd	2244	31.8	22.192	25.2
ppt	991	14.1	8.395	9.5
par	343	4.9	10.789	12.3
sinceSost	284	4.0	12.412	14.1
doy	255	3.6	10.735	12.2
pctgrass	81	1.1	14.612	16.6
tin	0	0.0	5.326	6.1

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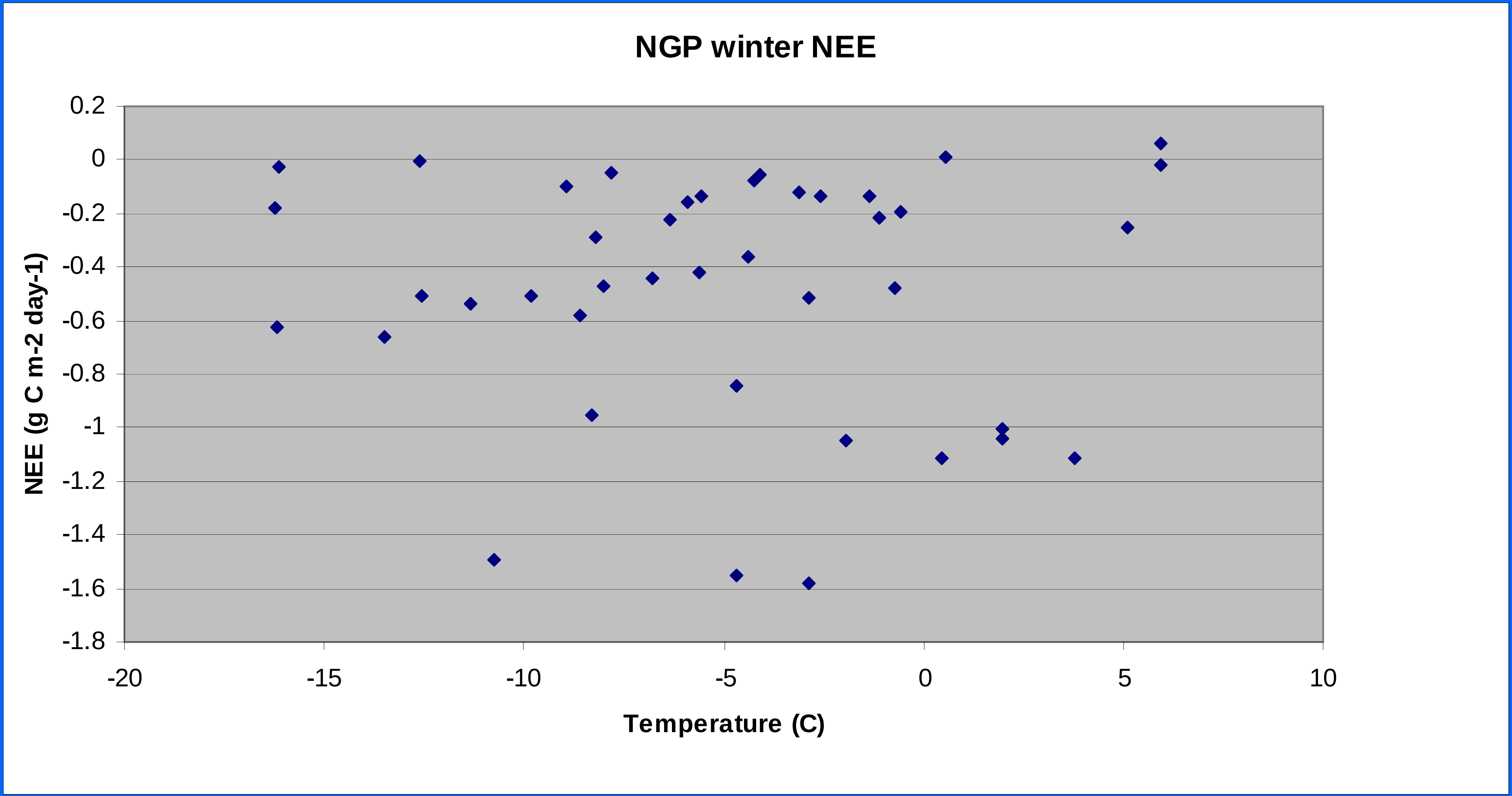
Model Accuracy Assessment

MAD = $1/n \sum | \text{observed} - \text{predicted} |$

Range = 95th percentile - 5th percentile

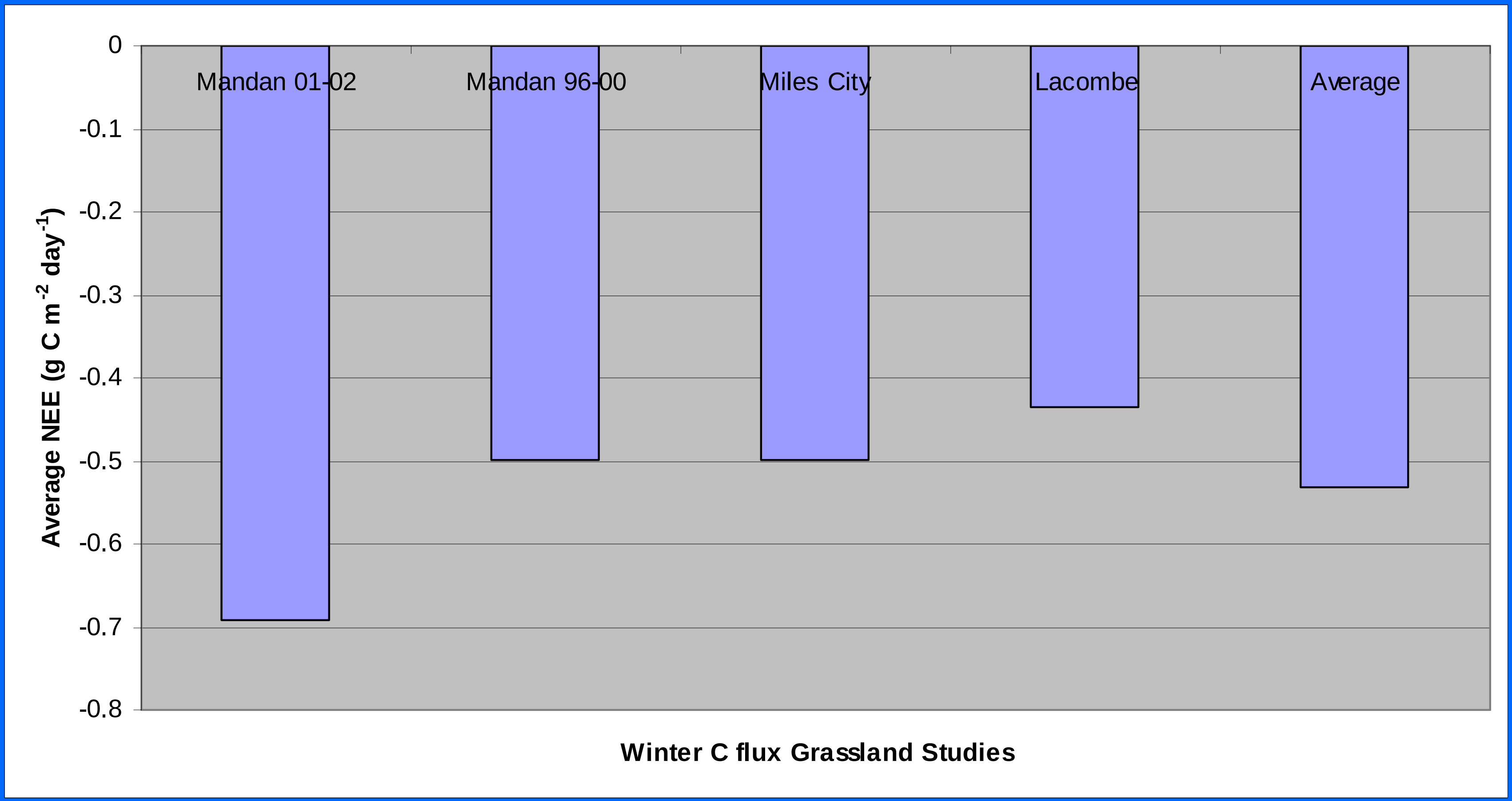
Relative Error = MAD / Range

Winter fluxes difficult to estimate….



