Time-Filtered Inverse Modeling of Land-Atmosphere Carbon Exchange

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Global CO_2 Sinks

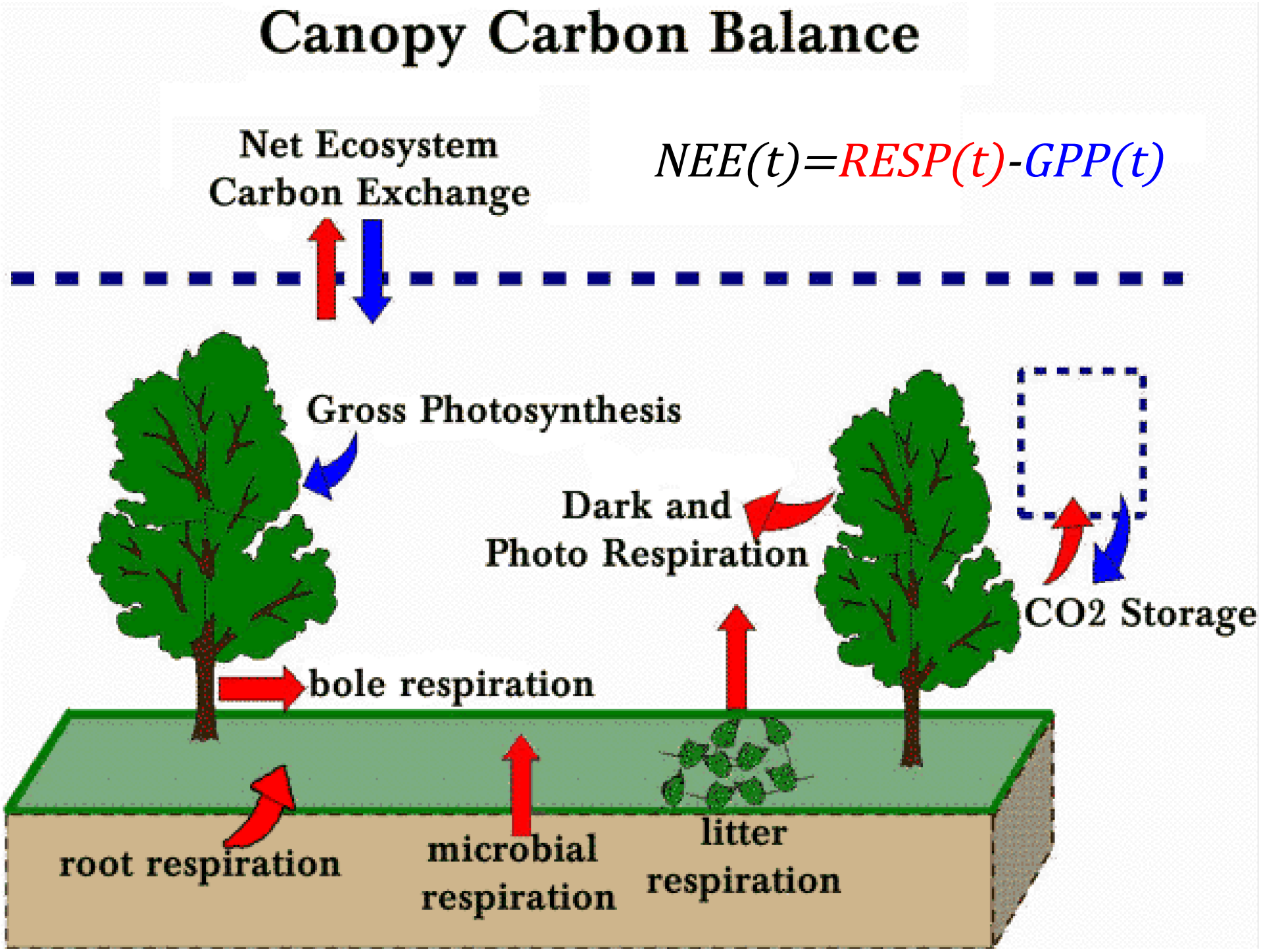
ATMOS: 9.9 ± .5 GtC

LAND: 2.9 ± .8 GtC

