



# A Process Based Stream Network Model for Predicting CO<sub>2</sub> Concentrations and Fluxes at High Resolution



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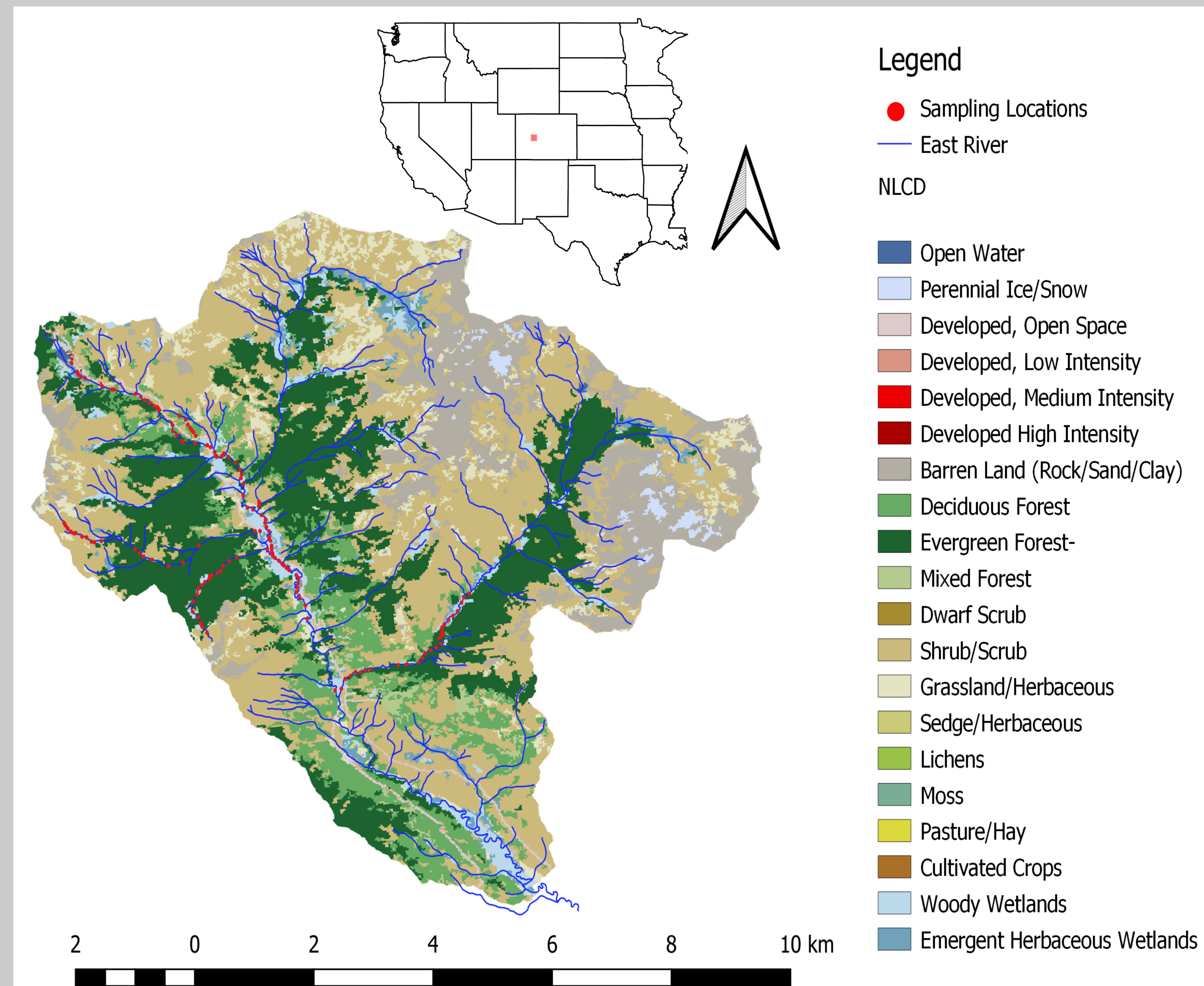
## 1. Background