30 min. data sets indicate snow depth and wind speed important

Winter fluxes (Nov. - Mar.) are need to convert model tree maps (Apr. - Oct.) to Annual Fluxes



Mandan 01-02, Gilmanov 2002; Mandan 96-00, Frank et al. 2002, Miles City, Gilmanov 2002; Lacombe, Baron et al. 2004

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Results

Cross validation

- Methodology to quantify robustness of small training data sets
- Random cross-validation produces realistic error estimates
- Cross-validation by sites evaluates influence of individual sites
- Cross-validation by year evaluates influence of individual years

Five-fold NEE (g C m^{-2} day^{-1}) cross-validation (random)

Random sample as test	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
Hold out data sample size	43	43	43	44	44
Mean Absolute Difference	0.49	0.43	0.48	0.38	0.600
Relative Error					

Average MAD = 0.48

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Cross-validation NEE (g C m^{-2} day^{-1}) by site

Site withheld as test	LE	MA	FP	CN	MC	None
Sample size (train)	159	144	196	196	173	217
Mean Absolute Difference (train)	0.45	0.29	0.36	0.37	0.38	0.35
Relative Error (train)	0.14	0.09	0.11	0.12	0.12	0.11
Sample size (test)	58	73	21	21	44	0
Mean Absolute Difference	0.46	0.66	0.31	0.55	0.59	
Relative Error	0.14	0.21	0.10	0.17	0.18	

Cross-validation NEE (g C m^{-2} day^{-1}) by years

Year withheld as test	1998	1999	2000	2001	None
Sample size (train)	196	192	120	143	217
Mean Absolute Difference (train)	0.37	0.33	0.44	0.39	0.35
Relative Error (train)	0.12	0.10	0.14	0.12	0.11
Sample size (test)	21	25	97	74	0
Mean Absolute Difference (test)	0.55	0.91	0.49	0.48	
Relative Error (test)	0.17	0.29	0.16	0.15	

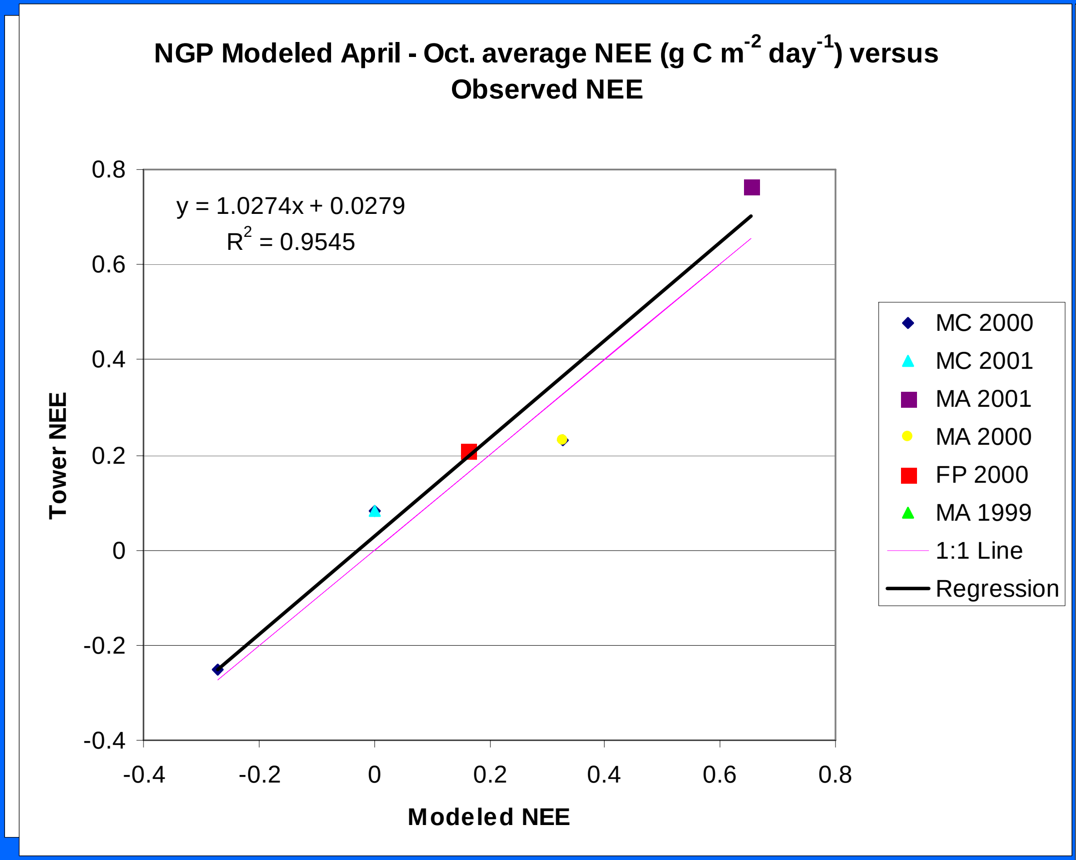
Robustness of Pg model tree: Cross Validation using Sites

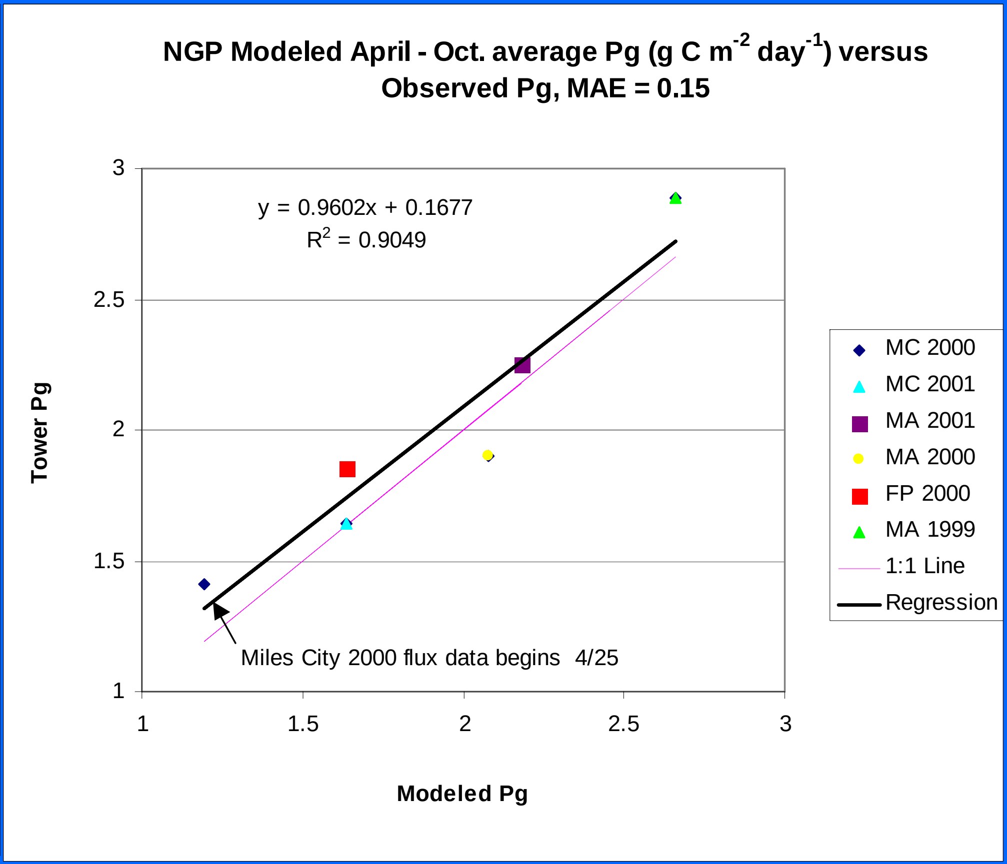
Site Withheld	CN	FP	LE	MA	MC	None
MAD (g C m^{-2} day^{-1})	0.94	0.32	0.46	1.65	0.53	0.32
Relative Error	0.21	0.07	0.10	0.37	0.12	0.07
N	21	21	58	73	43	217

- Cheyenne and Mandan are influential sites
  (high Pg in CH 1998 and MA 1999)
  (MA is only high precipitation, eastern site)
- Relative Errors on the other sites was from 7 to 12 %

Results

How Well do 10-day Model Tree Predictions Averaged over the Growing Season Compare with Flux Tower Observation?





