

# Towards Diurnal GPP with TEMPO and Machine Learning



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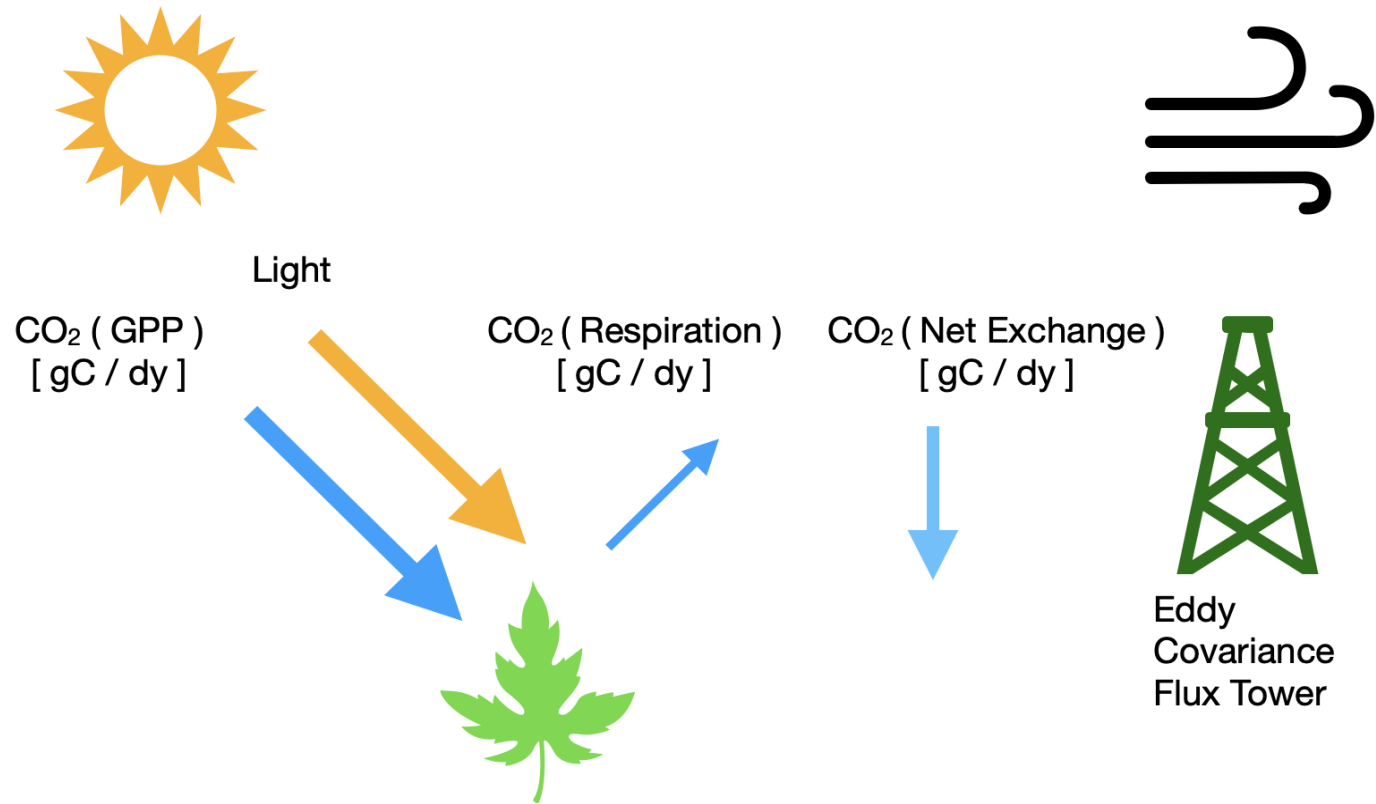
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# Why GPP?

- GPP ( Gross Primary Productivity ) is the rate of carbon uptake ( flux ) from the atmosphere by vegetation via photosynthesis.



- Measures vegetative growth and is an indicator for ecosystem health and crop yield.
- Major player in global terrestrial carbon cycle.

- Net carbon flux measurements are performed by eddy covariance flux towers.
- Rates of net carbon dioxide exchange are calculated from the covariance of CO<sub>2</sub> concentration and turbulent vertical air currents.
- GPP is inferred from net exchange using various flux partitioning approaches.

