A New Engineering Model and Sustainable Control on CO2 Flux and Climate Change, and HPC Algorithms for Supercomputing

(A collaborative work between **CDIAC @ ORNL, and IIE, EECS, ISSE @ UTK**)

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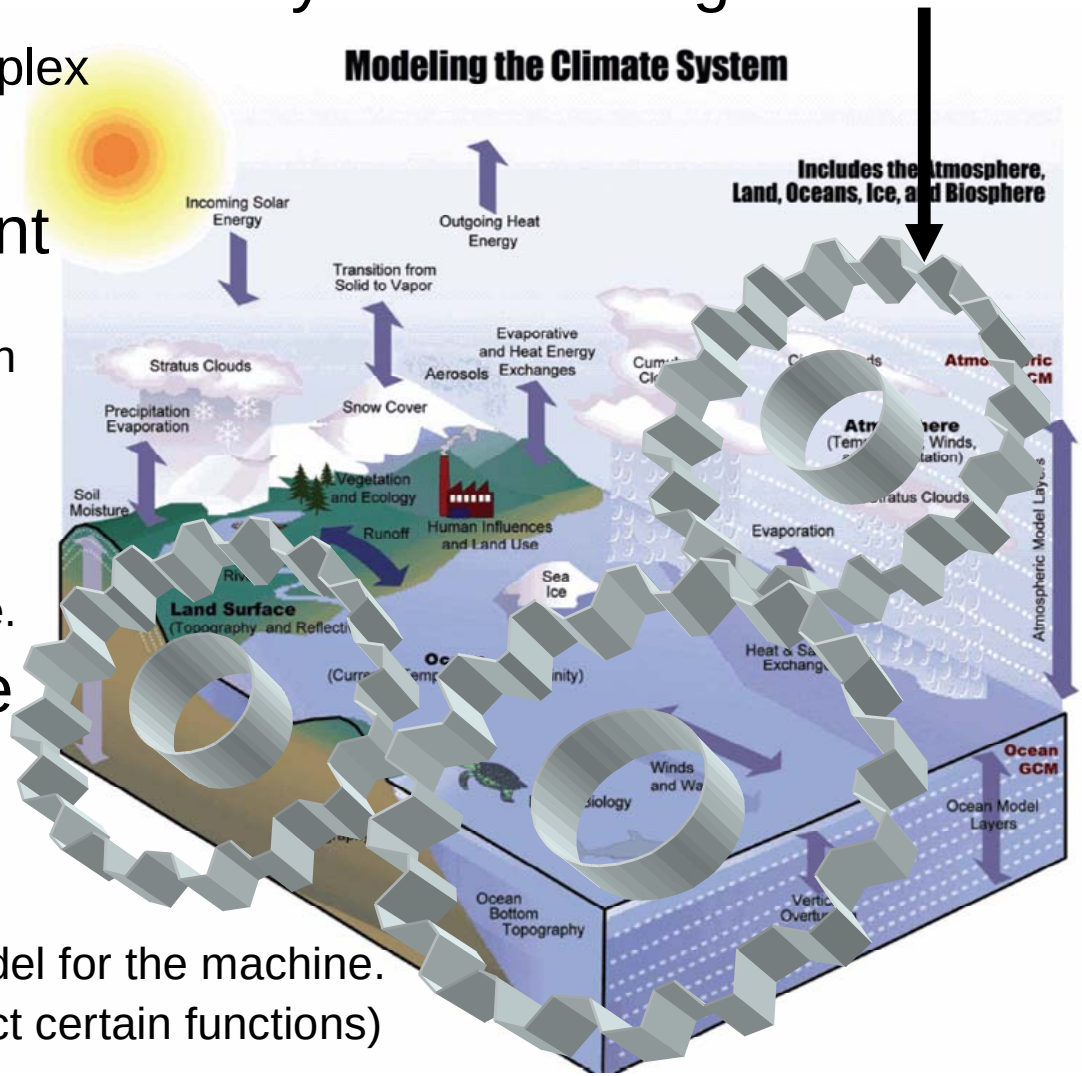
Outline

- A Novel Engineering **Modeling** Technology for Climate Systems
- HPC Modeling Algorithm for **Supercomputing**
- **Modeling Results** for Missouri Ozark CO2 Flux Site, 2005
- **Predictions** by Model for Missouri Ozark CO2 Flux Site, 2006
- **Globalized** CO2 and Climate Modeling
- Globalization Results to **Predict** Morgan Monroe State Forest, 2003
- **Sustainability** Assessment

Engineering Modeling Protocol to View the Climate System as a "Machine"

Engineer: View the climate system as a big "**Machine**"

How can this big and complex machine be tested?



1. **Design** the experiment

Set specific factors with low values (like low voltage) and some with high values (like high frequency).

2. **Test** as per design

Test the functions of the machine according to different designs above.

3. **Observe** the Machine

Observe the performance of the machine and record test results.

4. **Model** and Analyze

Use engineering tools to build a model for the machine. (what factors and interactions affect certain functions)

Uniqueness

Theoretical Modeling Approach (such as process-based):