The current estimate of atmospheric CO<sub>2</sub> fluxes from rivers and streams is uncertain ranging from 0.75 to 3.88 Pg C yr<sup>-1</sup> (Drake et al 2018). This uncertainty is in part due to our inability to measure or predict CO<sub>2</sub> accurately at high resolution and across regions. Additionally current models used to upscale *p*CO<sub>2</sub> fluxes only provide the magnitude of estimated fluxes and little to no insight on the sources of the CO<sub>2</sub>. We tested a process based stream network model to address these questions:

**Can process-based models accurately predict *p*CO<sub>2</sub> at high-resolution?**

**Do process-based model offer new insights to the sources of CO<sub>2</sub>?**

## 2. East River Watershed, CO



We used the East River at the Rocky Mountain Biological Laboratory in Gothic Colorado (USA) as the test site for our CO<sub>2</sub> Stream Network Model.

### The Watershed

- 87 km<sup>2</sup>
- 2760-4123 m above sea level
- 1.2±0.26 m y<sup>-1</sup>
- 1 °C
- 1-5 Strahler order streams

## 3. *p*CO<sub>2</sub> Model

C: carbon (mol/L)

v: velocity (m/s)

A: stream cross-sectional area (m<sup>2</sup>)

Q: discharge (m<sup>3</sup>/s)

x: distance (m)

\**C<sub>gw</sub>*: CO<sub>2</sub> in groundwater (mol/L)

*C<sub>atm</sub>*: CO<sub>2</sub> at equilibrium with the atmosphere (mol/L)

\**C<sub>hz</sub>*: hyporheic zone CO<sub>2</sub> (mol/L)

*k<sub>hz</sub>*: hyporheic zone gas transfer velocity of CO<sub>2</sub> (m/s)

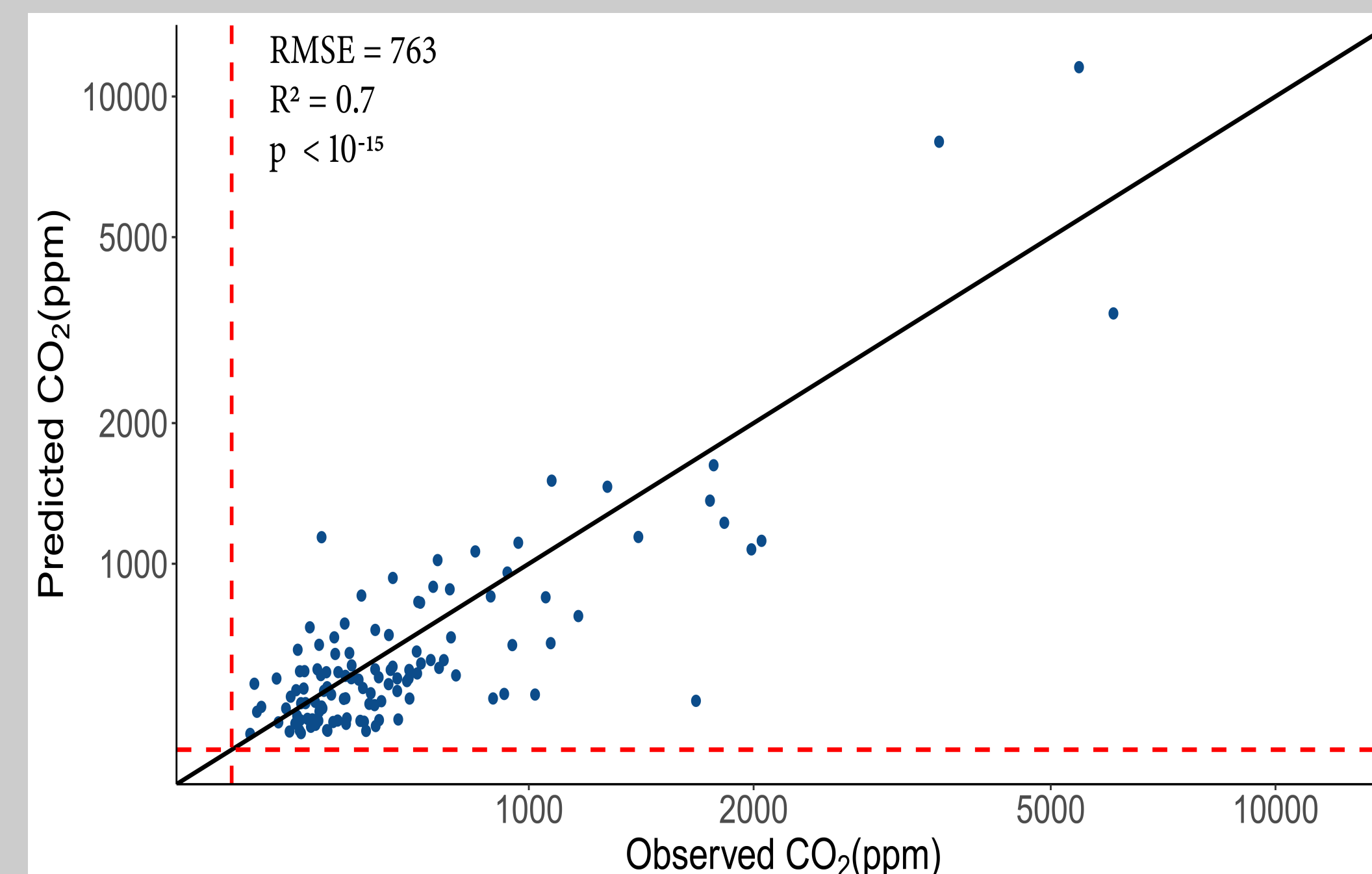
*k<sub>CO2</sub>*: gas transfer velocity of CO<sub>2</sub> (m/s)