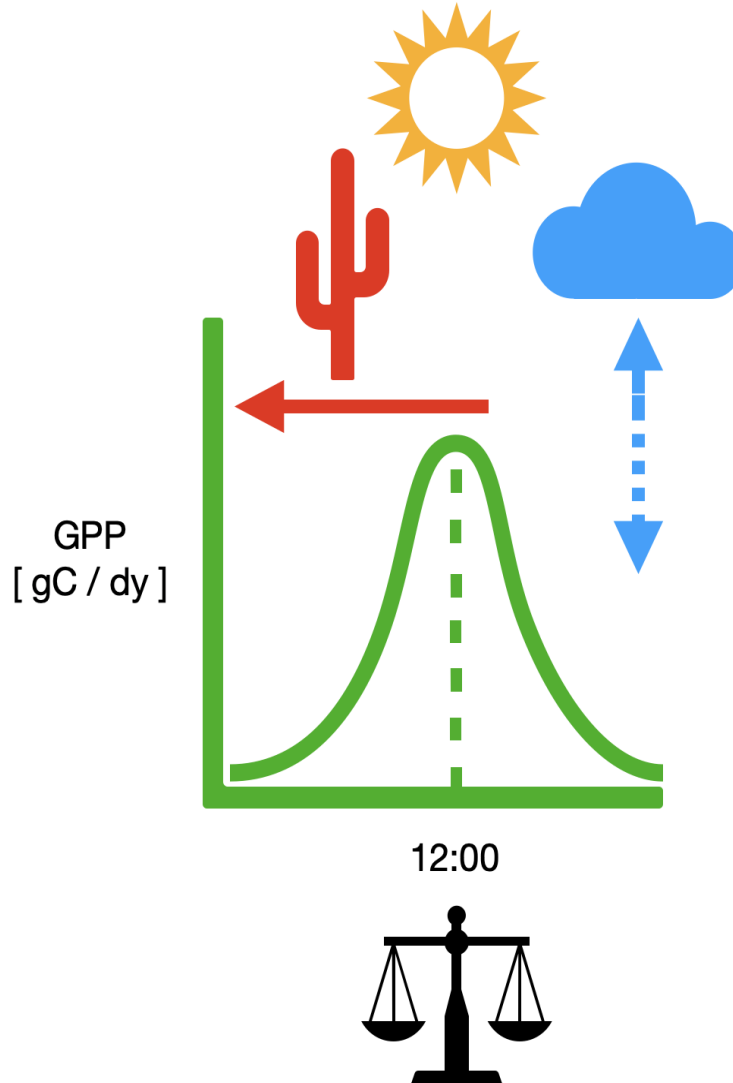
# Why TEMPO?

- Remote sensing can broadcast flux tower measurements across the entire globe assuming remote sensing spectra correlate well with GPP.
- We already do this with MODIS, producing the machine learning driven FluxSat product.
- Though TEMPO has a larger pixel size and lacks infrared, it is hyperspectral and makes hourly scans.

Sensor	Spatial Coverage	Spatial Resolution	Spectral Coverage	Spectral Mode	Temporal Resolution
MODIS ( MCD43D62 - MCD43D68 )	Global	1 km	VIS / IR 459 nm – 2155 nm	Multispectral 7 discrete band averages ( NBAR )	Daily ( 8 Day Moving Average )
TEMPO	North America	2 km x 5 km	UV / VIS 290 nm – 490 nm 540 nm – 740 nm	Hyperspectral 0.6 nm resolution	Hourly

# Why Diurnal GPP?

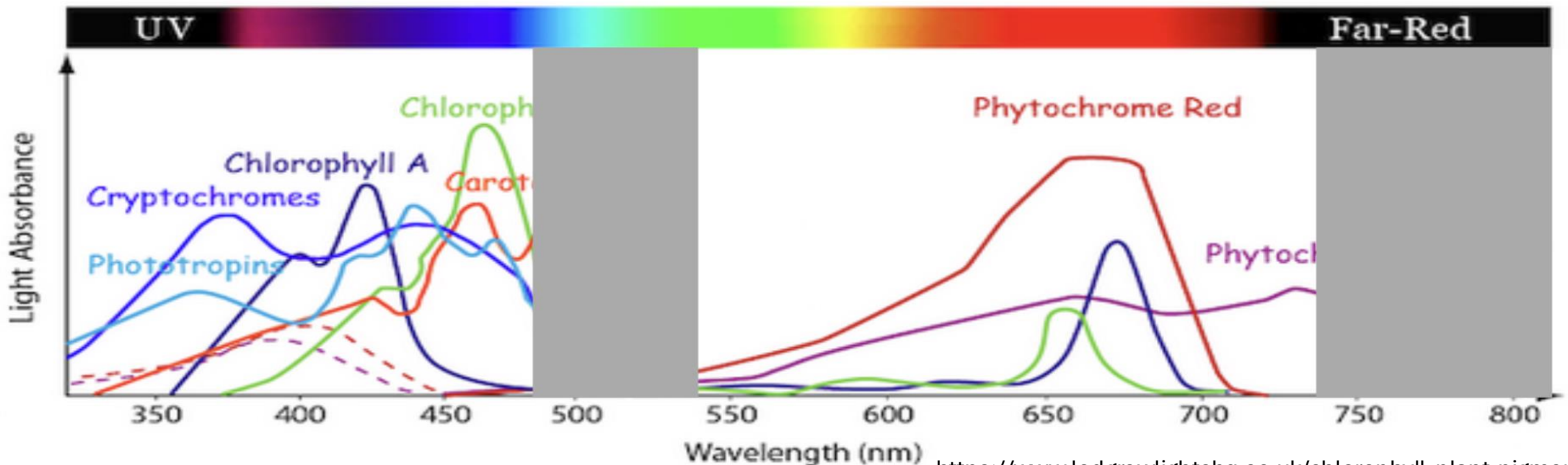
- GPP has a diurnal profile as it changes throughout the day. Daily totals come from integration.
- If solar radiation were the only factor, the diurnal profile would tend to have its peak and balance point at solar noon.
- A single daily remote sensing measurement such as from MODIS could characterize the entire daily total with high confidence.