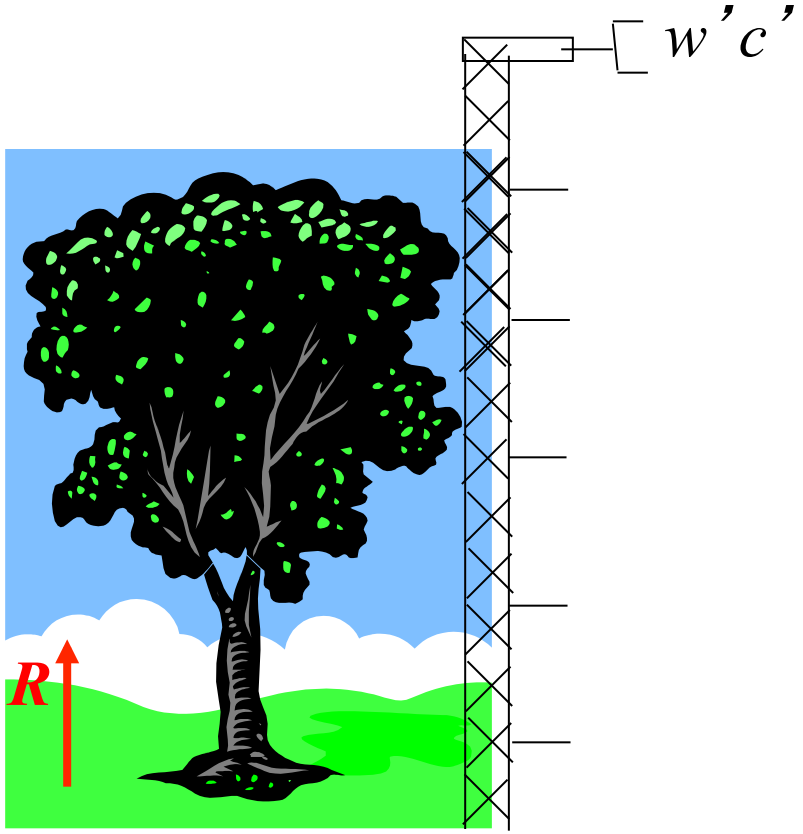
OCEAN: 2.6 ± .5 GtC

Data/Images: Courtesy of Global Carbon Project

Canopy Carbon Balance



Flux Towers and You!



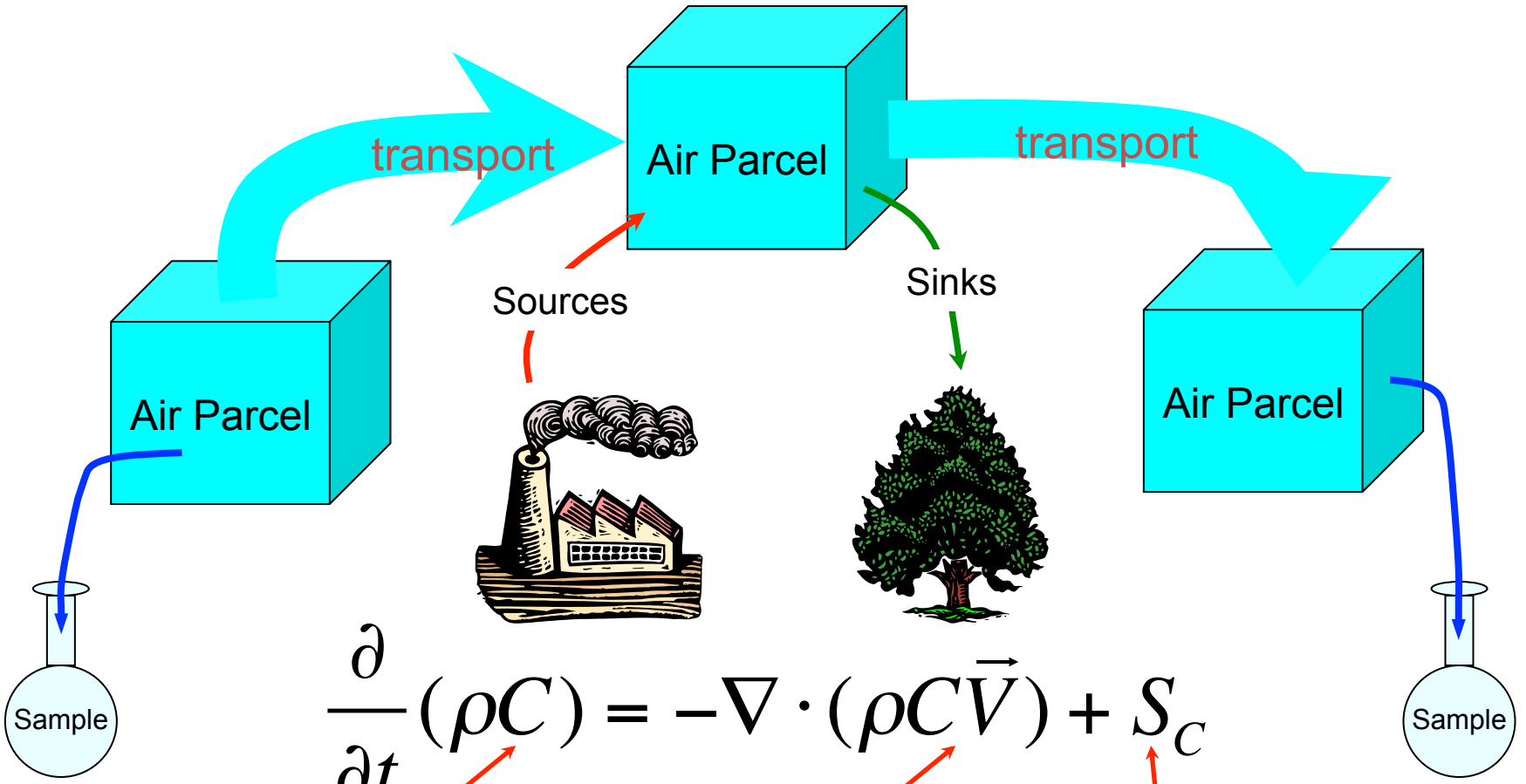
$$NEE = \overline{w'c'} - \frac{d}{dt}\int_0^h c(z)dz$$