\**F<sub>wc</sub>*: water column net respiration fluxes of CO<sub>2(aq)</sub> (mol/L/s)

\* indicate free parameters

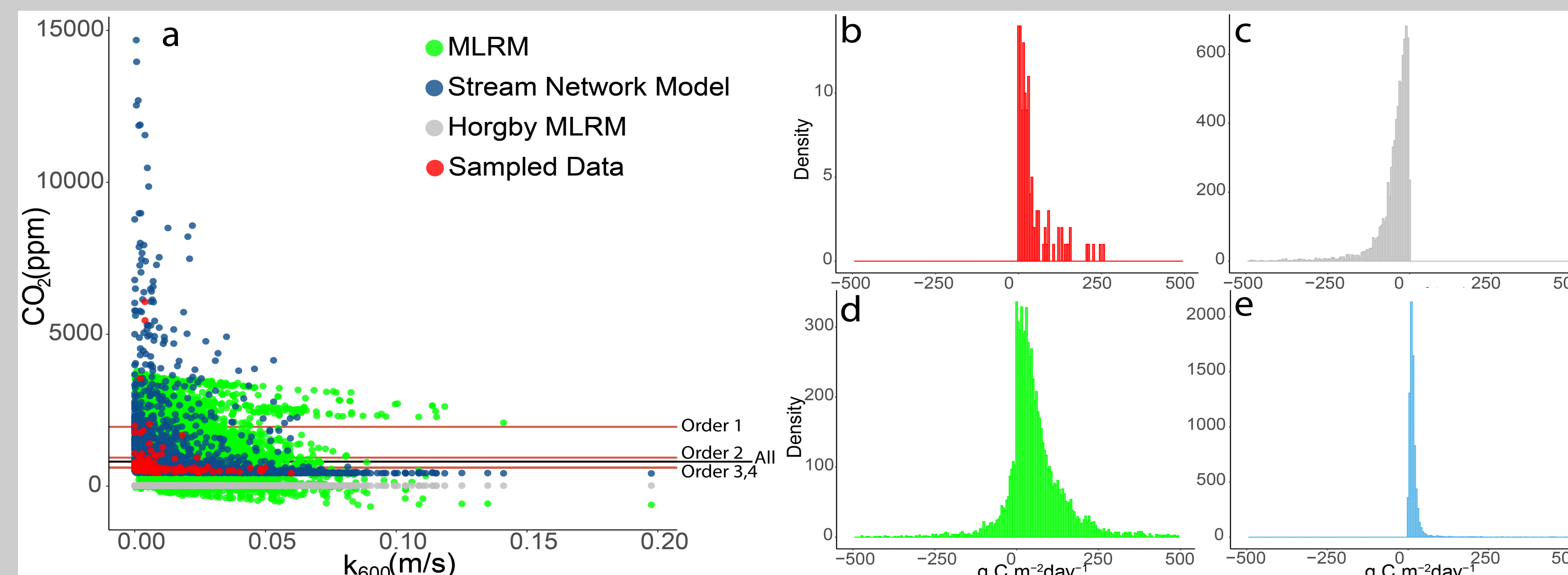
$$\frac{dC}{dt} = \underbrace{-v \frac{dC}{dx}}_{\text{Advection}} + \underbrace{\frac{1}{A} \frac{dQ}{dx} (C_{gw} - C)}_{\text{Ground water input of CO}_2} - \underbrace{k_{CO2}(C - C_{atm})}_{\text{Losses from evasion}} + \underbrace{k_{hz}(C_{hz} - C)}_{\text{Benthic respiration}} + \underbrace{F_{wc}}_{\text{Water column respiration}}$$