- Moisture stress can cause the peak and balance point to shift earlier as stomata close before noon to prevent moisture loss.
- Clouds can also have complex effects, blocking solar radiation but also triggering higher efficiency diffuse light pathways.
- Diurnal GPP can both improve accuracy of carbon accounting and be an ecosystem diagnostic.

# TEMPO Spectra

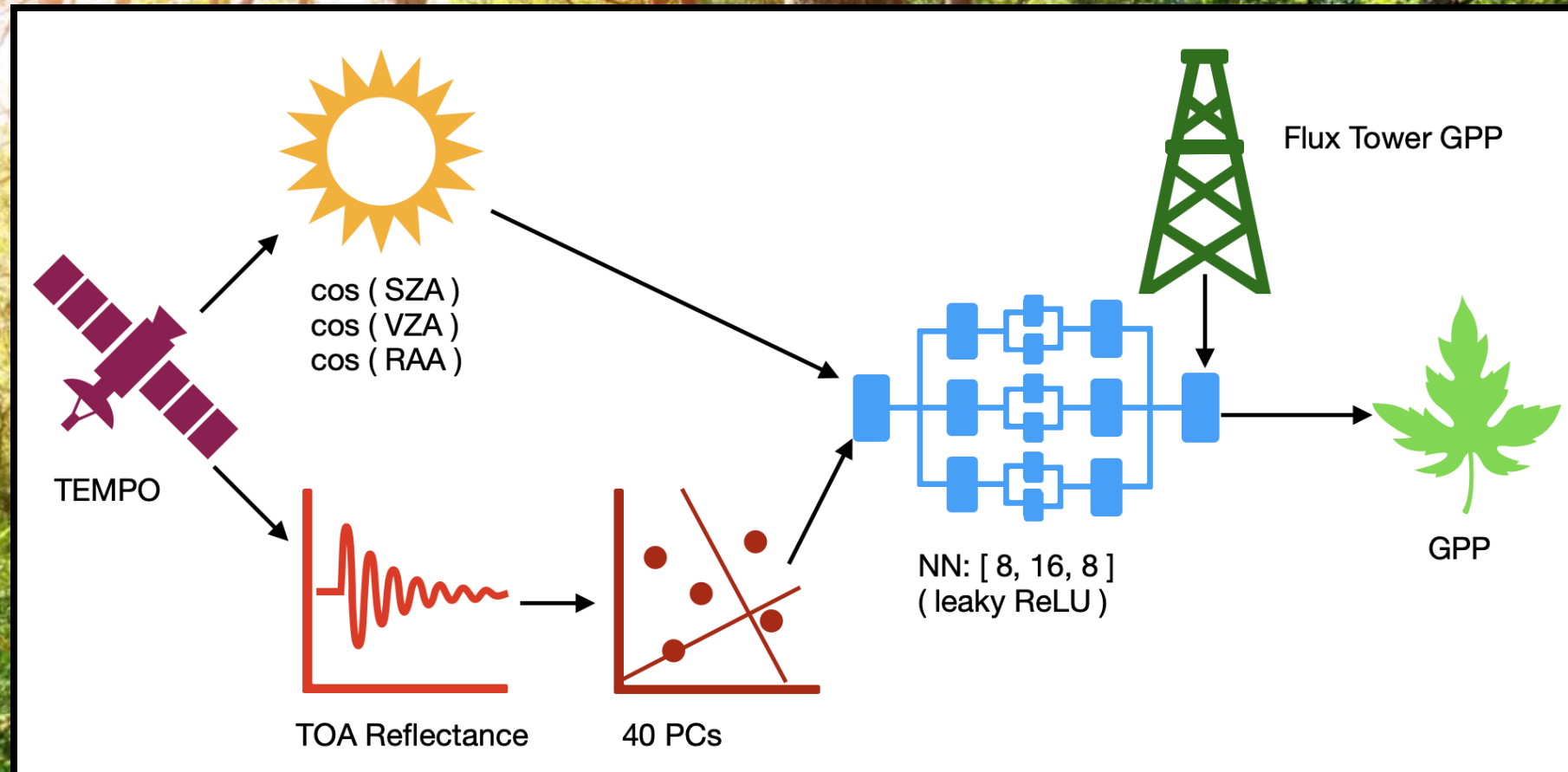
- Hyperspectral signals offer a richer view than discrete bands or derived indices ( like NDVI ).
- Covers the absorption spectra for several plant pigments.
- However, missing infrared and blue-green regions are not trivial.