turbulent flux

storage "flux"

- Nocturnal stable layer inhibits mixing of CO_2 produced by soil respiration from reaching instruments, accumulates below reference height
  - NEE underestimated
- Solar heating during early morning releases stored CO_2 in a big "burst"
  - NEE overestimated
- Maybe OK unless stored CO_2 "leaks out" by horizontal advection or gravitational drainage flow
- Try to correct for these effects by directly measuring changes in storage

Inverse Modeling of CO_2



$$\frac{\partial}{\partial t}(\rho C) = -\nabla \cdot (\rho C \vec{V}) + S_C$$

concentration
(observe)

transport
(model)

sources and sinks
(solve for)

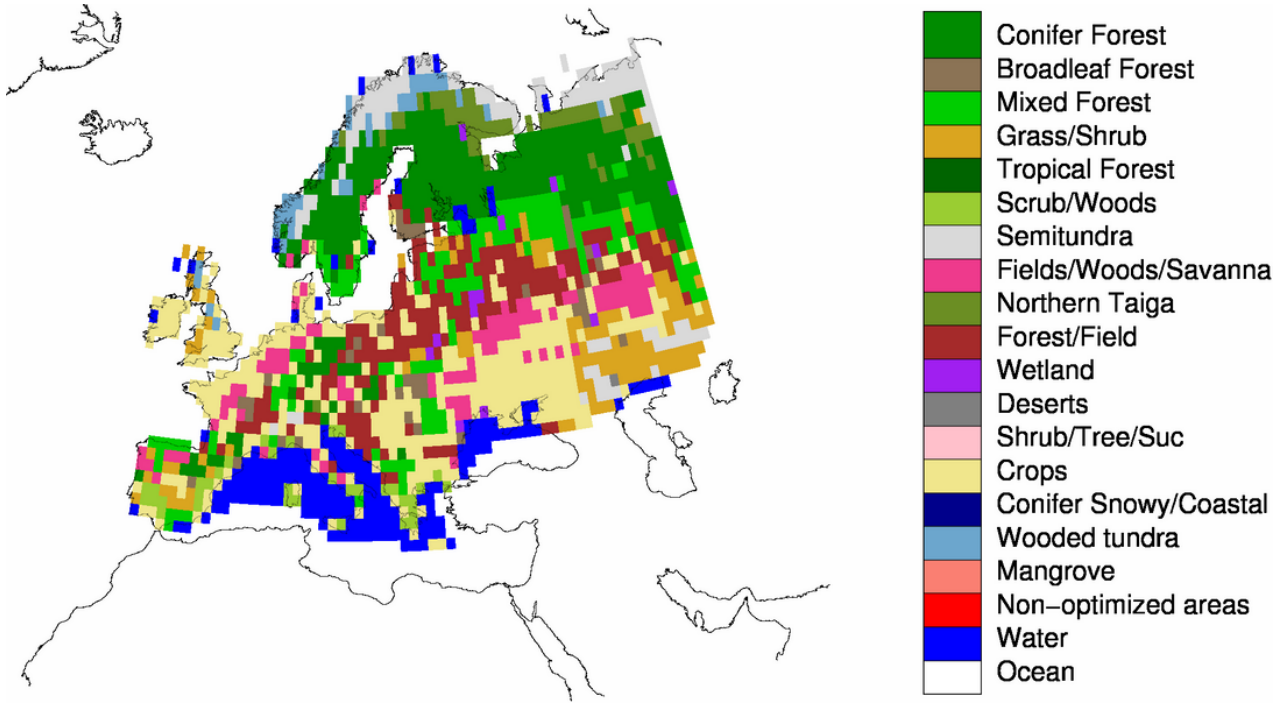
What's Been Done?