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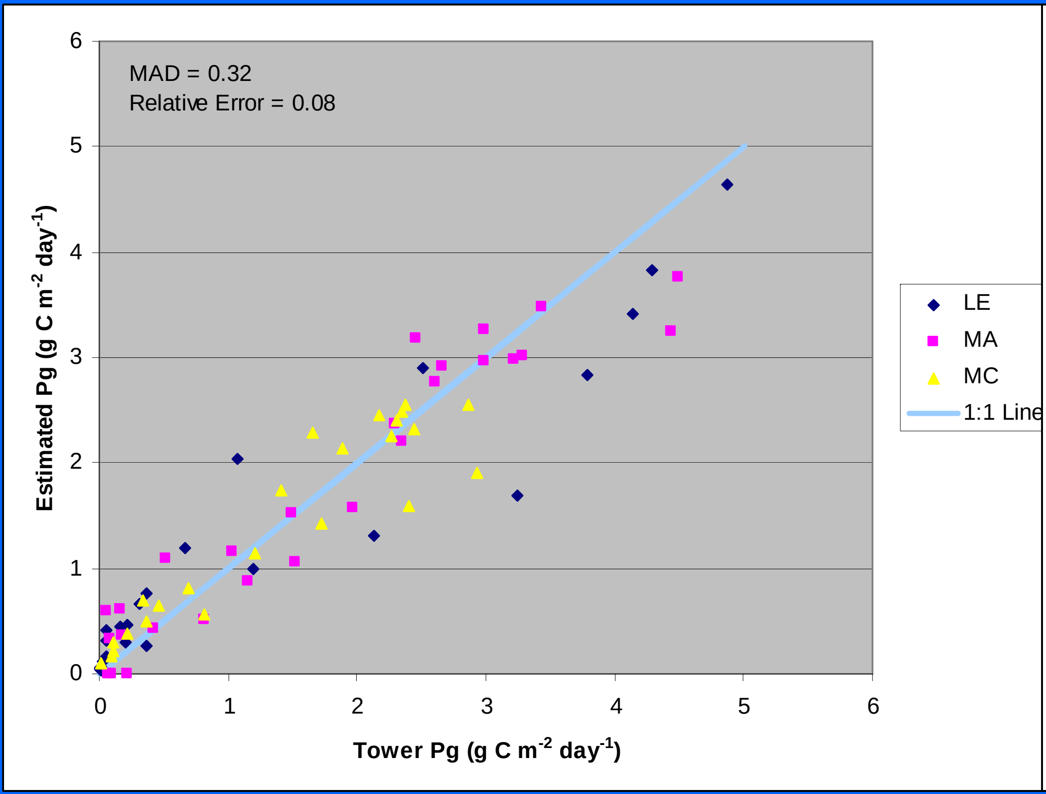
Model Tree Predictions Match 2001 Flux Tower Observations Better than MODIS Net Photosynthesis

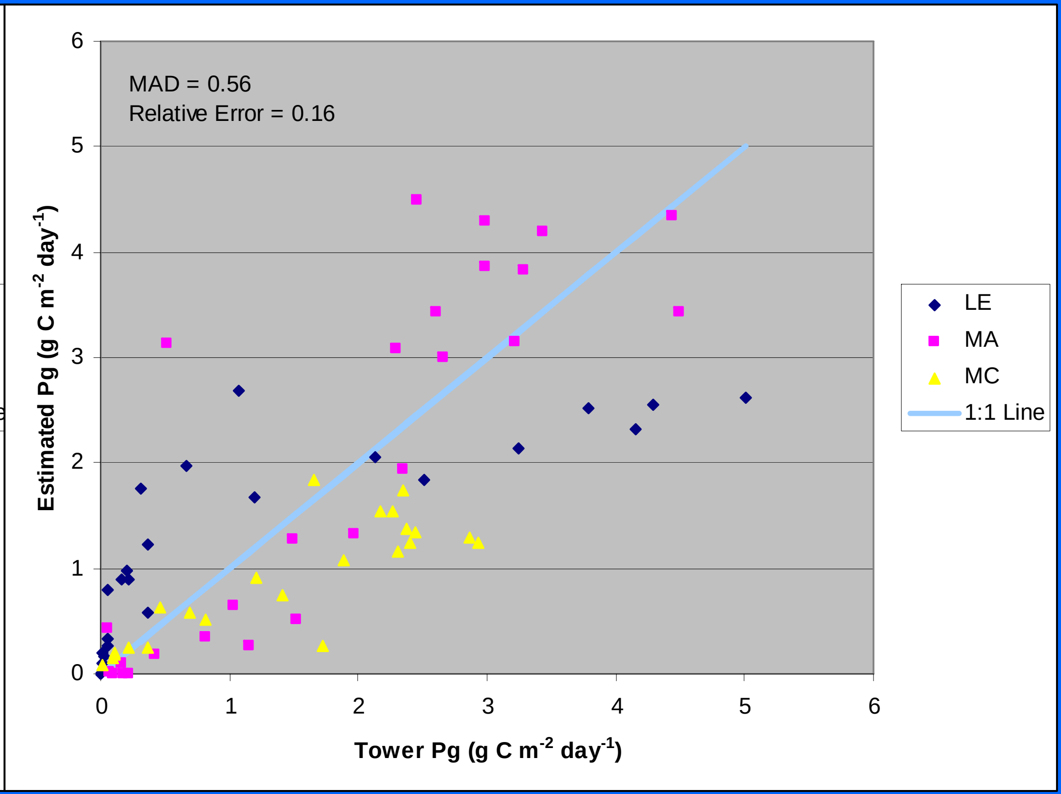
- Captures General Tend in Tower Pg
- Predictions seem site specific

Model Tree (trained from all towers)

(withheld 2001 MAD was 0.48)