## 4. Validation & Results

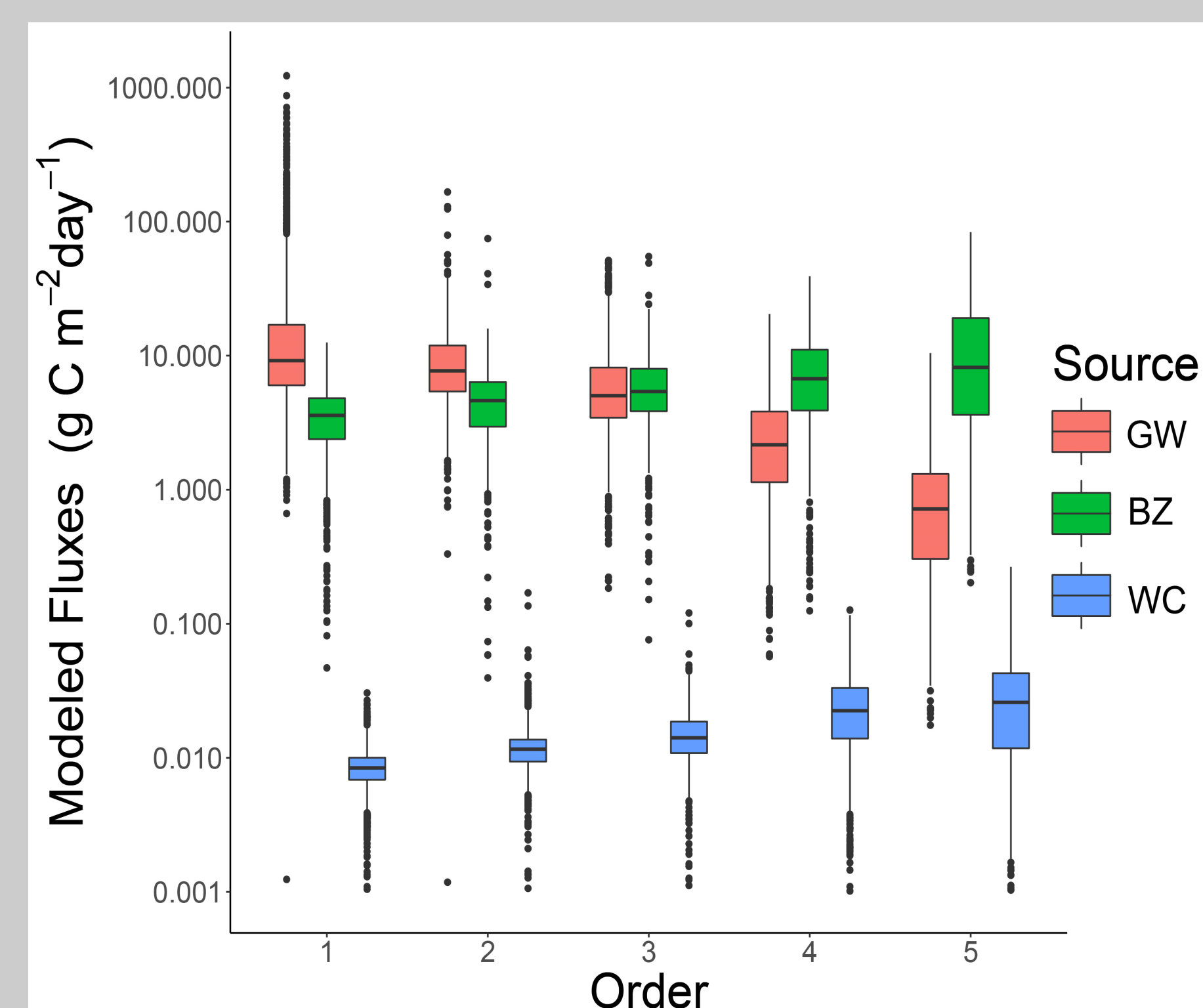


The Stream Network Model was validated using 121 sampled points across the East River. The validation samples include 1<sup>st</sup> to 5<sup>th</sup> Strahler order streams, with *p*CO<sub>2</sub> ranging from 423 to 6066, and a mean slope of 23°.

The Stream Network Model predicted *p*CO<sub>2</sub> is plotted on the Y axis with the measured *p*CO<sub>2</sub> on the X axis. The red dashed lines are atmospheric concentrations of CO<sub>2</sub> (400 ppm) and the black line is a 1:1 line.