- CO_2 inversions are underconstrained problems
- Traditionally, inversion models have implemented spatial and spatio-temporal smoothing methods to provide constraint.
- These attempt to geolocate biological sources and sinks of CO_2 using NEE on weekly timescales.

$$NEE_{obs} = (1 + \beta_{NEE})NEE$$

CarbonTracker

- Estimates 52 weekly bias corrections to only NEE every year
- Uses pre-aggregated “ecoregions” to generalize ecosystems that are similar.



A Better Way

- Use the inversion methodology to isolate the long-lived biases of the component fluxes on several timescales.
  - Previous work used a single bias coefficient updated on a particular timescales.

$$NEE_{obs} = (1+\beta_{RESP})RESP - (1+\beta_{GPP})GPP$$

  - Prevents "wasting" valuable statistical information from limited observations.
- Want to extend this to multiple terms to better associate biases with land model biological parameterizations.

$$\beta = \overline{\beta} + \beta' + \beta''$$

Temporal Smoothing Inversion Methodology

- Uses the Kalman Filter as a temporal smoother to estimate the long-lived biases in SiB4. No spatial dependence. No need for an transport model.

$$\Phi = \left[(\beta - \beta_{prior})^T C_\beta^{-1} (\beta - \beta_{prior}) + (G\beta - d)^T C_d^{-1} (G\beta - d) \right]$$

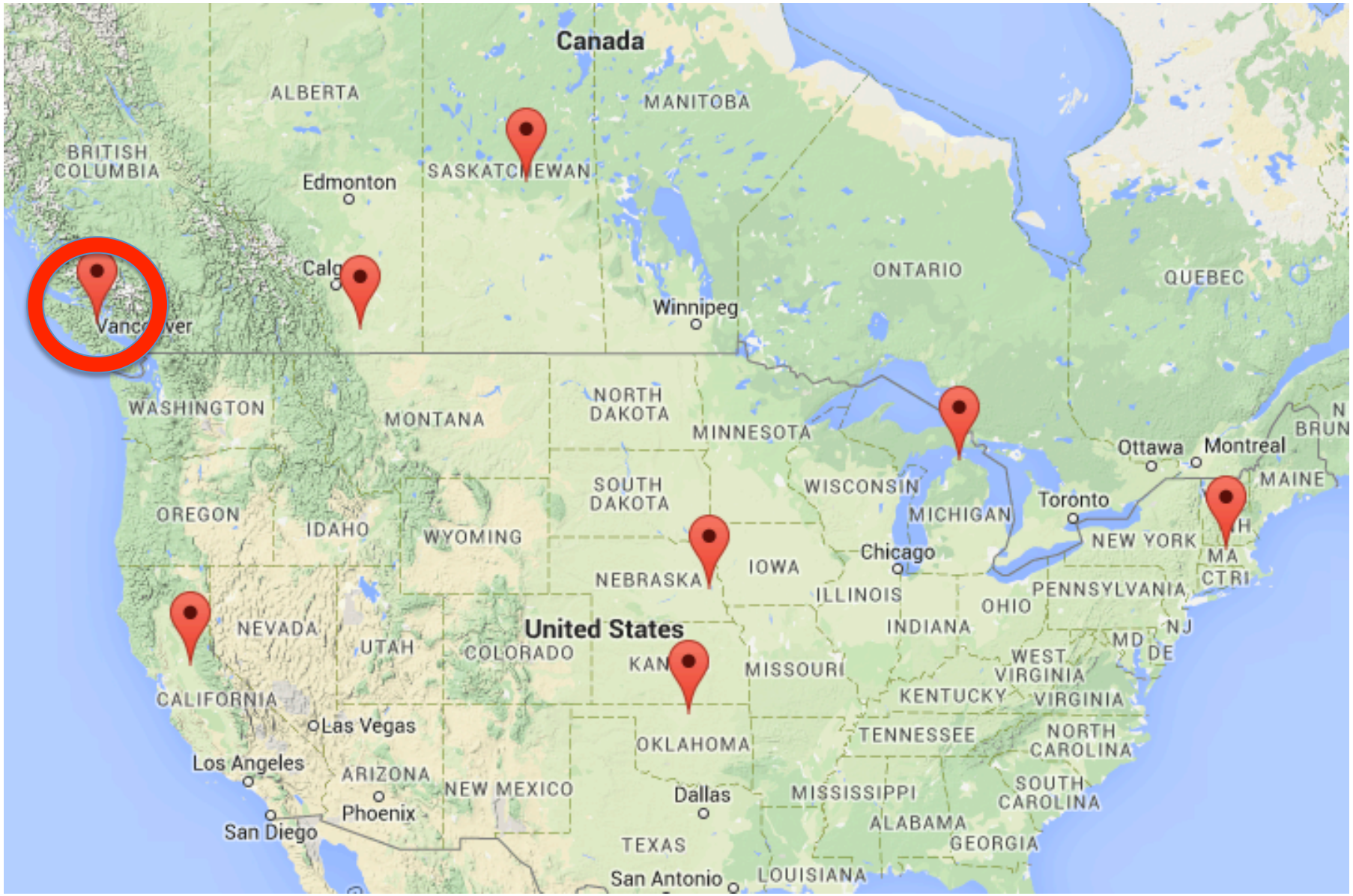
- Uses harmonics to provide a continuous estimate of the bias coefficients.
- Trade-offs