Theories(Phy/Che/Geo/Bio)→Processes→Model

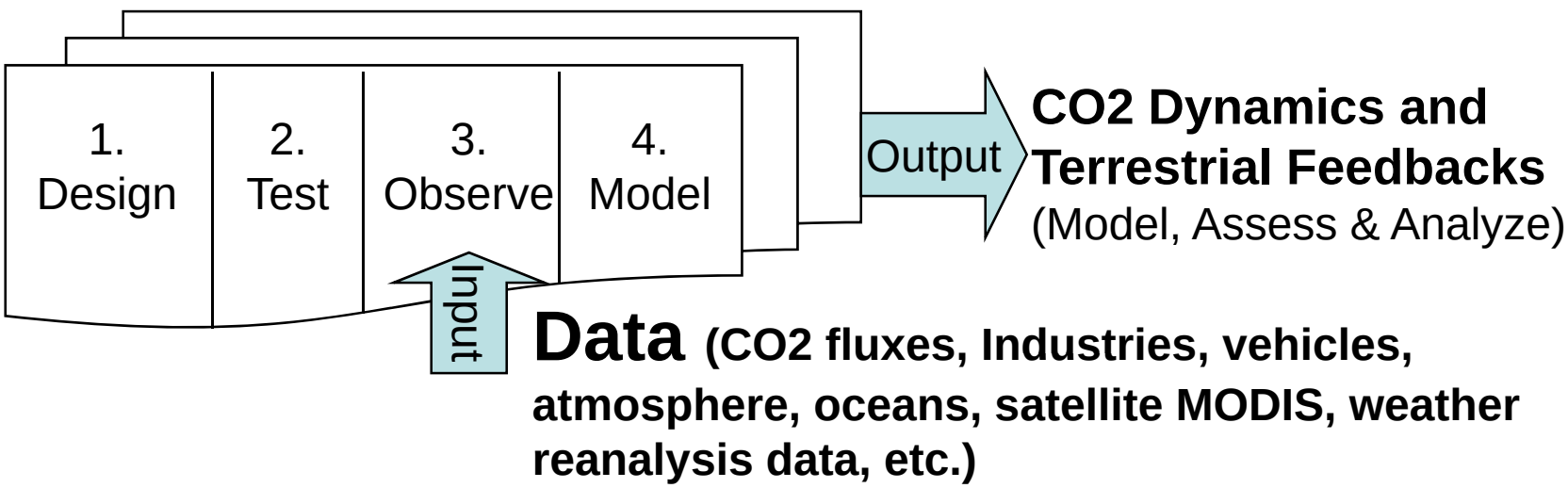
Statistical Modeling Approach (such as data-mining):

Data→Analysis→Model

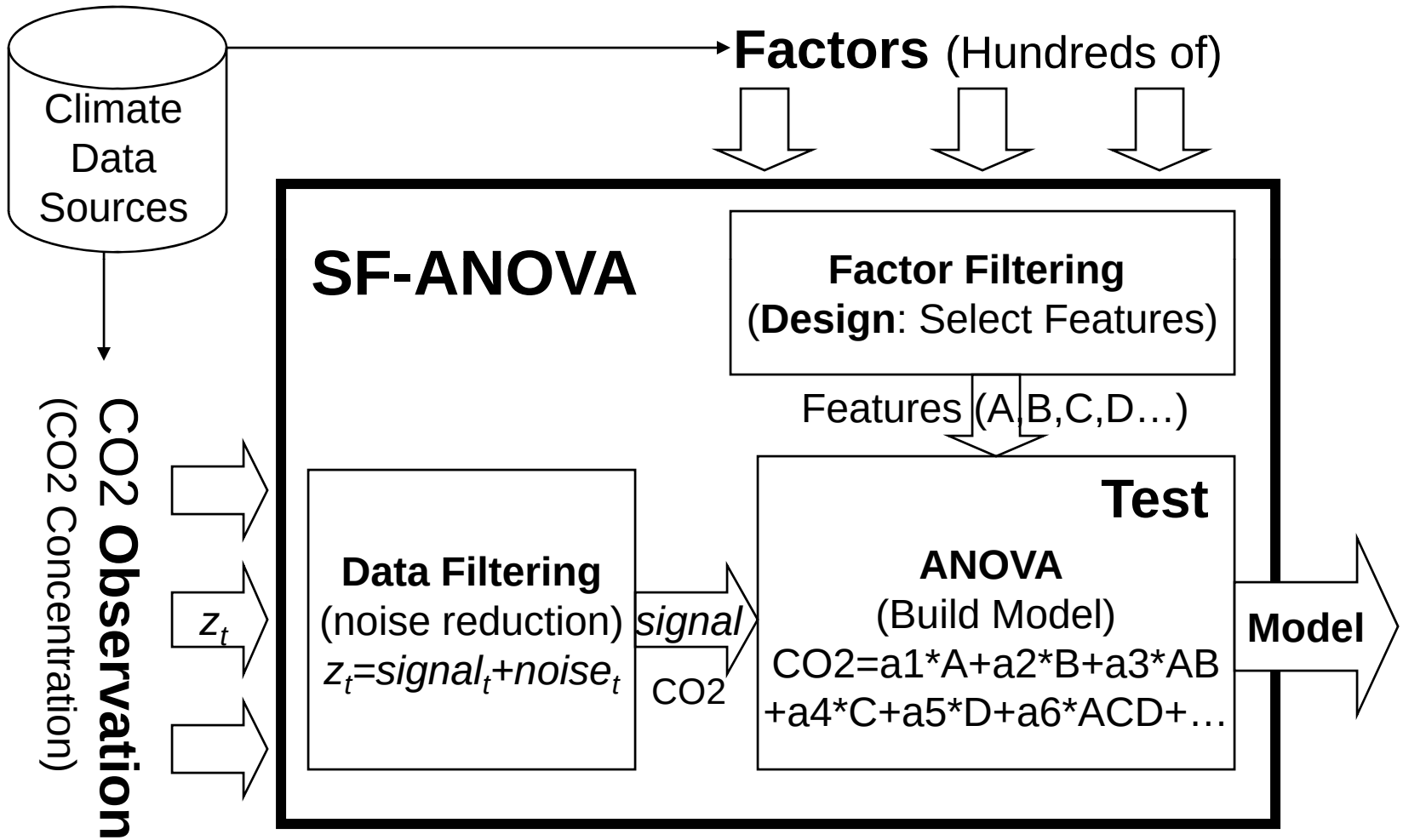
Engineering Modeling Approach:

Design→Test→Observation→Model

Modeling Climate by adapting the Engineering Protocol



Stochastic Filtering Analysis of Variance (SF-ANOVA)