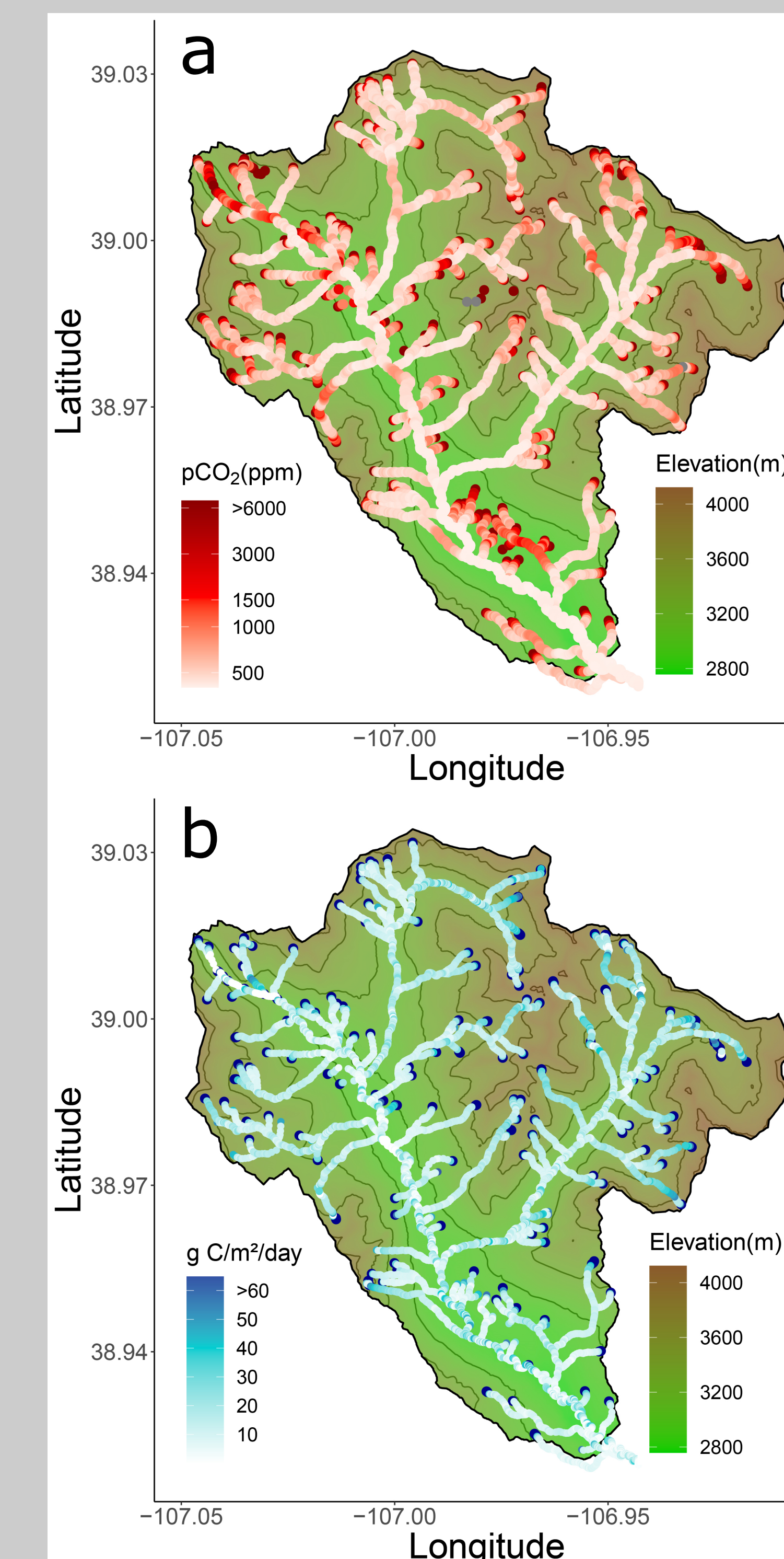


*p*CO<sub>2</sub> is often restricted by reaeration rates, as high *k*<sub>600</sub> can rapidly equilibrium dissolved stream gases to atmospheric levels (Rocher-Ros et al., 2019). The stream network model was able to capture these patterns as seen in (a). Additionally, *p*CO<sub>2</sub> data is often right skewed as seen in the sampled data (b) which is reflected only in the Stream Network Model (e) and not in the multiple linear regression (MLRM) (d) or the Horgby mountain stream model (c) (Horgby et al., 2019).



In addition to *p*CO<sub>2</sub> predictions the Stream Network Model allows for a separation of CO<sub>2</sub> sources and therefor fluxes by groundwater (GW), benthic hyporheic zone respiration (BZ), and water column respiration (WC). With GW decreasing and respiration (BZ, WC) increasing as stream order increases agreeing with the findings of (Hotchkiss et al., 2015).

## 5. Discussion



The East River *p*CO<sub>2</sub> (ppm) in red (a) area normalized fluxes in blue (b)

• **The process-based model outperformed statistical methods of predicting *p*CO<sub>2</sub> within the East River watershed.**

• **The stream network model provides estimates of external and internal CO<sub>2</sub> contributions, suggesting that benthic hyporheic exchange represents a significant portion of stream CO<sub>2</sub>.**