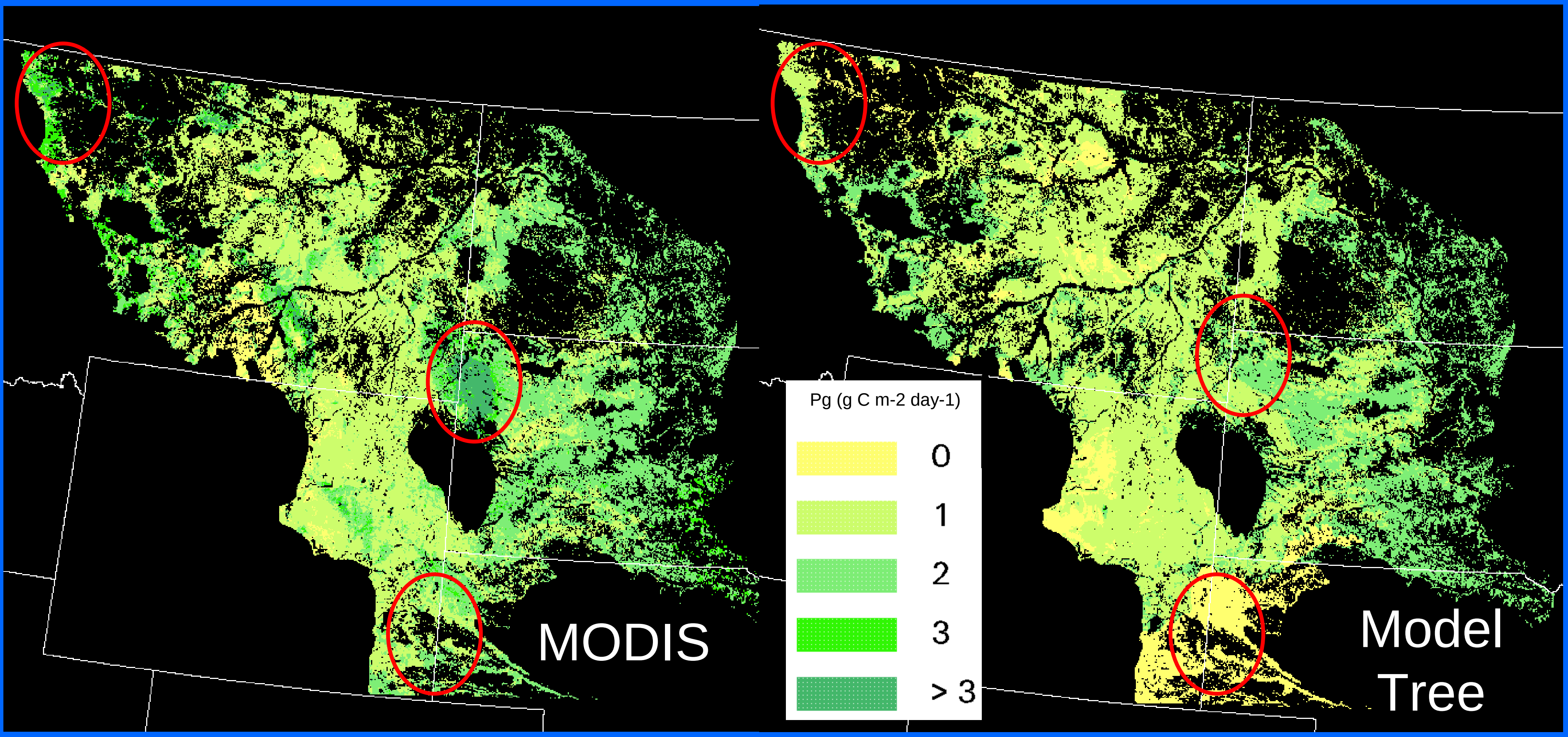
MODIS GPP

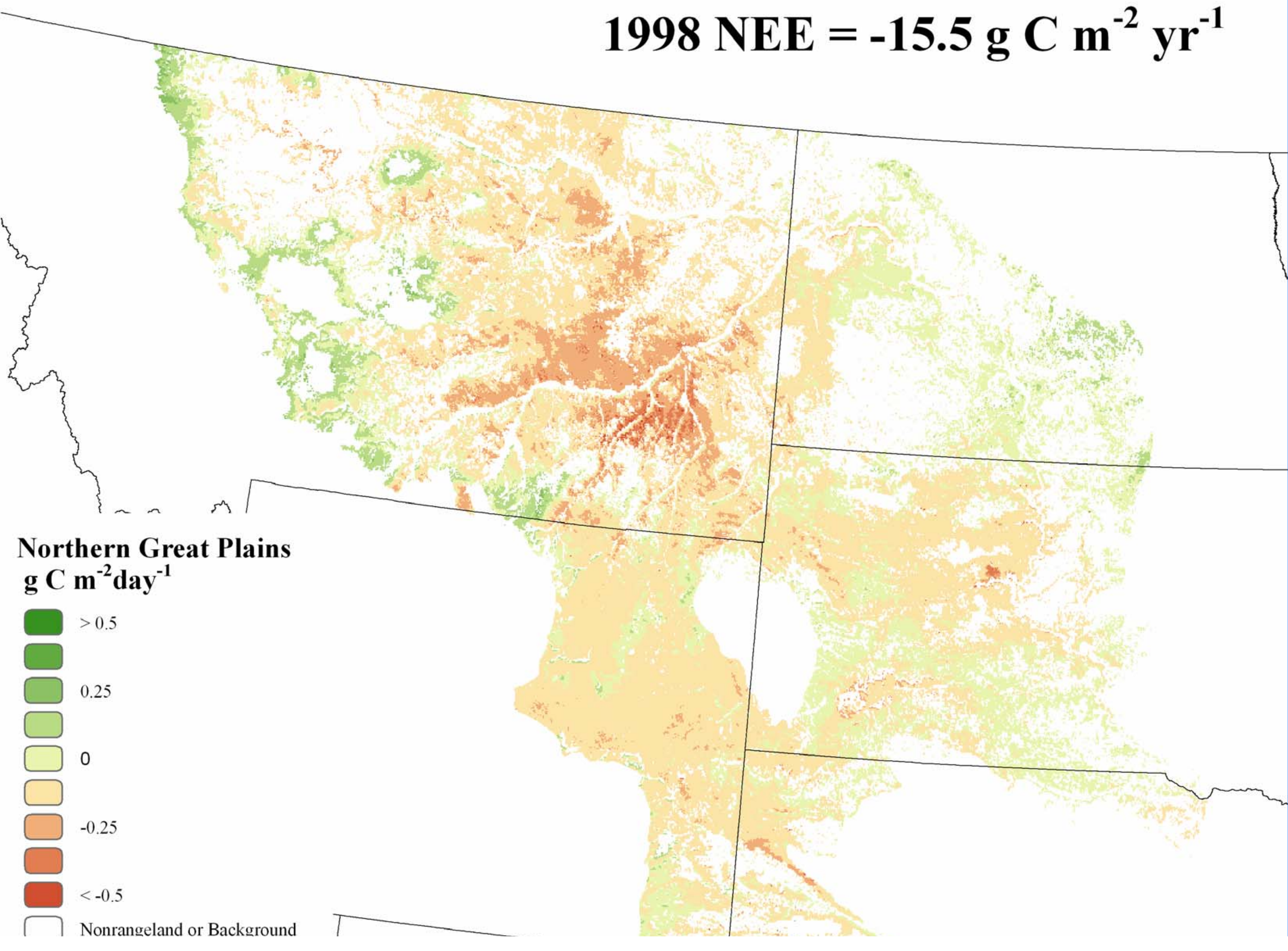




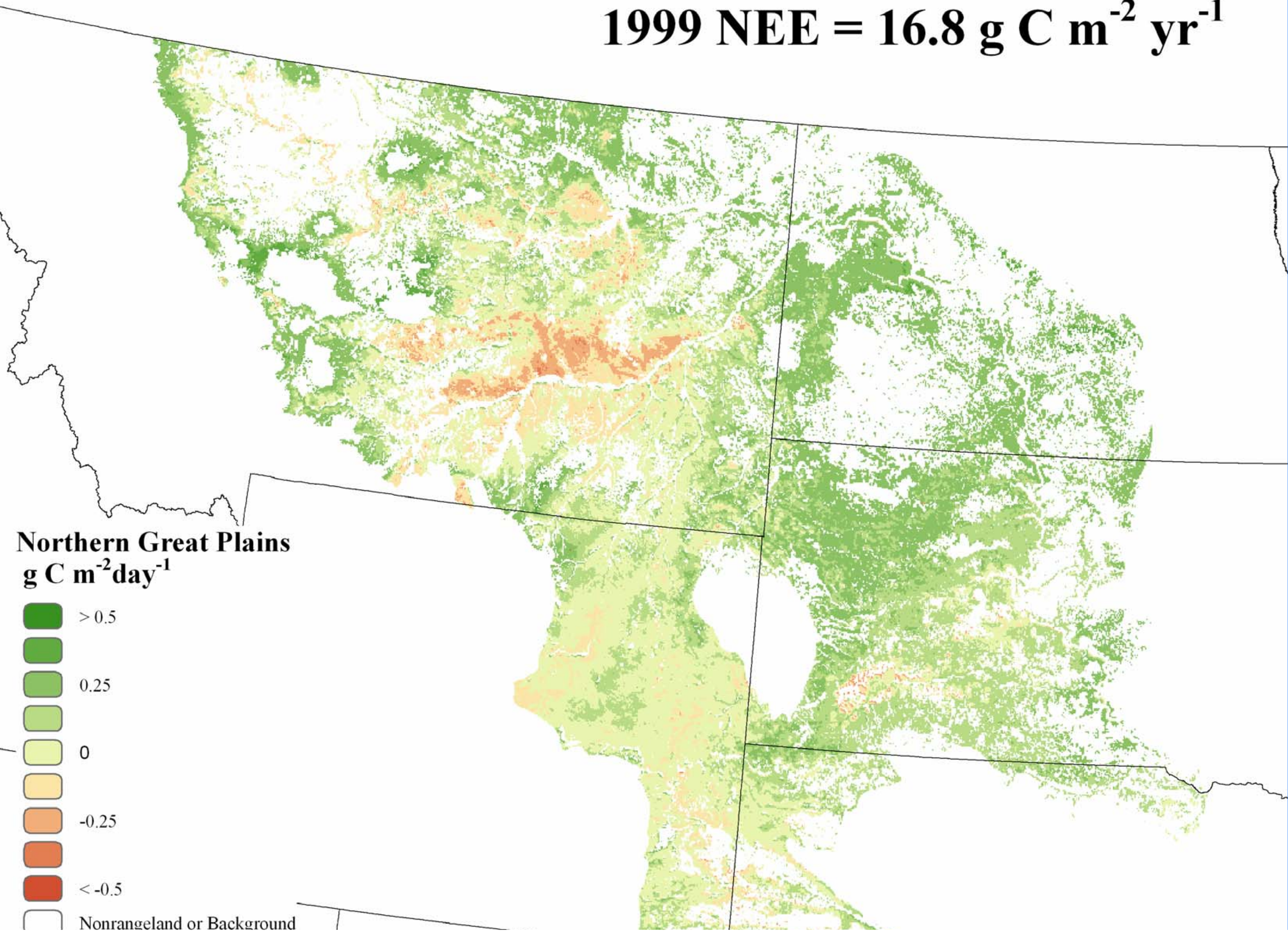
Regional Comparison of 2001 MODIS GPP and Model Tree Pg on Rangelands