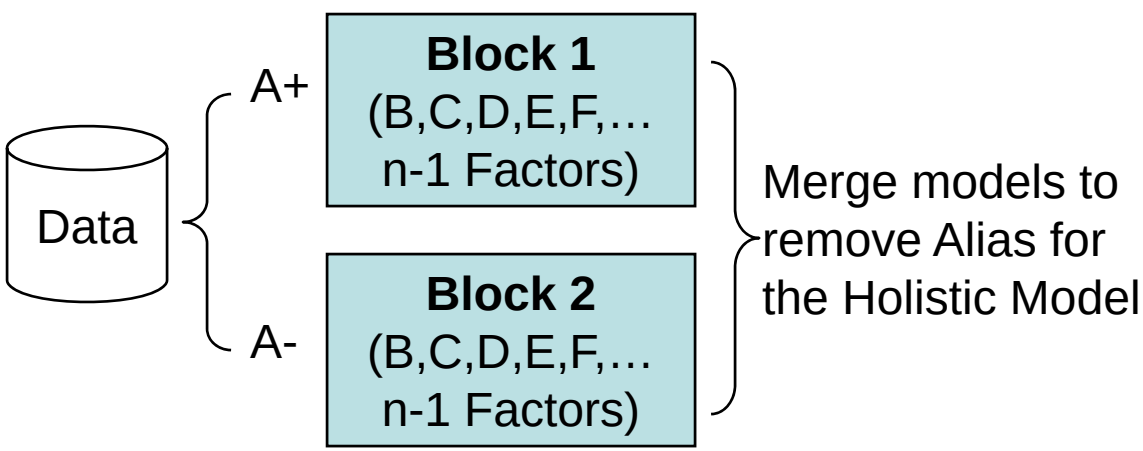
HPC Algorithm for Modeling to use **Supercomputer**

Based on Maths/Stats Theory

1) Blocking and Confounding (Alias)

2) Fractions and Merge (Remove Alias)