$$\beta = \overline{\beta} + \sum_{k=1}^{N/2} \left(\beta_{A,k} \cos(\frac{2\pi ki}{N}) + \beta_{B,k} \sin(\frac{2\pi ki}{N}) \right) + \beta''$$

Experiments

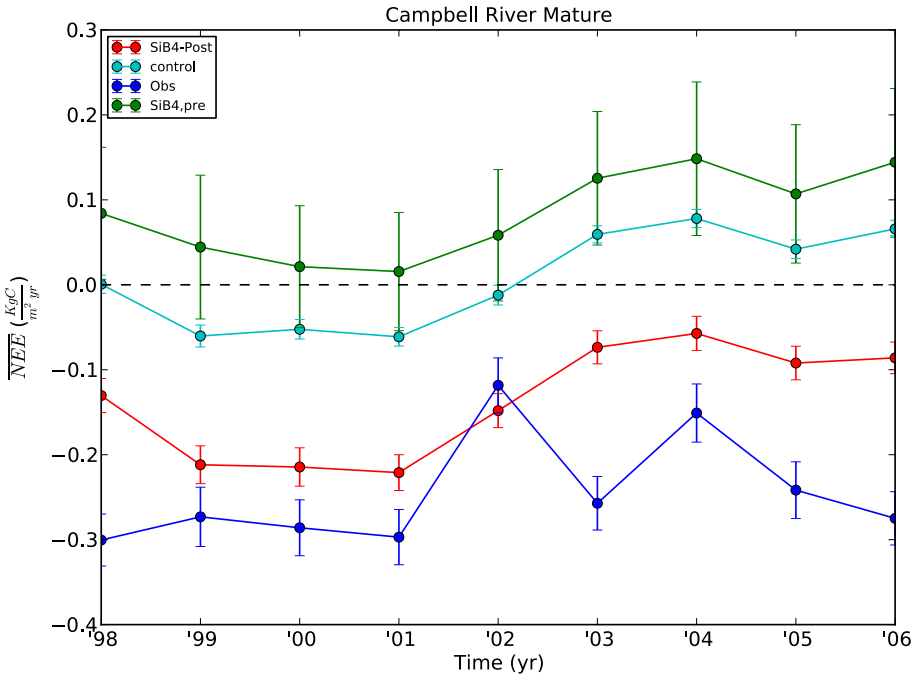
- Control vs Temporal Inversion
  - Control mimics CarbonTracker
    - Uses same Kalman Filter, but does not retain memory of previous bias coefficients or prior covariance estimates
    - 1 bias coefficient for NEE that updates weekly.
- EXP 1: Optimize NEE using NEE only
- EXP 2: Optimize NEE using GPP and RESP
- EXP 3: Optimize GPP and NEE using GPP and RESP
- Inversion Set-Up
  - 1 year assimilation cycle of daily averaged CO_2 fluxes
  - Waves K=0, 5 (12 bias coefficients estimated)
  - If necessary, covariance between corresponding NEE and GPP is half of NEE uncertainty.