# Machine Learning Model

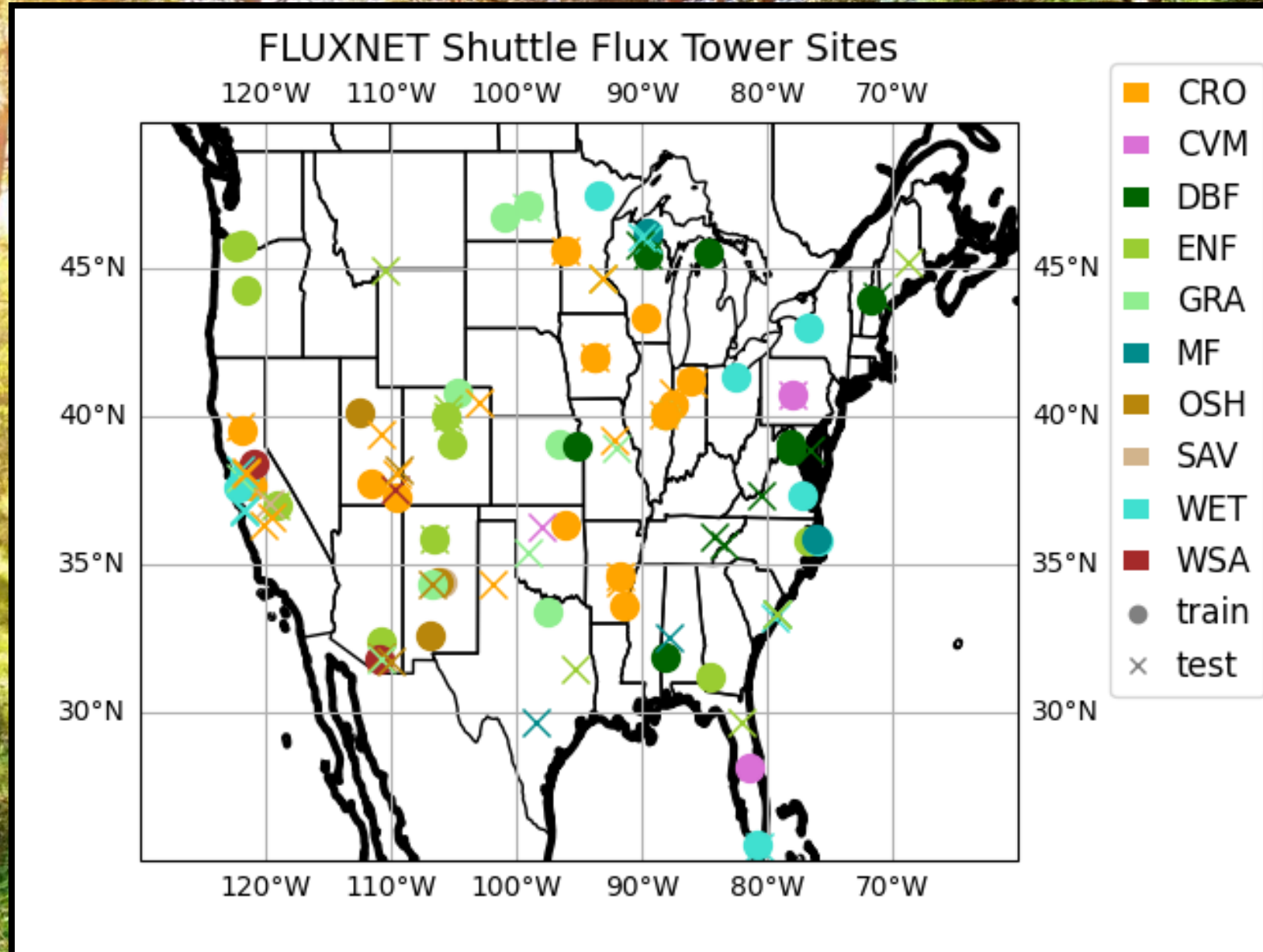
- V3 TEMPO TOA reflectances are decomposed into linearly independent PCA components.
- Viewing geometry added for additional context.
- Ground truth from eddy covariance fluxtower data.

- Feed Forward Neural Network
- Leaky ReLU activation
- 3 hidden layers [ 8, 16, 8 ]
- Cloud screening ( CRF < 0.5 )