• **Relationships between *p*CO<sub>2</sub> and atmosphere exchange velocities result in overestimates of CO<sub>2</sub> fluxes from statistical upscaling methods**

- 18.2 g C m<sup>-2</sup> day<sup>-1</sup> mean predicted *p*CO<sub>2</sub> flux
- 3.9 Mg C day<sup>-1</sup> total East River watershed flux
- First order reaches had the largest emissions totaling 1.2 Mg C day<sup>-1</sup>
- 49.3% of CO<sub>2</sub> emitted is from groundwater
- 50.6% of CO<sub>2</sub> emitted is from benthic hyporheic respiration
- Water column respiration contributed 0.1%.

	<i>p</i> CO <sub>2</sub> range(ppm)	R <sup>2</sup>	Fluxes Mg C/day	Sampled reach Fluxes Mg C/day
Sampled data	423 - 6066	-	-	0.16
Stream network Model	417 - 18000	0.7*	3.9	0.08
MLRM	-674 - 3795	0.21*	47.9	0.02
Horgby MLRM	12 - 32	0.27*	-16.1	-0.38
Upscaling by Mean <i>p</i> CO <sub>2</sub>	806	-	16.9	0.39
Upscaling by Mean order <i>p</i> CO <sub>2</sub>	603 - 1951	-	16.7	0.24

The predicted range of CO<sub>2</sub> and the R<sup>2</sup> with \* denoting significance for each tested model. The Fluxes represent total predicted watershed C emissions whereas sample reach Fluxes represent C emissions of only the sampled points.

## 6. Conclusion

## References

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