Factors (n): A,B,C,D,E,F,…

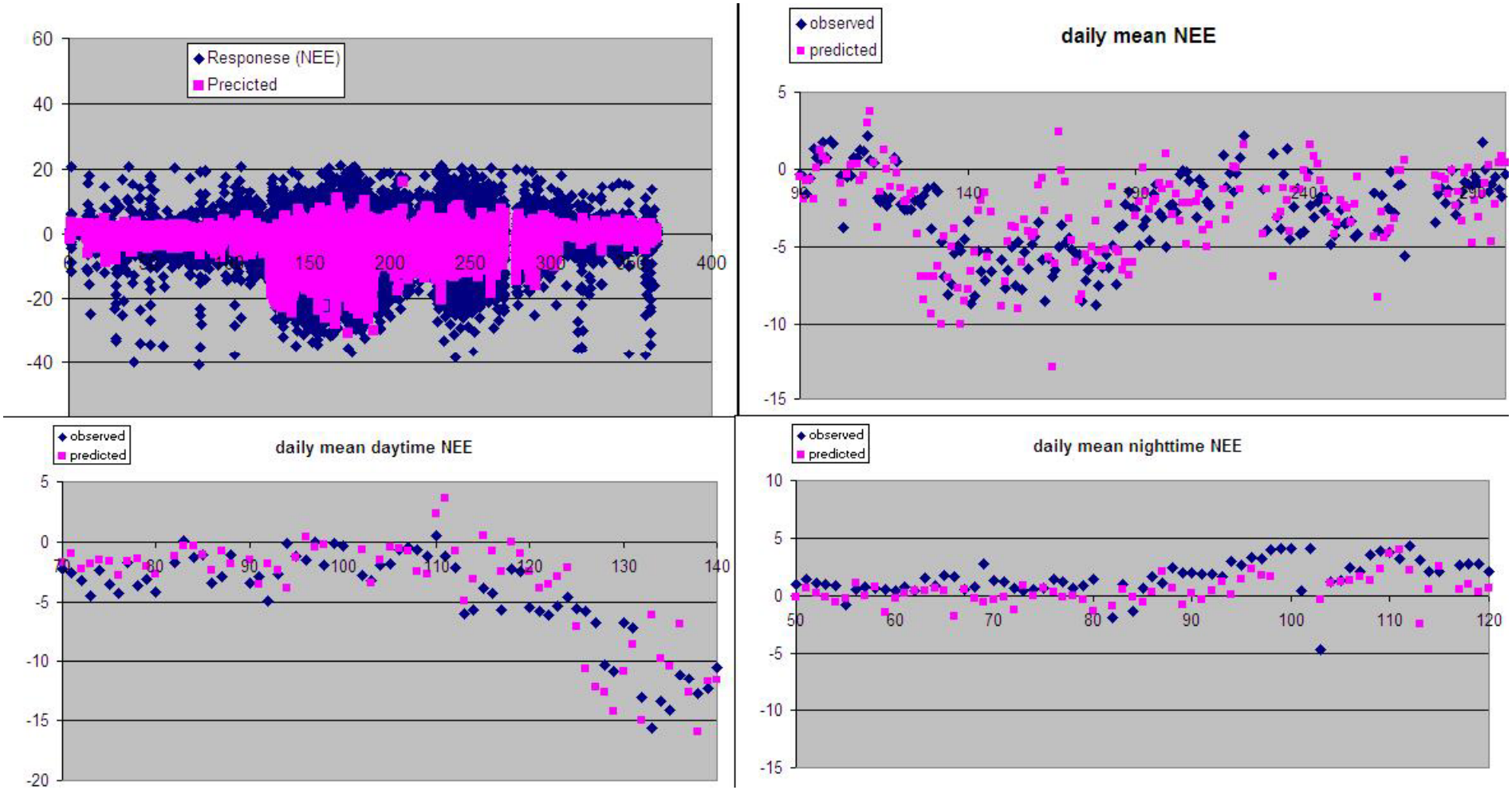


Two Fractions, but generate **Alias**

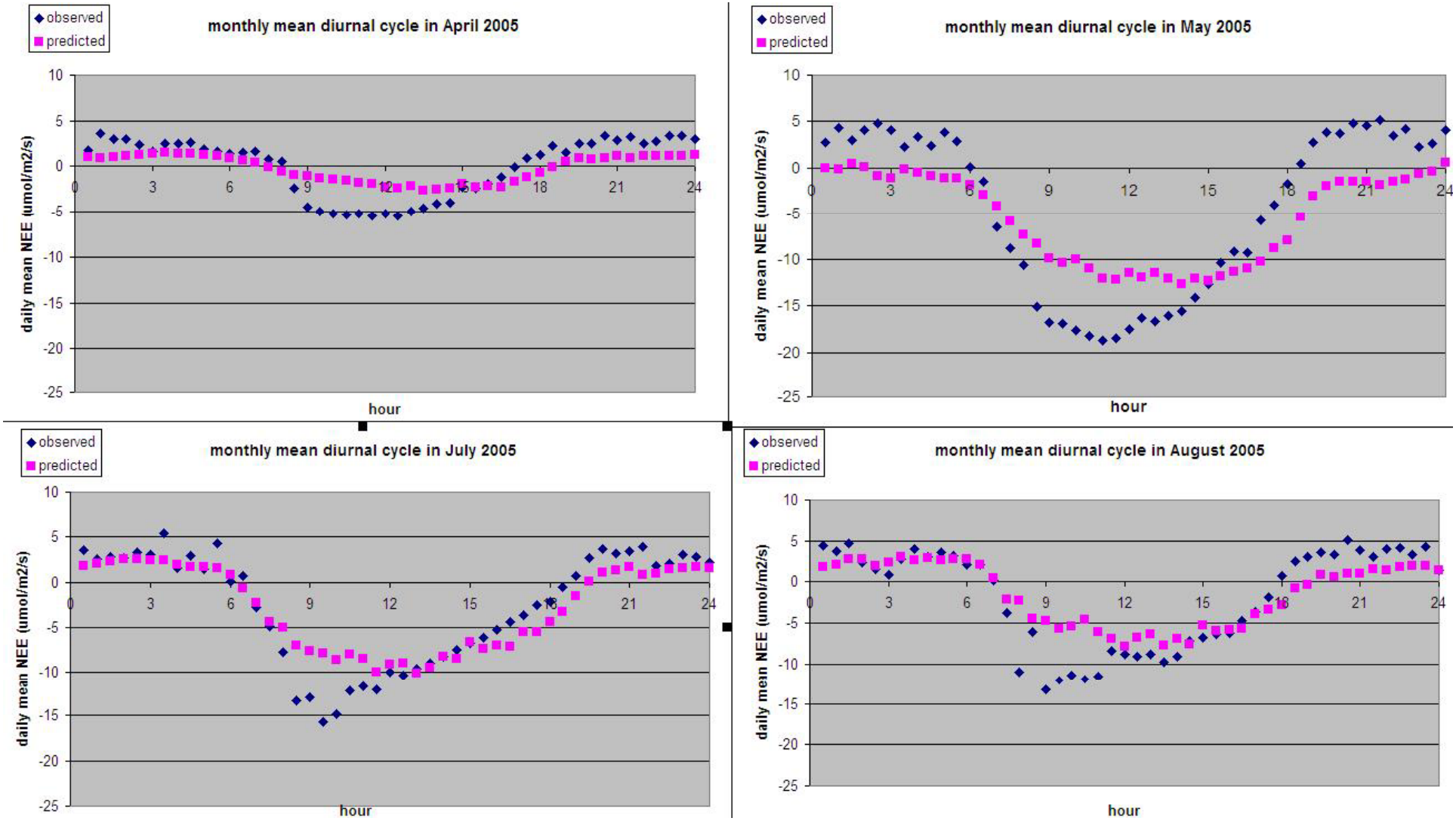
For example: 31 factors
So $\mathbf{2^{31}}$ designs/test data needs **3.5 years** to model it by one single computer.