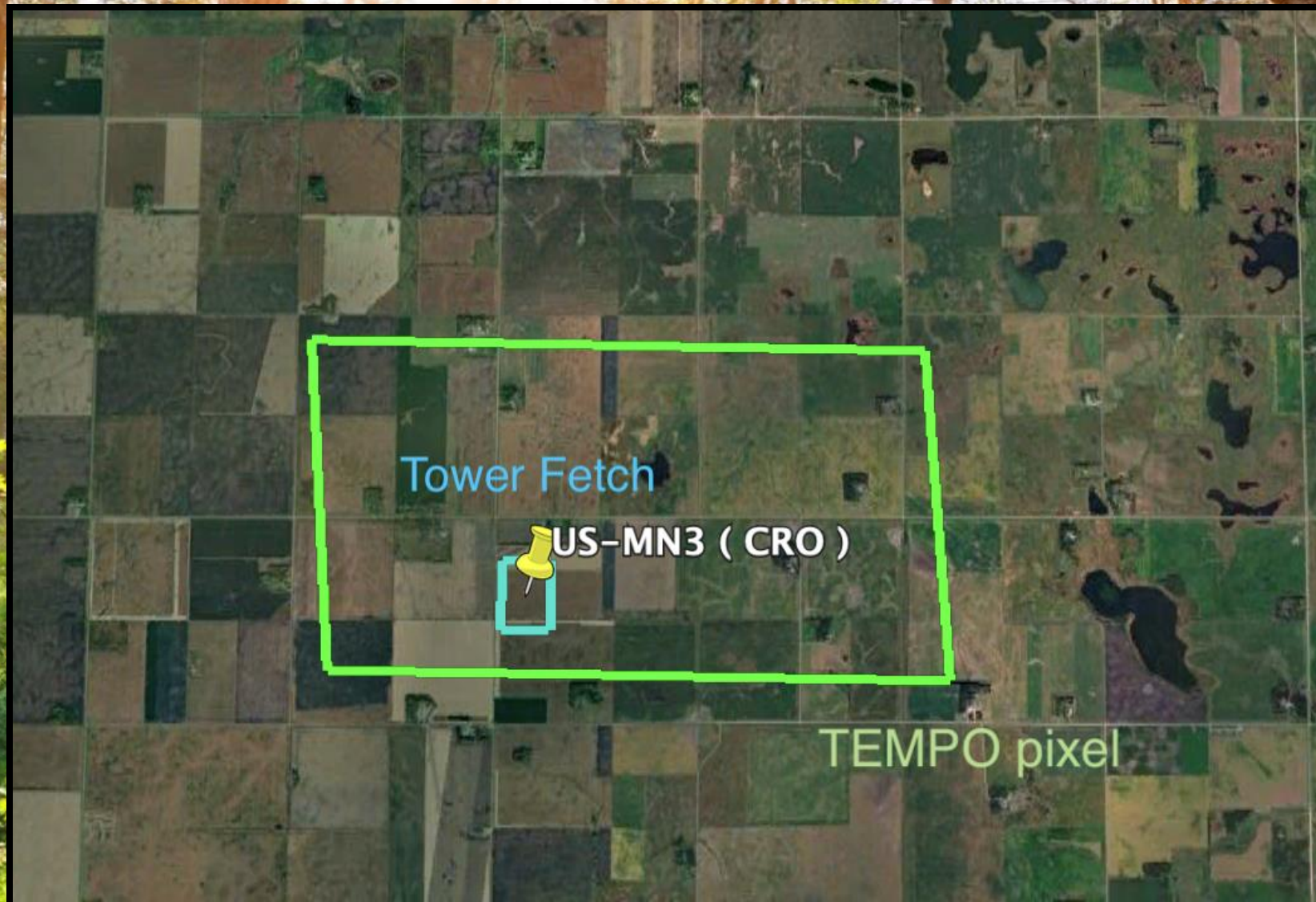


# Flux Tower Sites

- 124 US Fluxnet Shuttle sites.
- 62 training sites selected at random.
- Remaining 62 sites used for testing.
- Split also optimized for comparable geographic spread and IGBP land type distribution.
- All data during July 2024 (growing season).