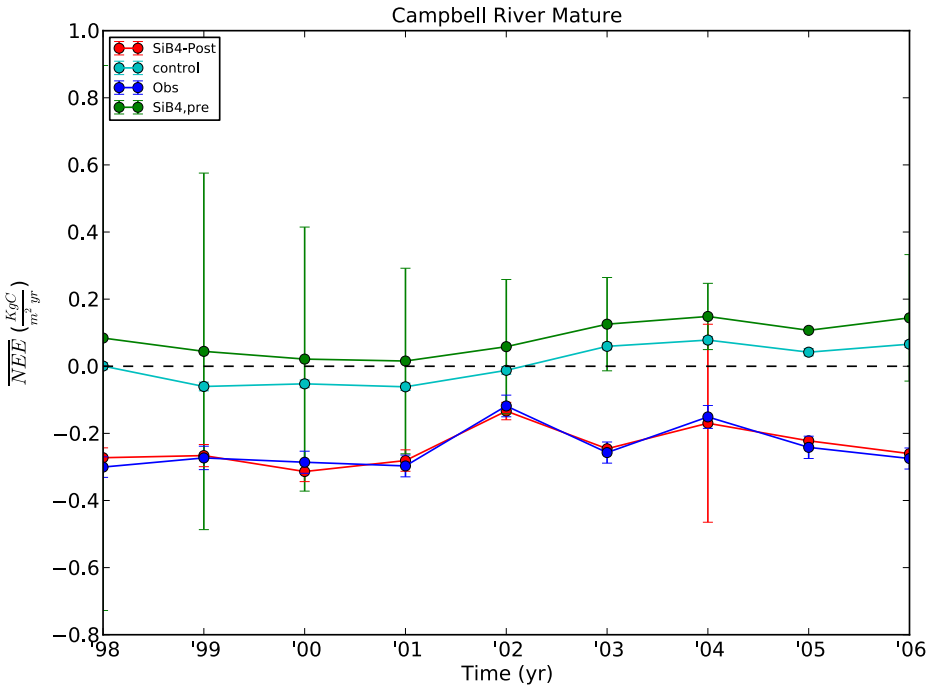
FLUXNET Towers Used



The Simple Biosphere Model 4 (SiB4)

- 4th implementation of the original enzyme kinetic equations developed by Sellers et al. 1992. Improvements from previous models:
  - Prognostic Phenology (Stockli et al. 2008; 2011)
  - Usage of crop algorithm from SiB-Crop (Lokupitiya et al. 2009, Corbin et al. 2010)
  - Implements Carbon Pools from SiB-CASA (Schaefer et al. 2008)
- 11 carbon pools above and below ground
- 24 plant functional types replace the 11 biomes of SiB2 and SiB3
- Capable multiple PFTs in a grid cell
- MERRA driver meteorology used