We can fracture 15 factors for blocking, so a total of $\mathbf{2^{15}}$ blocks that can use **30000+** cores In parallel, each core will calculate $\mathbf{2^{16}}$ data within only **1 hour.**

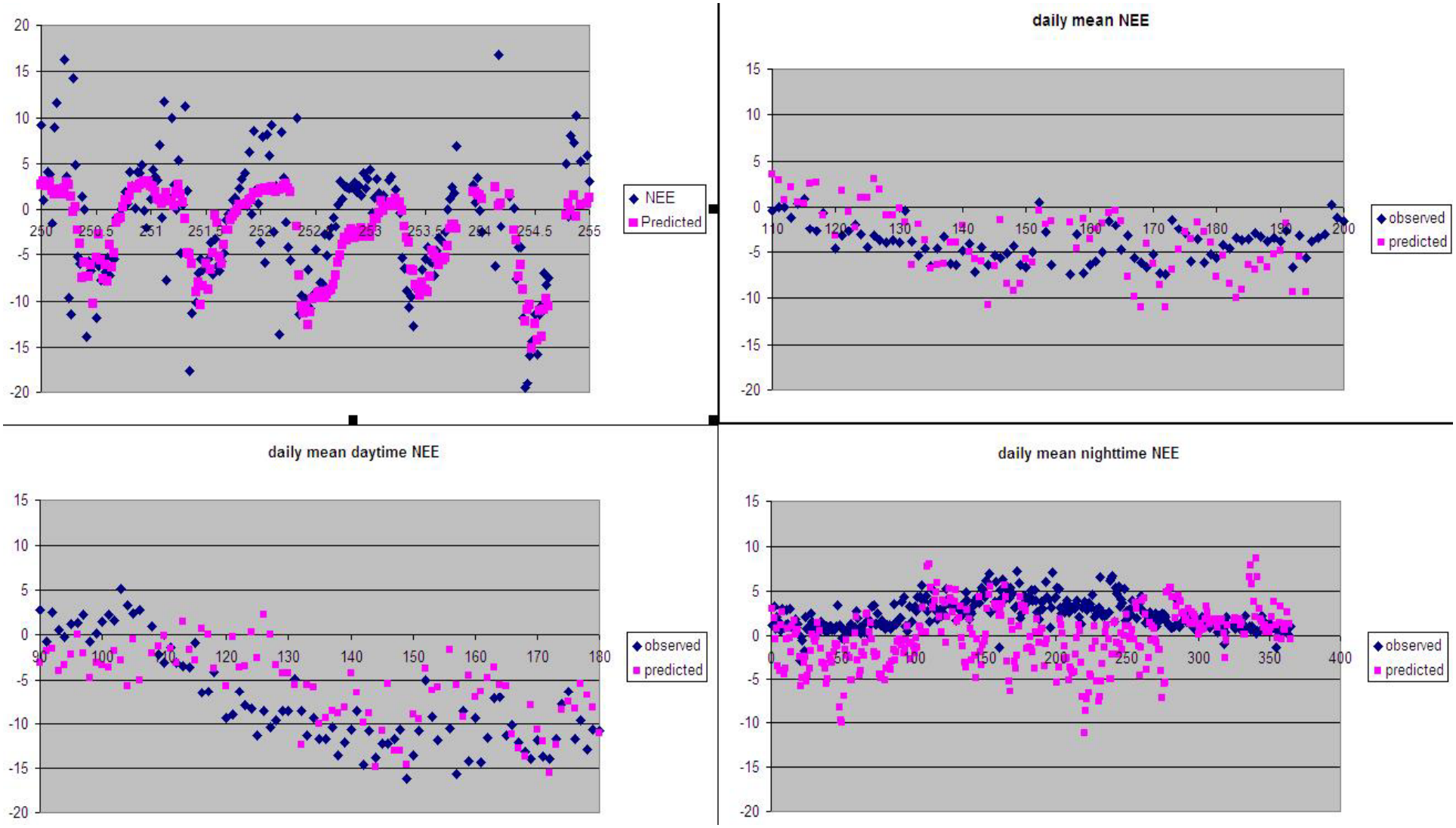
Modeling Results on Missouri Ozark CO2 Flux Site 2005