# Spatial Heterogeneity

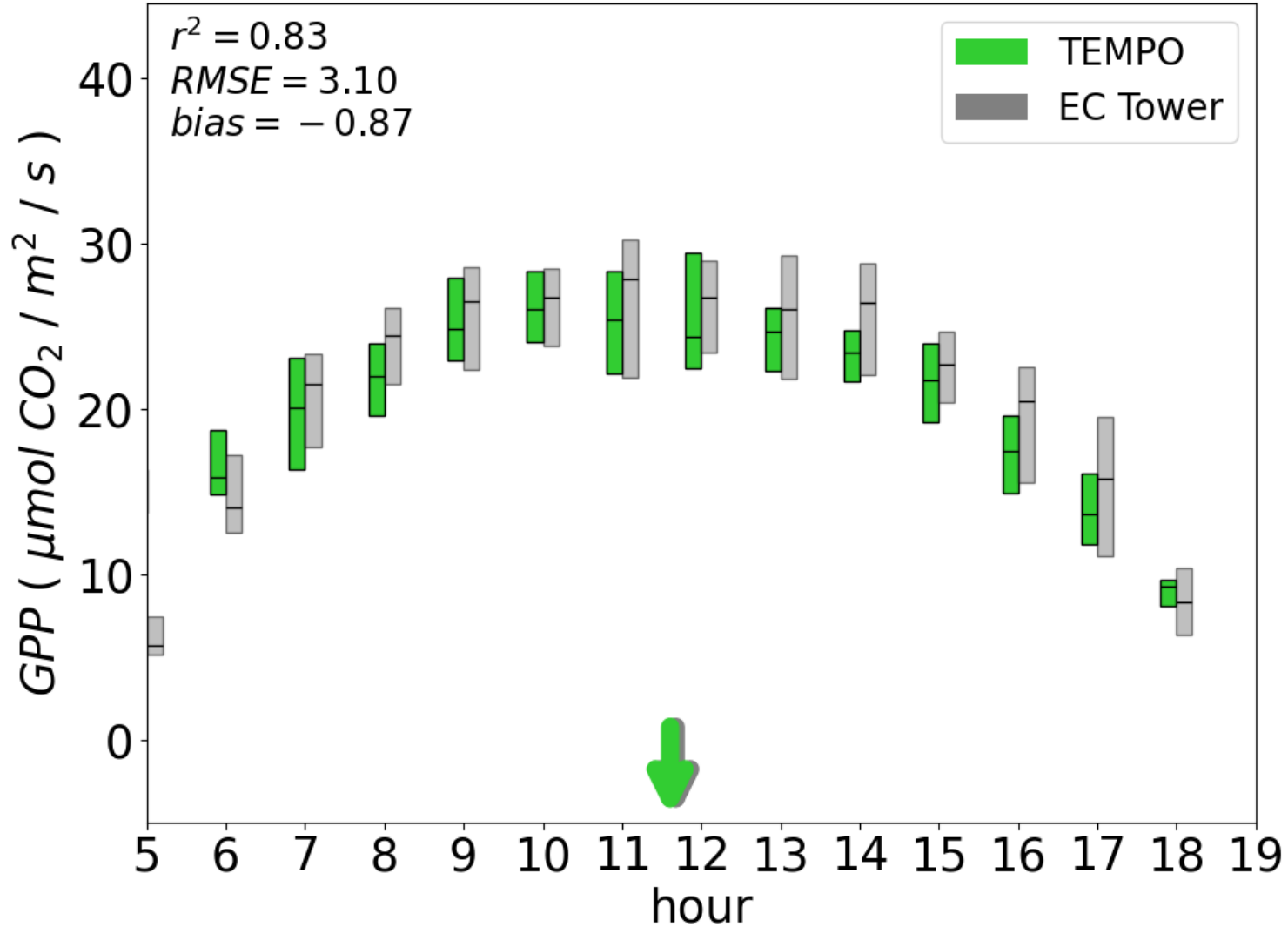


- TEMPO pixel large compared to typical flux tower fetch ( ~500m ).
- Surrounding terrain can be very heterogenous.

- TEMPO pixels for training are taken within 5km from site, and weighted according to distance.

# Model Evaluation

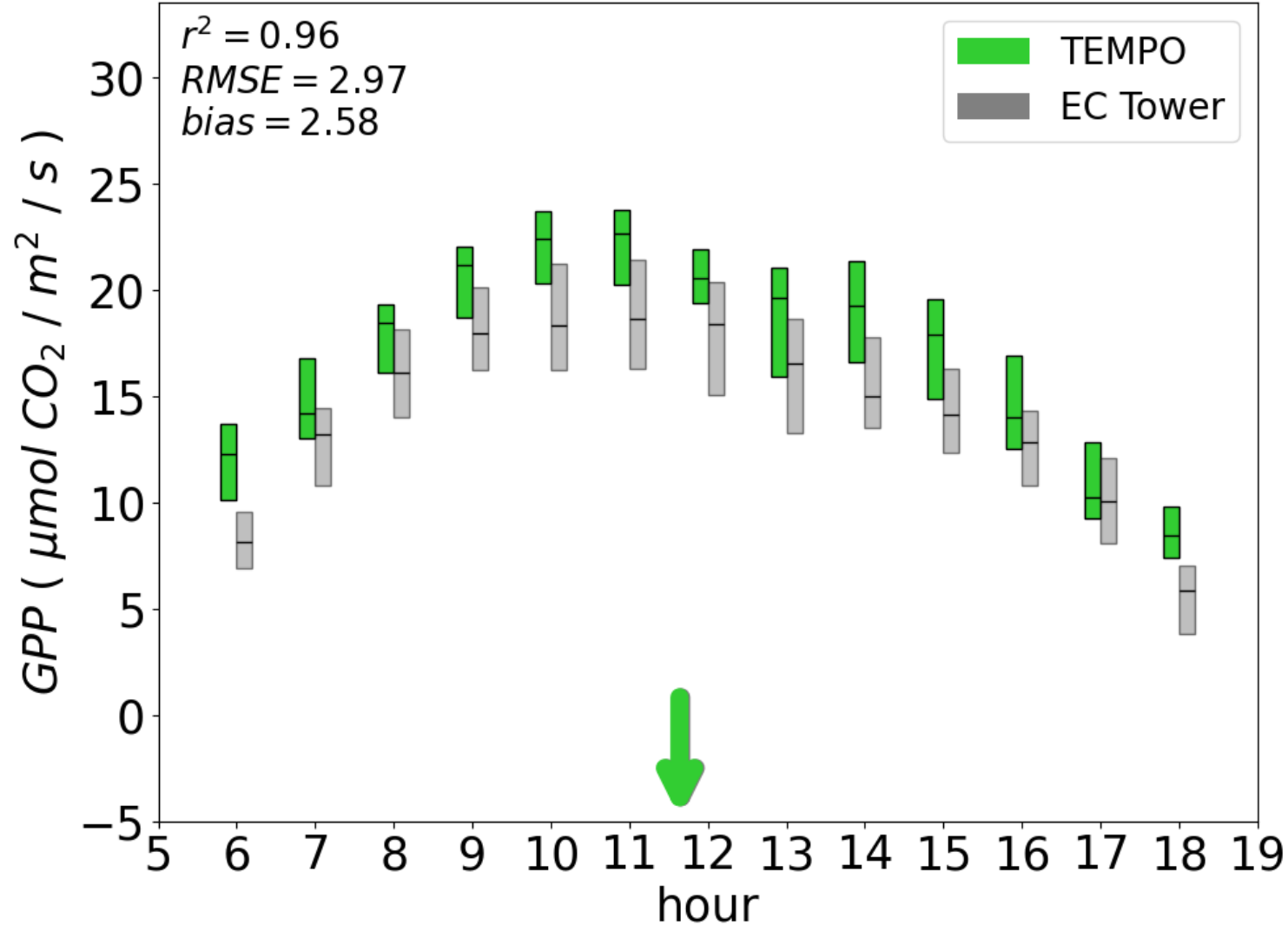
( testing ) US-xBR ( DBF ), ( NH, 44N, 071W )  
GPP July 2024