- General Agreement
- MODIS had outlier values > 6 g C m^{-2} day^{-1}

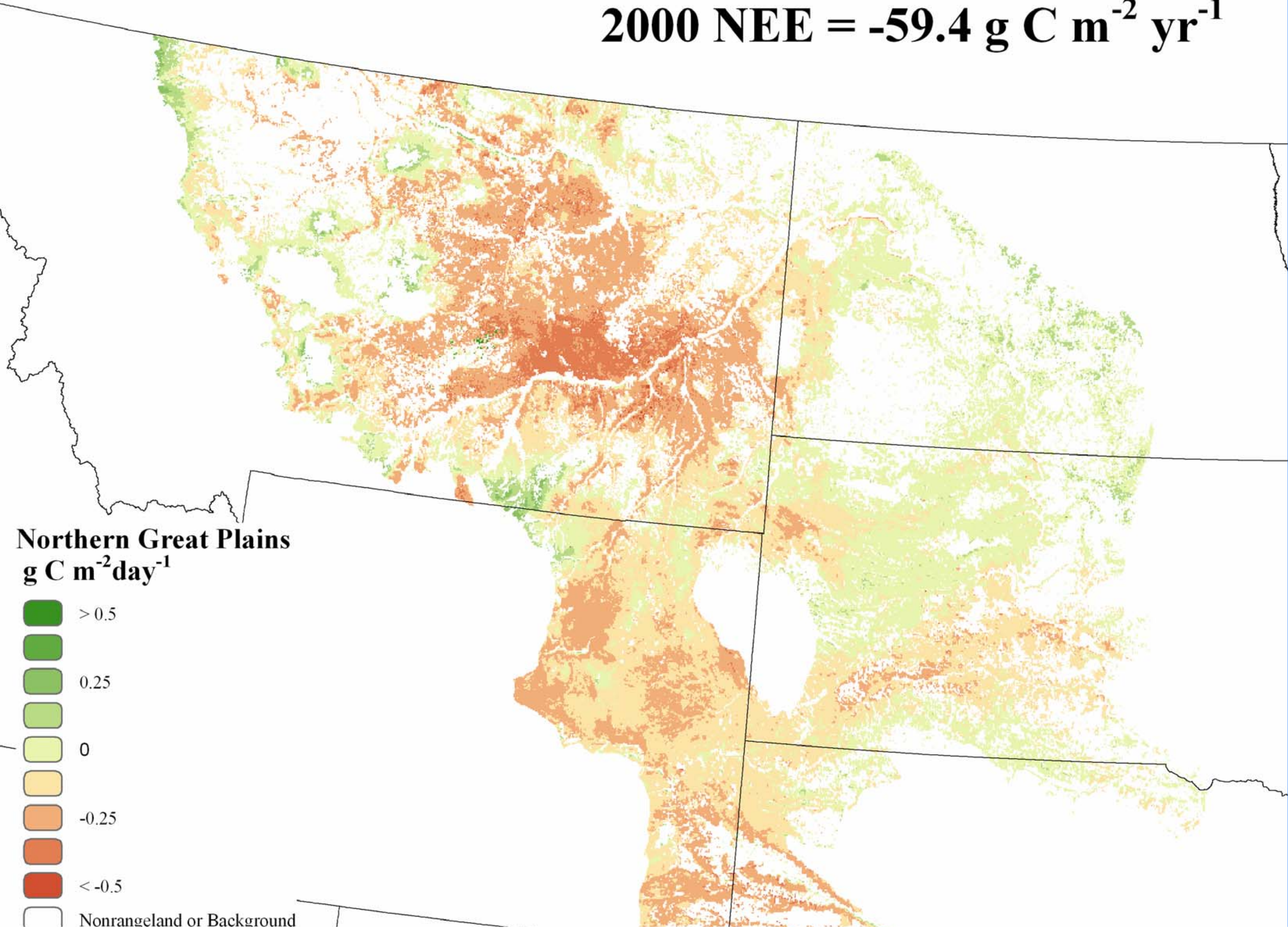


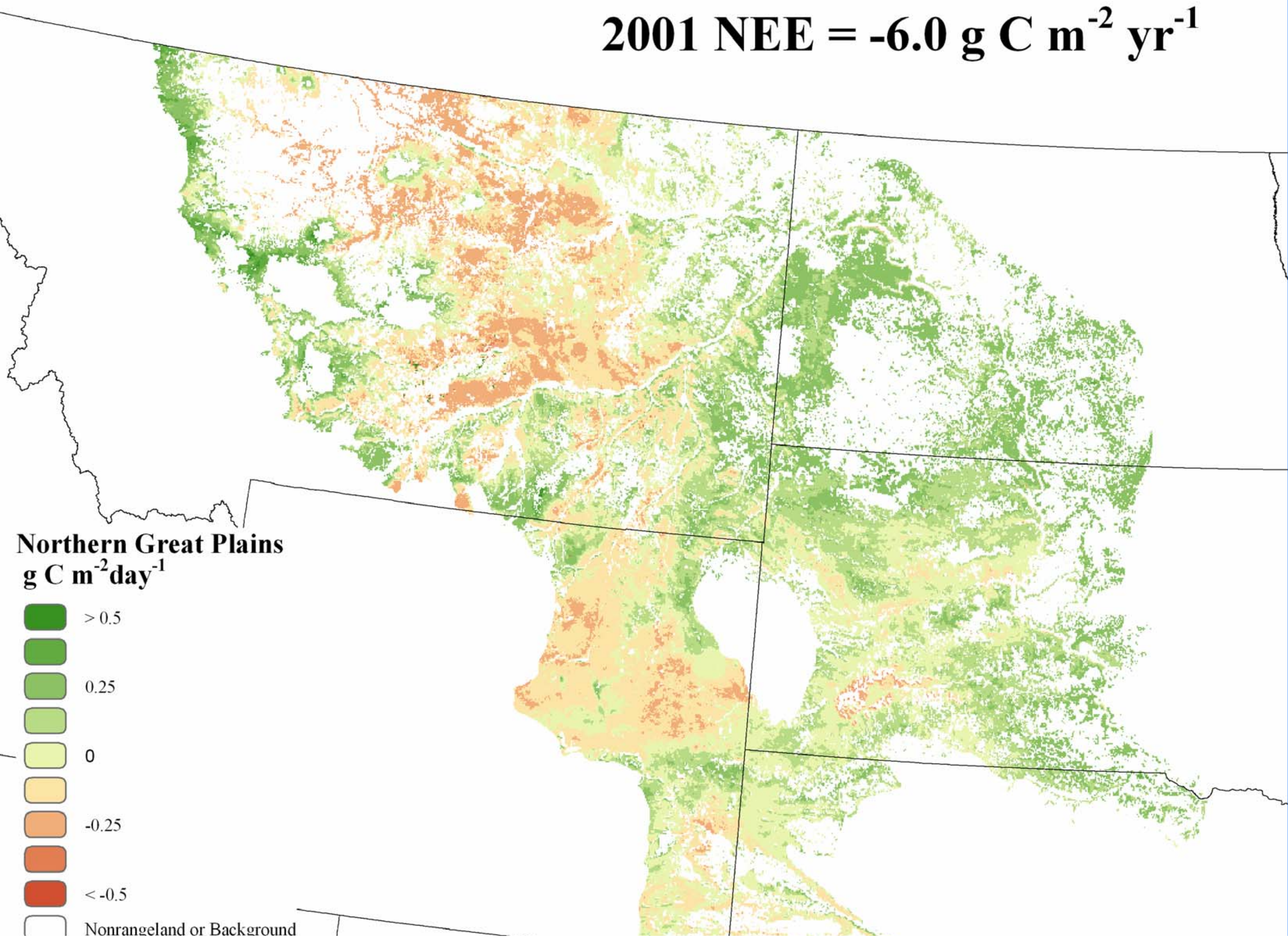

1998 NEE = -15.5 g C m-2 yr-1
Northern Great Plains
g C m-2day-1
> 0.5
0.25
0
-0.25
< -0.5
Nonrangeland or Background

1999 NEE = 16.8 g C m^{-2} yr^{-1}



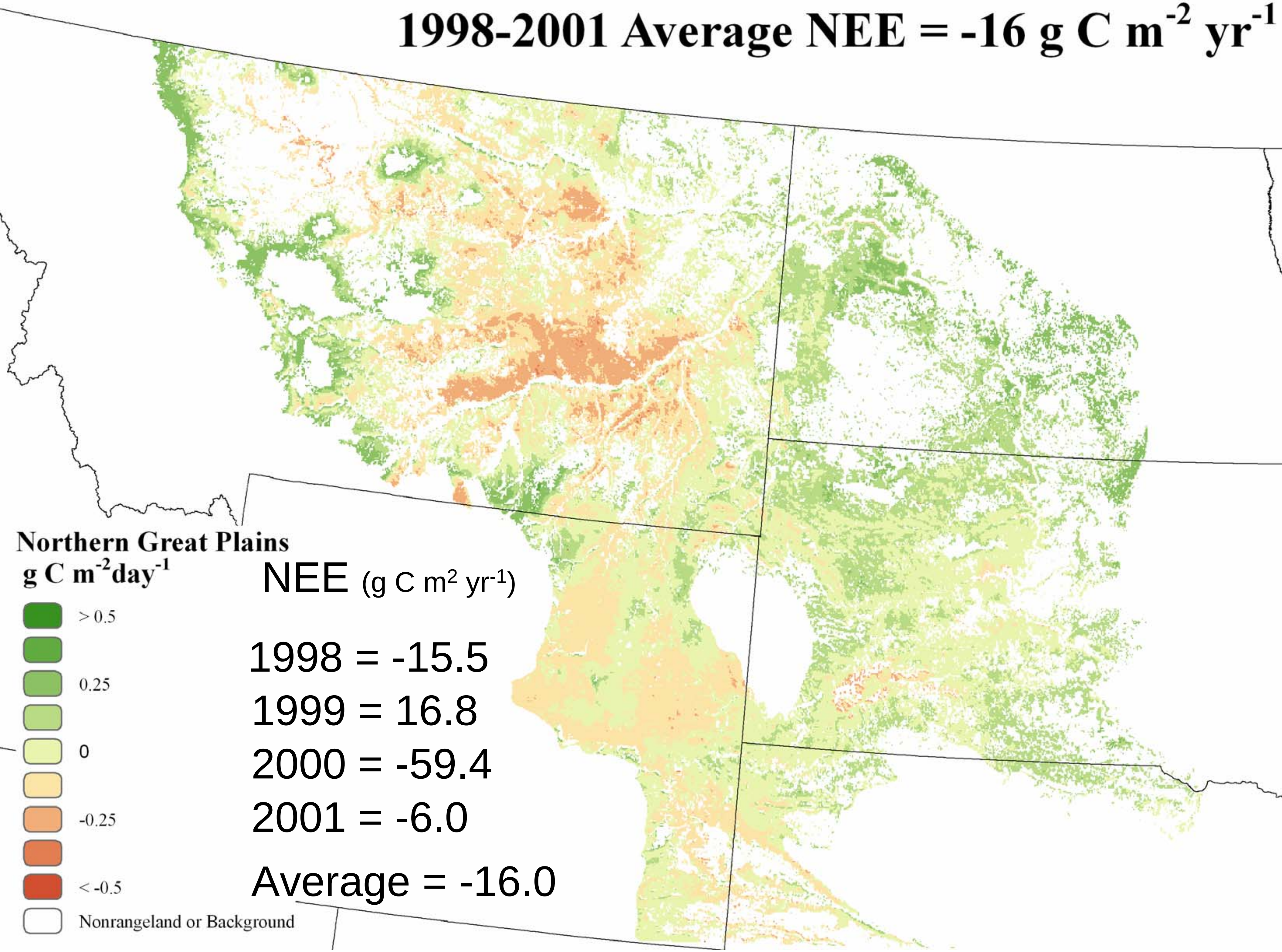