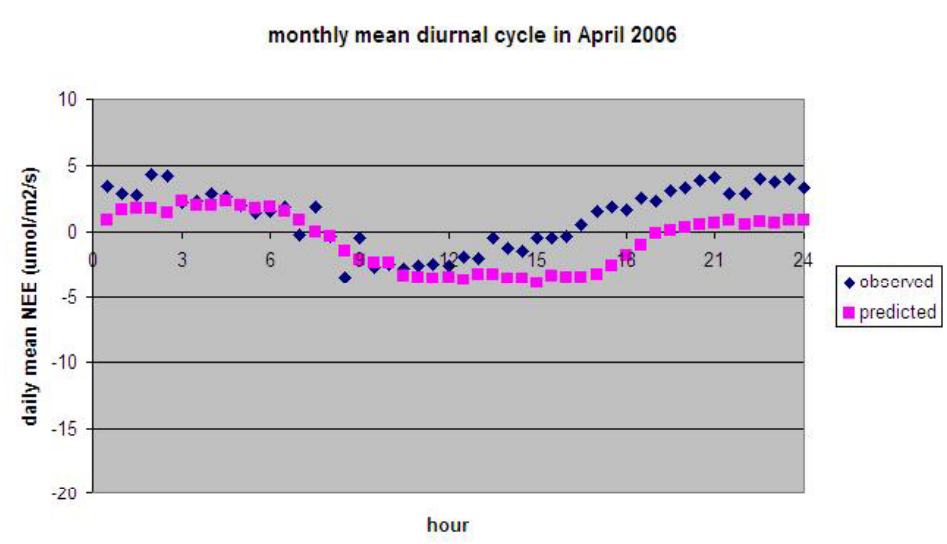
Modeling Results on Missouri Ozark CO2 Flux Site 2005

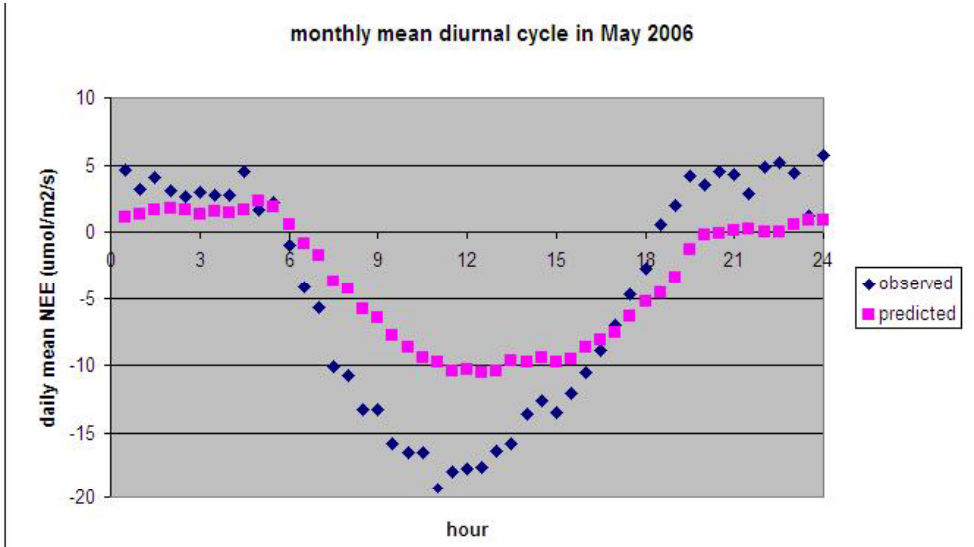


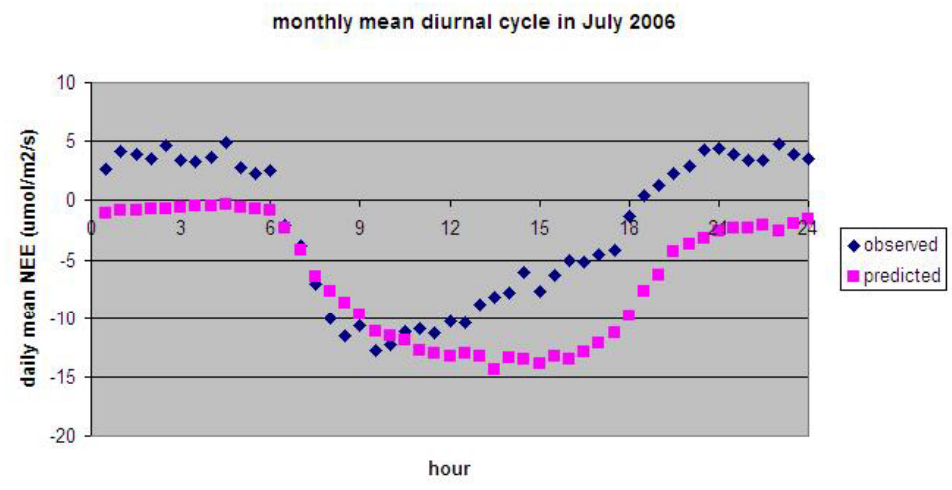
Modeling Prediction on Missouri Ozark CO2 Flux Site 2006