- Deciduous broadleaf forest site in New Hampshire.
- Box plot shows 25th – 75th percentile ranges.
- Statistics reported for monthly medians at every hour ( not on a point by point basis ).
- Balance points also a great match.

# Model Evaluation

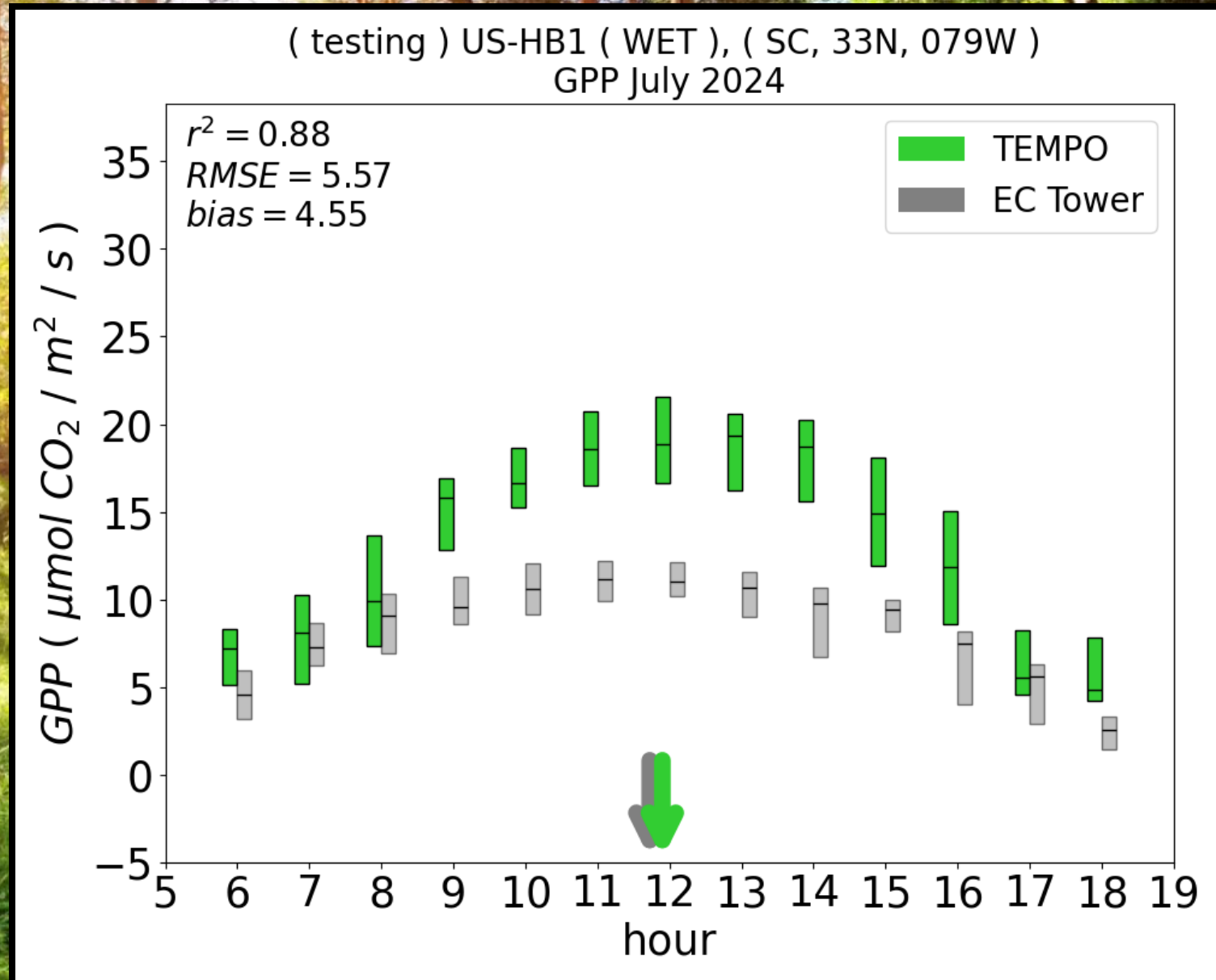
( testing ) US-Los ( WET ), ( WI, 46N, 089W )  
GPP July 2024



- Wetlands site in Wisconsin.
- Though predictions are on the high side, nuances in shape are well captured.
- Balance points match exactly.