2000 NEE = -59.4 g C m^{-2} yr^{-1}



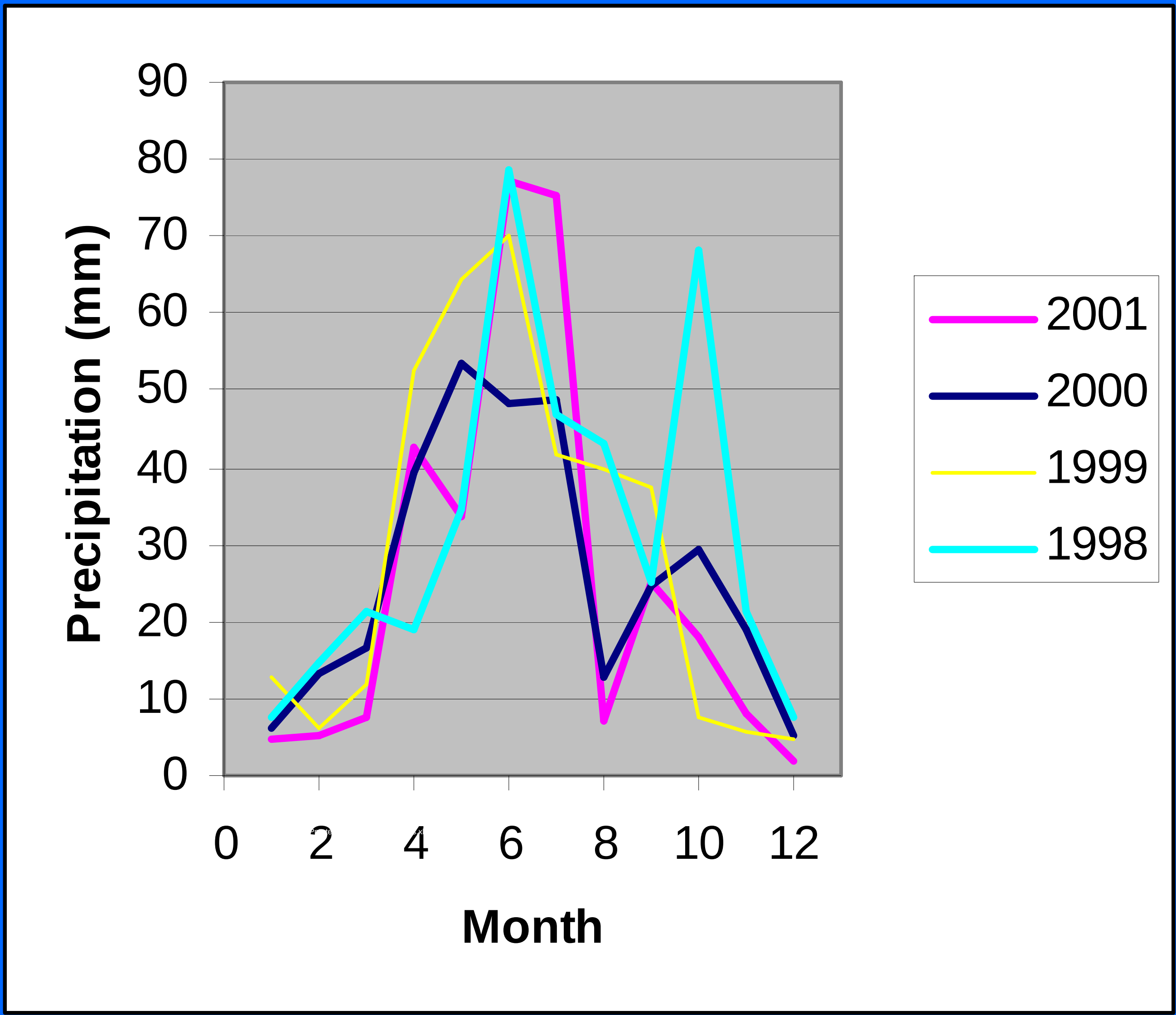


2001 NEE = -6.0 g C m-2 yr-1
Northern Great Plains
g C m-2day-1
> 0.5
0.25
0
-0.25
< -0.5
Nonrangeland or Background

1998-2001 Average NEE = -16 g C m^{-2} yr^{-1}



Why was 2000 NEE so low?



NEE (g C m^2 yr^{-1})

1998 = -15.5

1999 = 16.8

2000 = -59.4