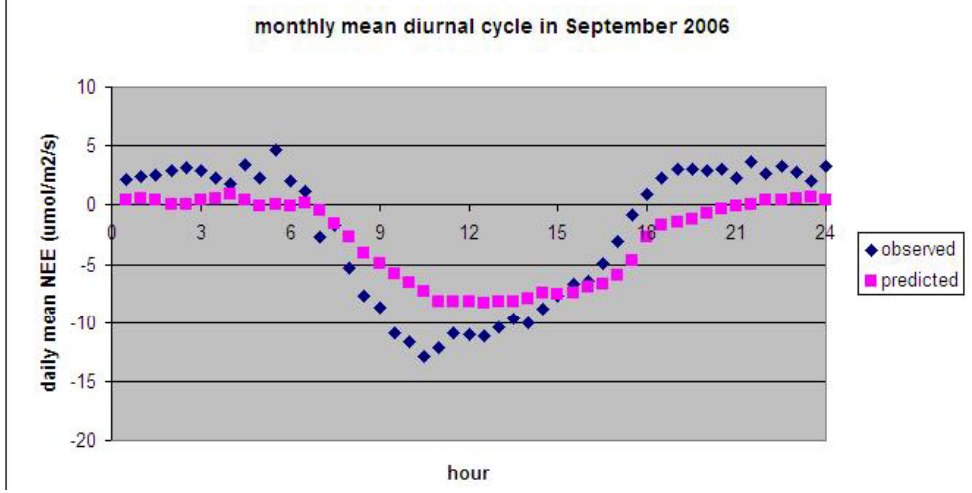


Modeling Prediction on Missouri Ozark CO2 Flux Site 2006







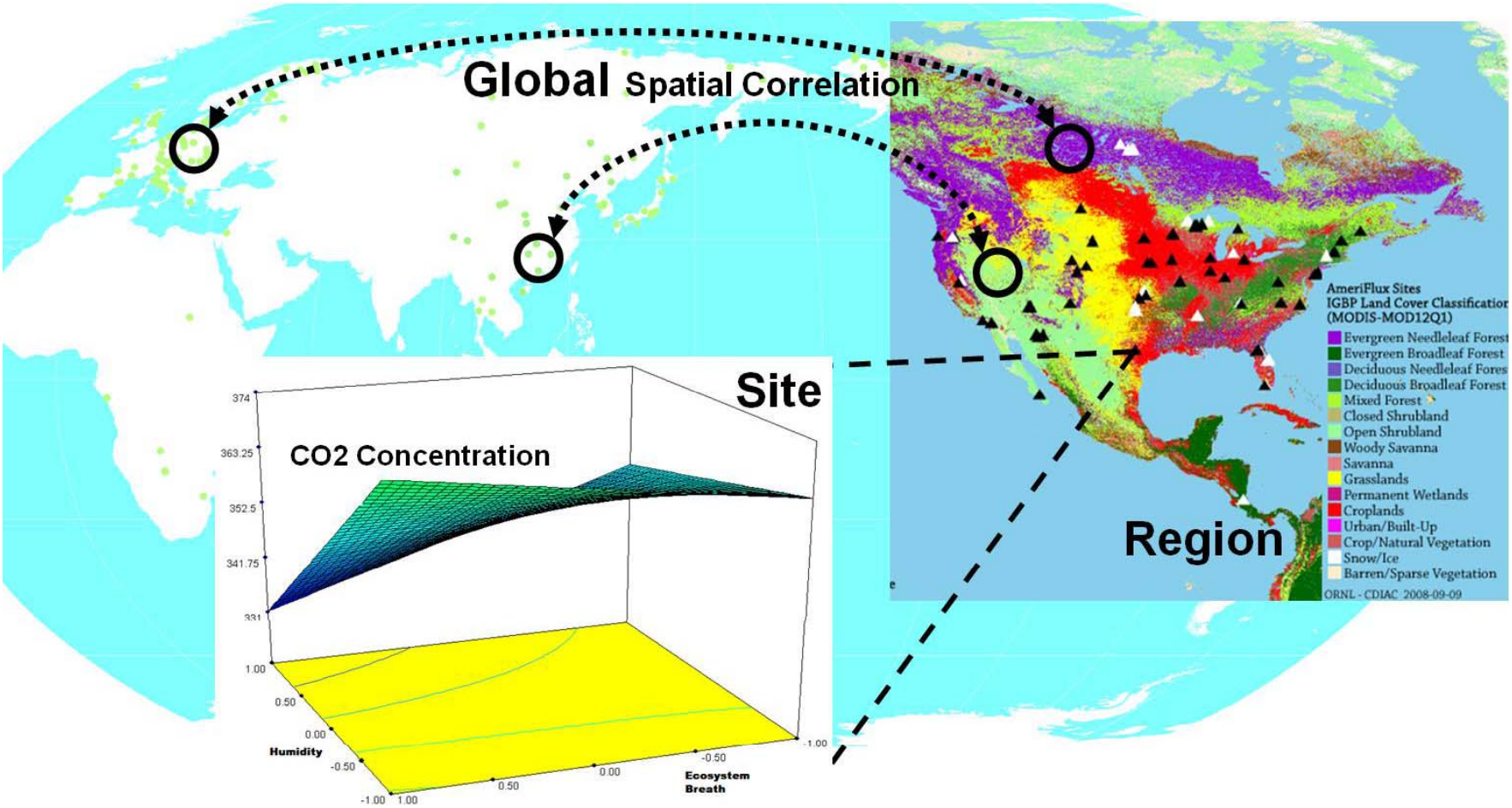


Comparisons

Modeling / Aspects	Engineering	Theoretical	Statistical	Neural Network
Start from	Design	Theory	Data	Training
Vision	Machine	Processes	Statistics	Simulation
Approach	Top-Down	Bottom-Up	Data-Driven	Trial-Error
Tools	Engr. Design of Experiments (DoX)	Biogeochemical Principles	Data Mining	Machine Learning
Output	Maths Model (Significant Factors and Interactions)	Process Models (e.g. carbon cycle, water cycle)	Statistical Models (e.g. regression models, etc.)	A Trained Neural Network
Complexity	Low	High	Medium	Medium
Accuracy	Medium	High	Medium	Low
Interpret	Easy	Easy	Easy	Hard

This table summarizes the uniqueness and differences of our new modeling technology from Theoretical Modeling (such as process models), statistical modeling (such as data-mining models), and neural networks

Globalization

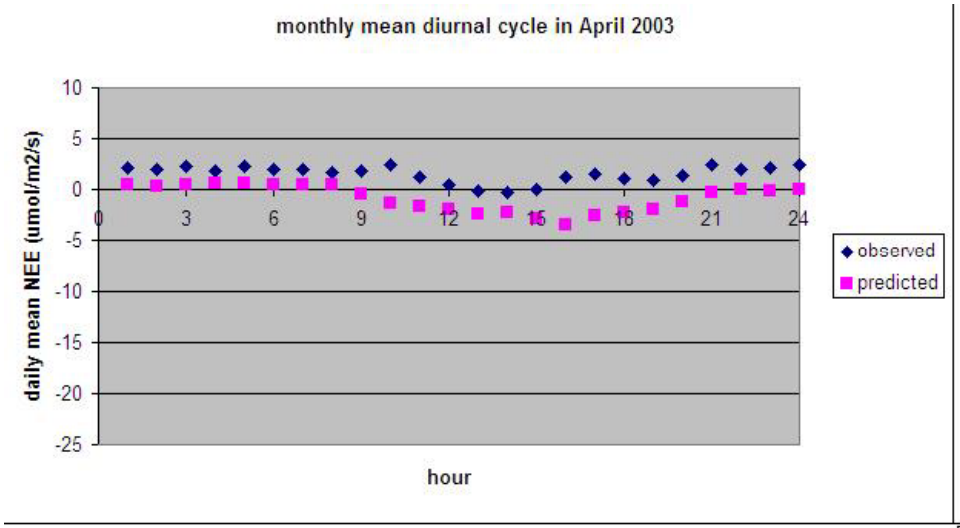


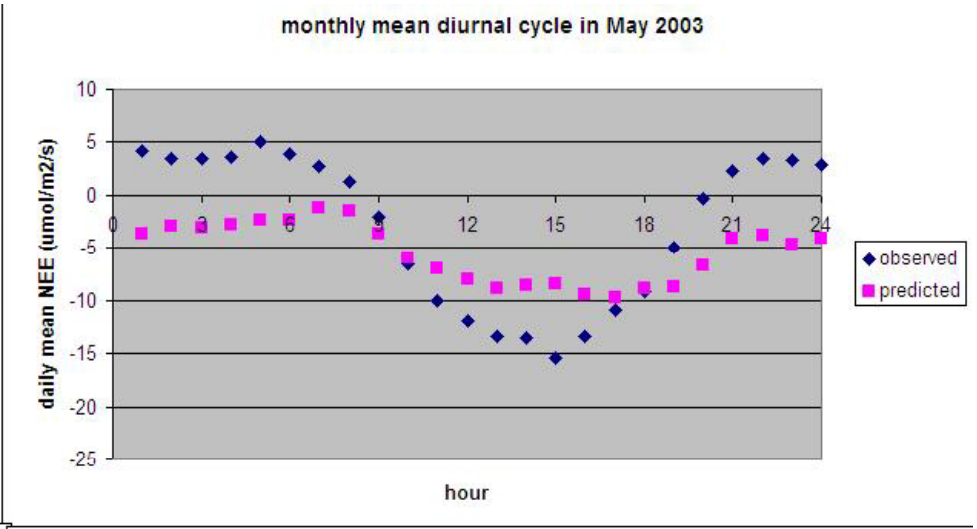
Apply the new modeling technology to build models for CO2 fluxes at

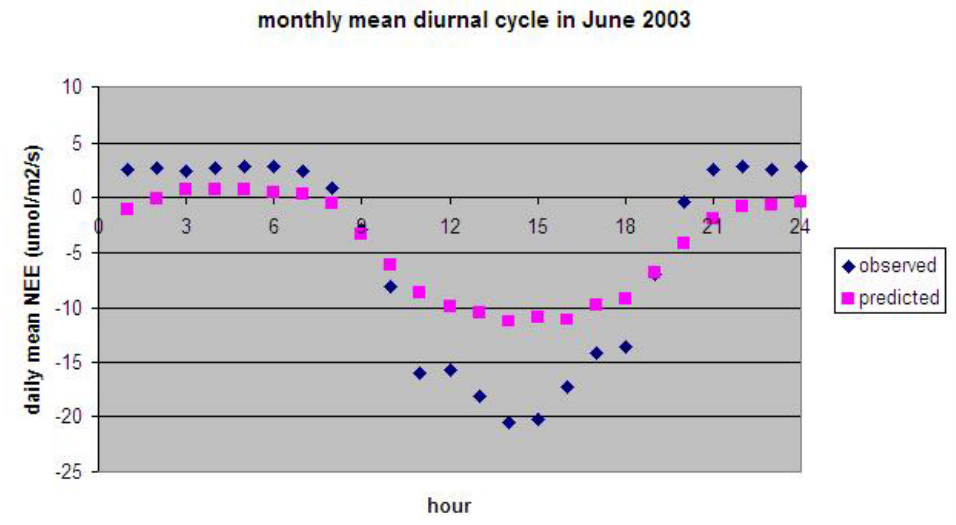
1) 200+ **sites** in US, Europe, China, Canada and Brazil. (collaborate now)
2) Model different **regions** according to transects (e.g. grassland or forest)
3) **Global** spatial correlation of the earth. (i.e. Models built in Europe can be utilized to help assess/predict US lands with similar profiles)