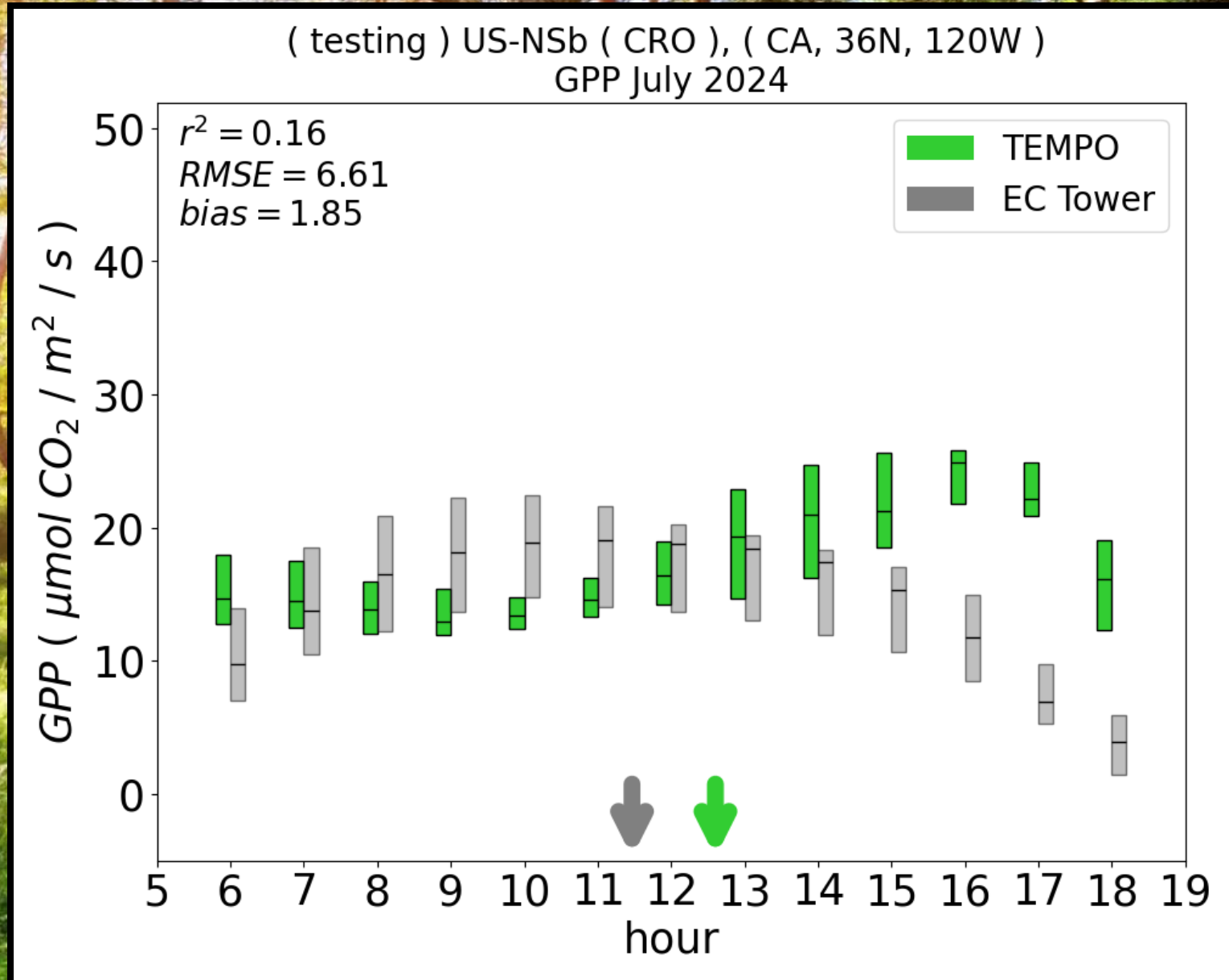
# Model Evaluation

- Wetlands site in South Carolina.
- Model predicts much higher GPP than record by flux towers.
- Wetlands sites are often small in footprint and near drier landscapes.
- Relationships of GPP to vapor pressure deficit are somewhat unique due to soil saturation.



# Model Evaluation

- Croplands site in California.
- Very unusual diurnal pattern, generally depressions occur in later afternoon rather than morning due to lesser stomatal conductance.
- Croplands in general are tricky due to irrigation, heterogenous fields close to one another, and other land management activities.



# Summary

- Despite never being designed for vegetation studies, TEMPO can indeed capture median diurnal GPP patterns.

- However, the model as it stands struggles to generalize, especially to wetlands and cropland sites.
- A route to better generalization may require accounting for moisture conditions, perhaps a synergy with ABI for infrared signals.

- Also, an important next step is a comparison with daily totals such as FluxSat to ascertain accuracy over large swaths of landscape.

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- Thanks for listening, and thank you to the TEMPO team!