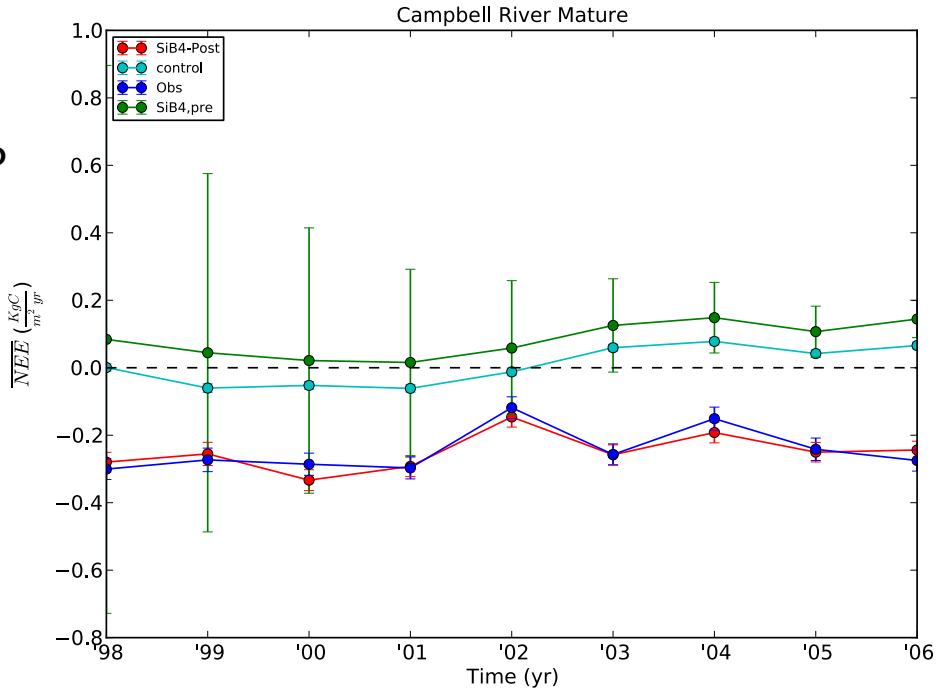




Top Left: NEE Only

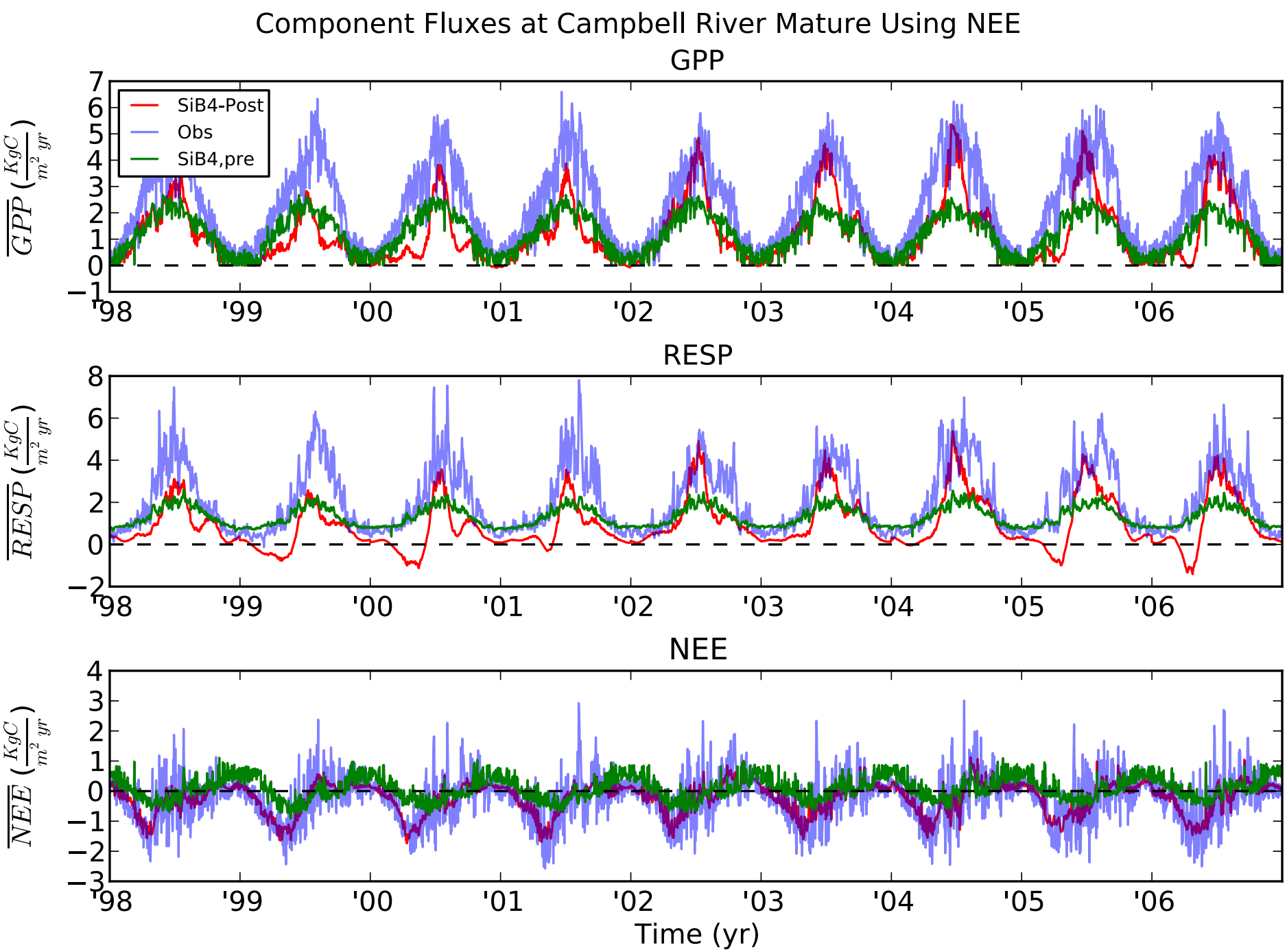
Top Right: GPP/RESP optimized from NEE

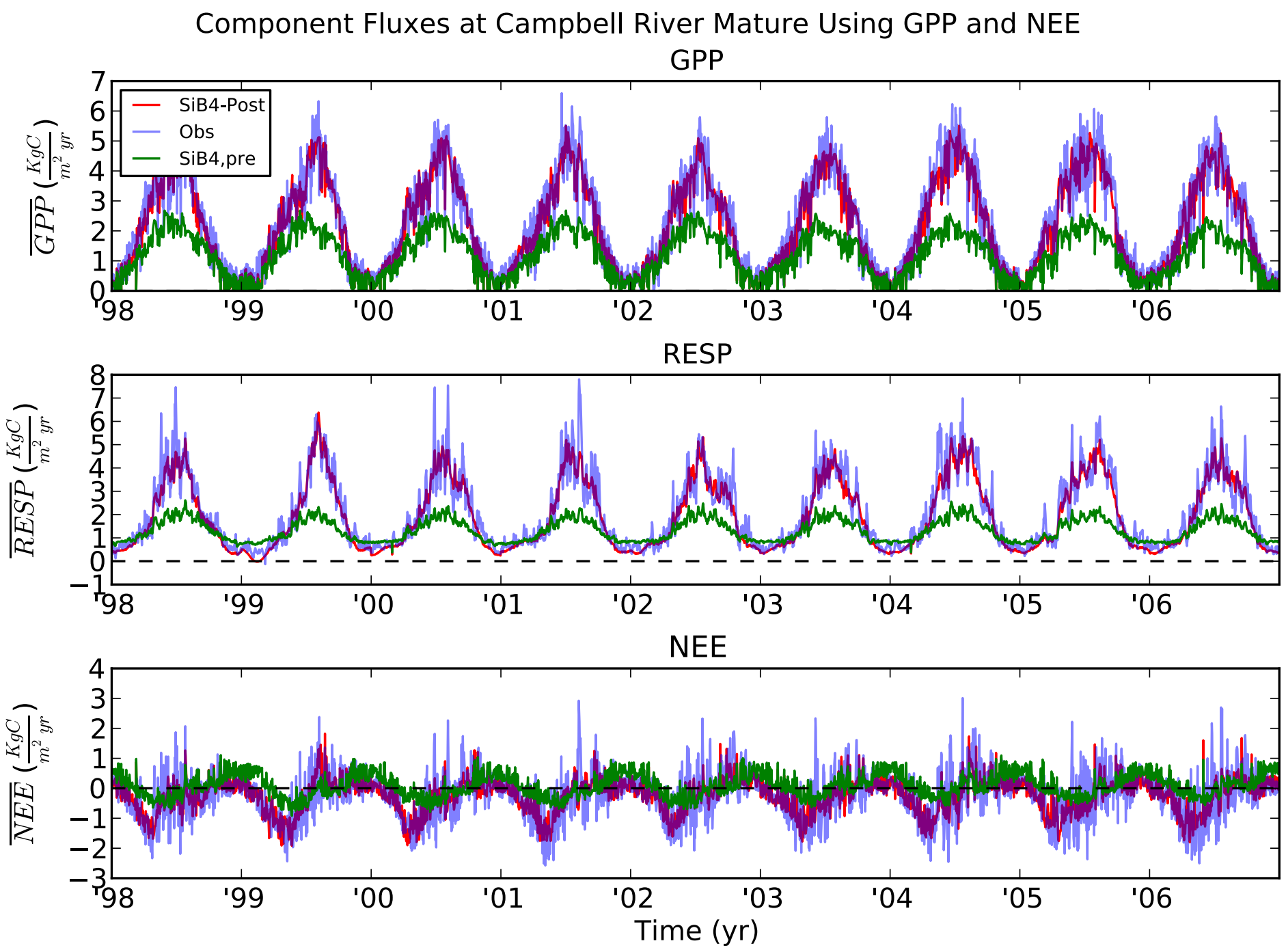
Bottom Center: GPP and RESP optimized from NEE



KEY

- SiB4 Posterior
- SiB4 Prior
- Observations
- Control


Component Fluxes at Campbell River Mature Using NEE
GPP
SiB4-Post
Obs
SiB4,pre
$\overline{GPP}\ (\frac{KgC}{m^2\ yr})$
RESP
$\overline{RESP}\ (\frac{KgC}{m^2\ yr})$
NEE
$\overline{NEE}\ (\frac{KgC}{m^2\ yr})$
'98
'99
'00
'01
'02
'03
'04
'05
'06
Time (yr)


Component Fluxes at Campbell River Mature Using GPP and NEE
GPP
SiB4-Post
Obs
SiB4,pre
$\overline{GPP}\ (\frac{KgC}{m^2\ yr})$
RESP
$\overline{RESP}\ (\frac{KgC}{m^2\ yr})$
NEE
$\overline{NEE}\ (\frac{KgC}{m^2\ yr})$
'98
'99
'00
'01
'02
'03
'04
'05
'06
Time (yr)

Conclusions and Future Work

- Using a time smoothing inversion methodology allows for a more accurate representation of annual NEE budgets than current weekly estimates with a minimal number of estimated parameters.
- Computationally, we have lowered the number of estimates per year, but retained a much better estimate of fluxes.
- Using the component fluxes to optimize NEE is better than using NEE alone because their signal is slower.
- If only optimizing NEE using the component fluxes, we will only optimize NEE. However, if we include a component flux in the optimization, there all three fluxes are recovered with better seasonality.
- Future work should be to extend this methodology to fluorescence and CO_2 mixing ratio inversions on regional and global transects.
- Also, work should be to use the patterns and cycles deduced by the bias coefficients to influence biological parameterizations in our land-surface models.