2001 = -6.0

Average = -16.0

- Low June precipitation
- Low previous fall precipitation

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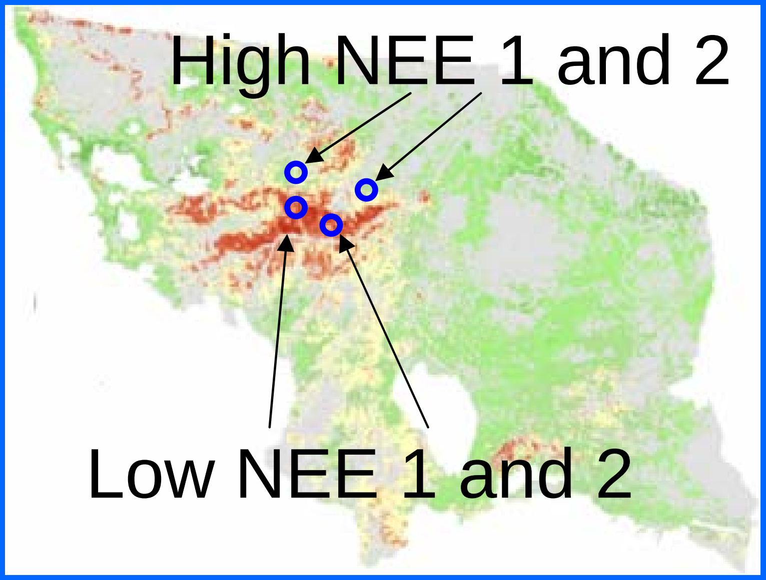
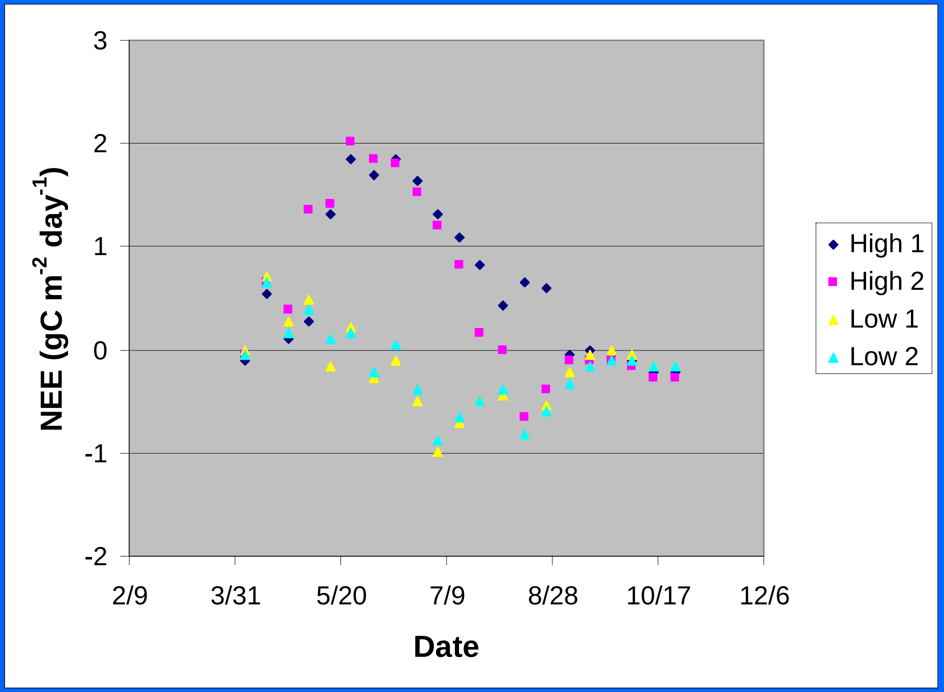
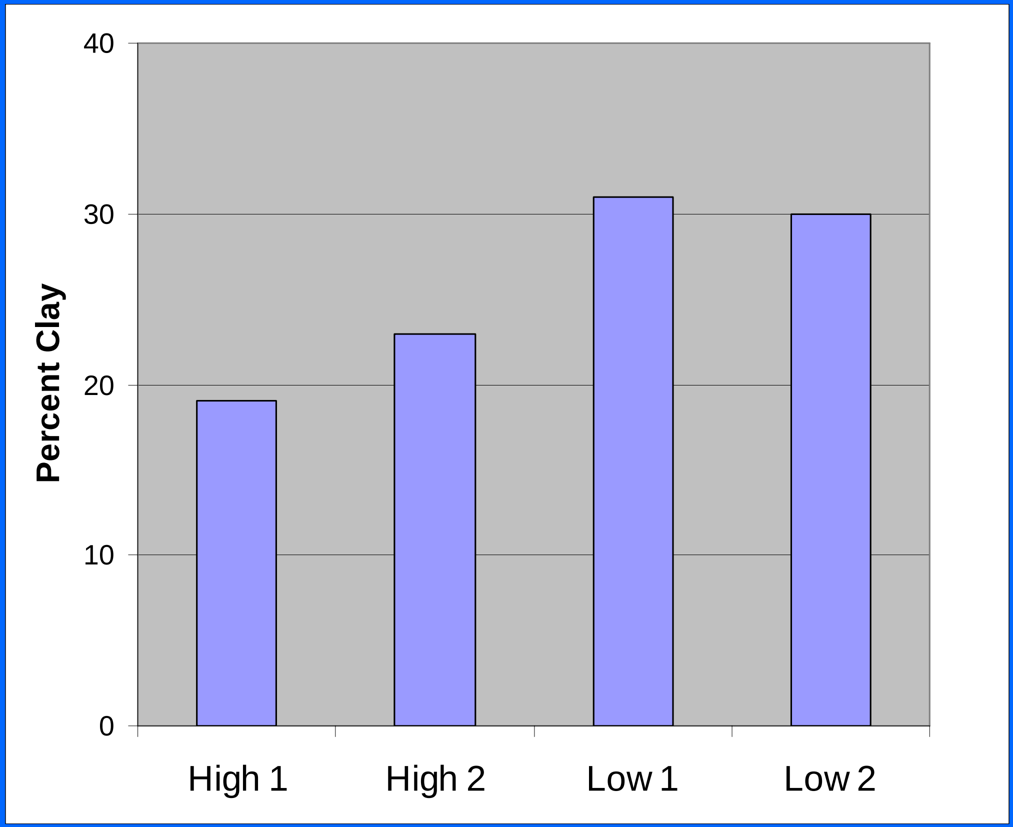
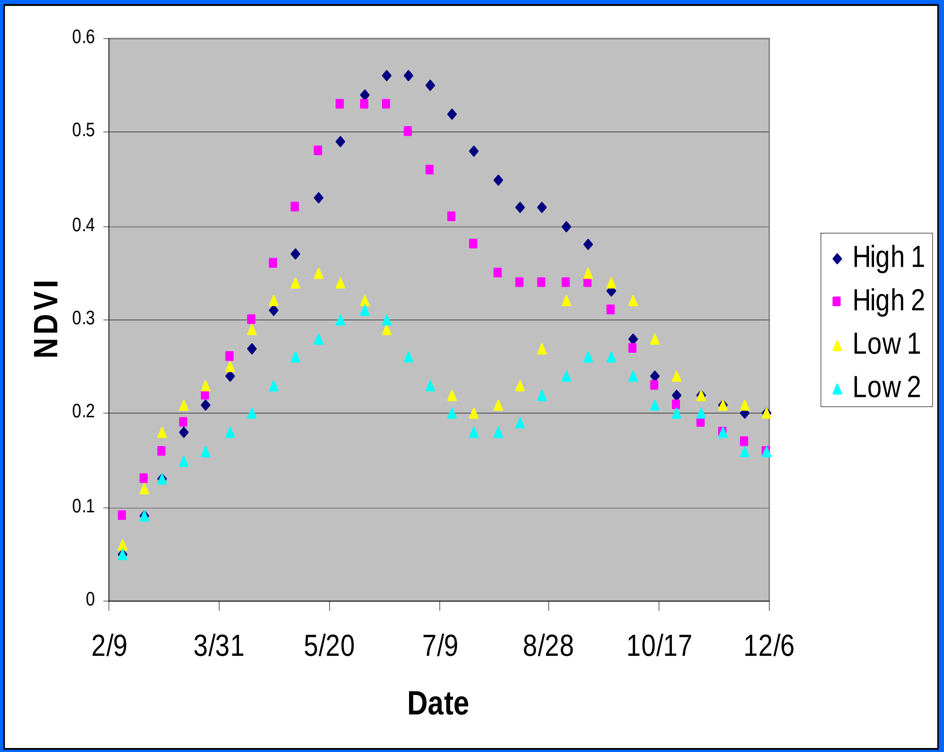
Investigating Causes of Sinks and Sources: 1999

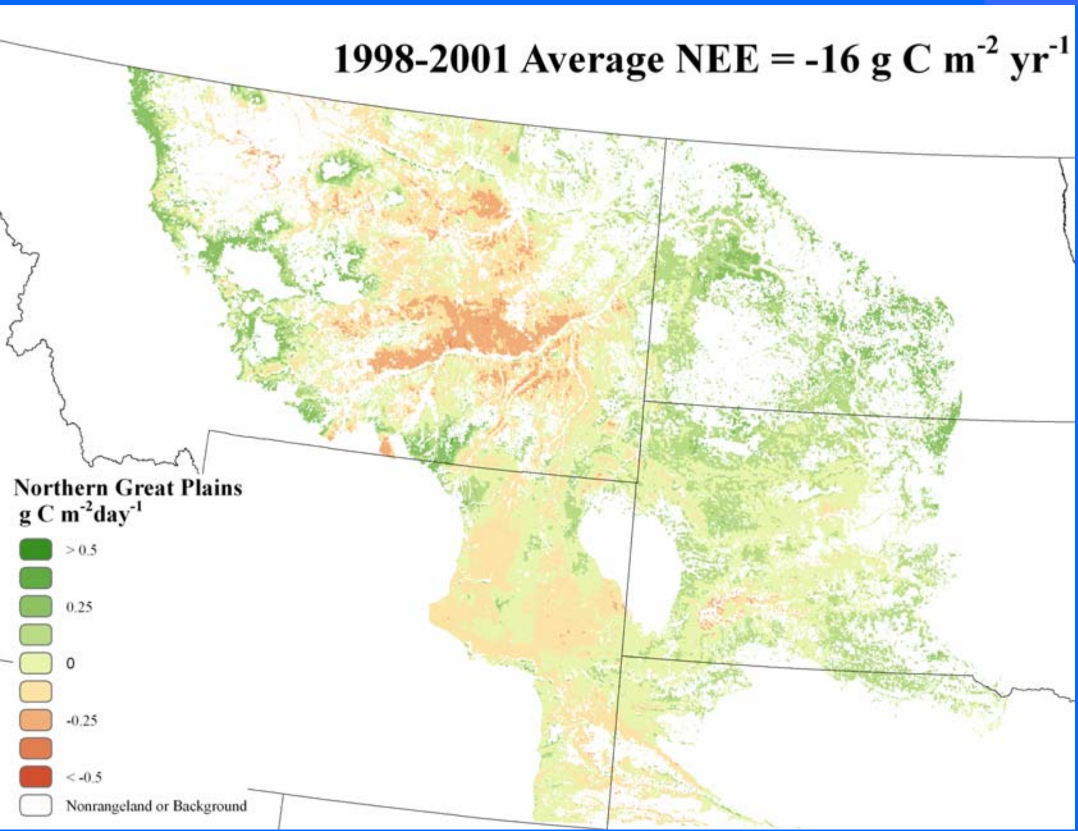




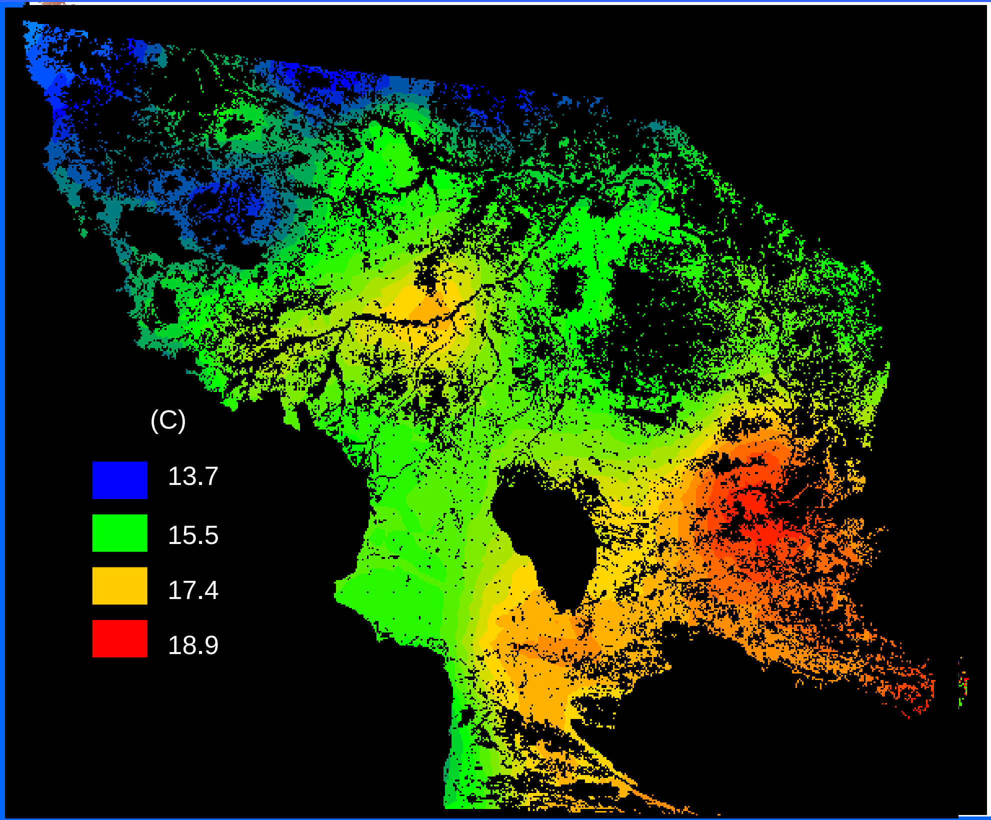




Environmental Drivers of 1998-2001 Source Areas



Average Temperature (Apr. - Oct., 1998-2001)



Conclusions

- Model Tree predictions of Pg and NEE agreed well with tower observations

- Heavy reliance of Model Tree predictions on NDVI insures tracking of temporal and spatial dynamics not evident in climatic data sets

- Winter flux estimates need improvement

- N. Great Plains Rangelands from 1998-2001 were a WEAK source of C.

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