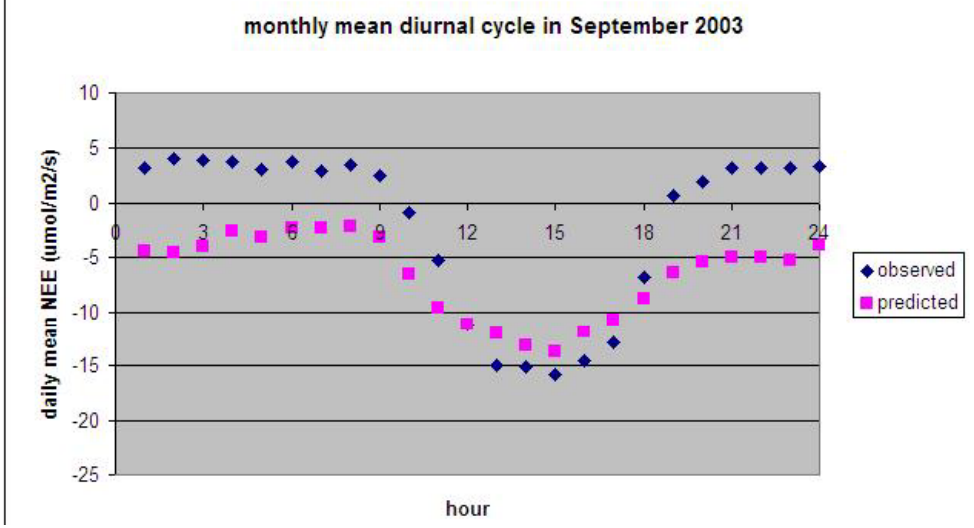
Results of Globalization

- From 2005 Missouri Model to predict the CO2 Fluxes of Morgan Monroe State Forest, 2003



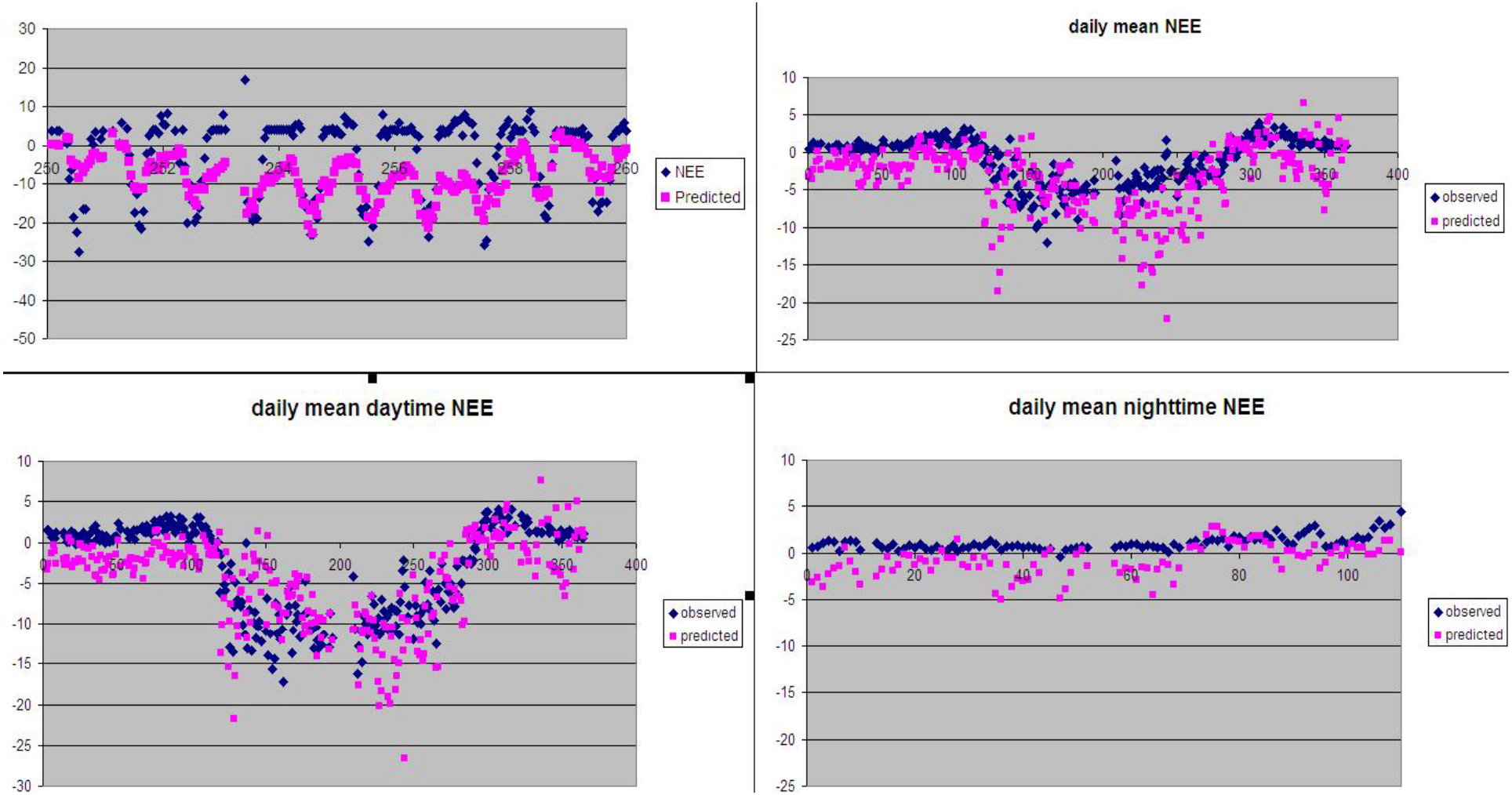




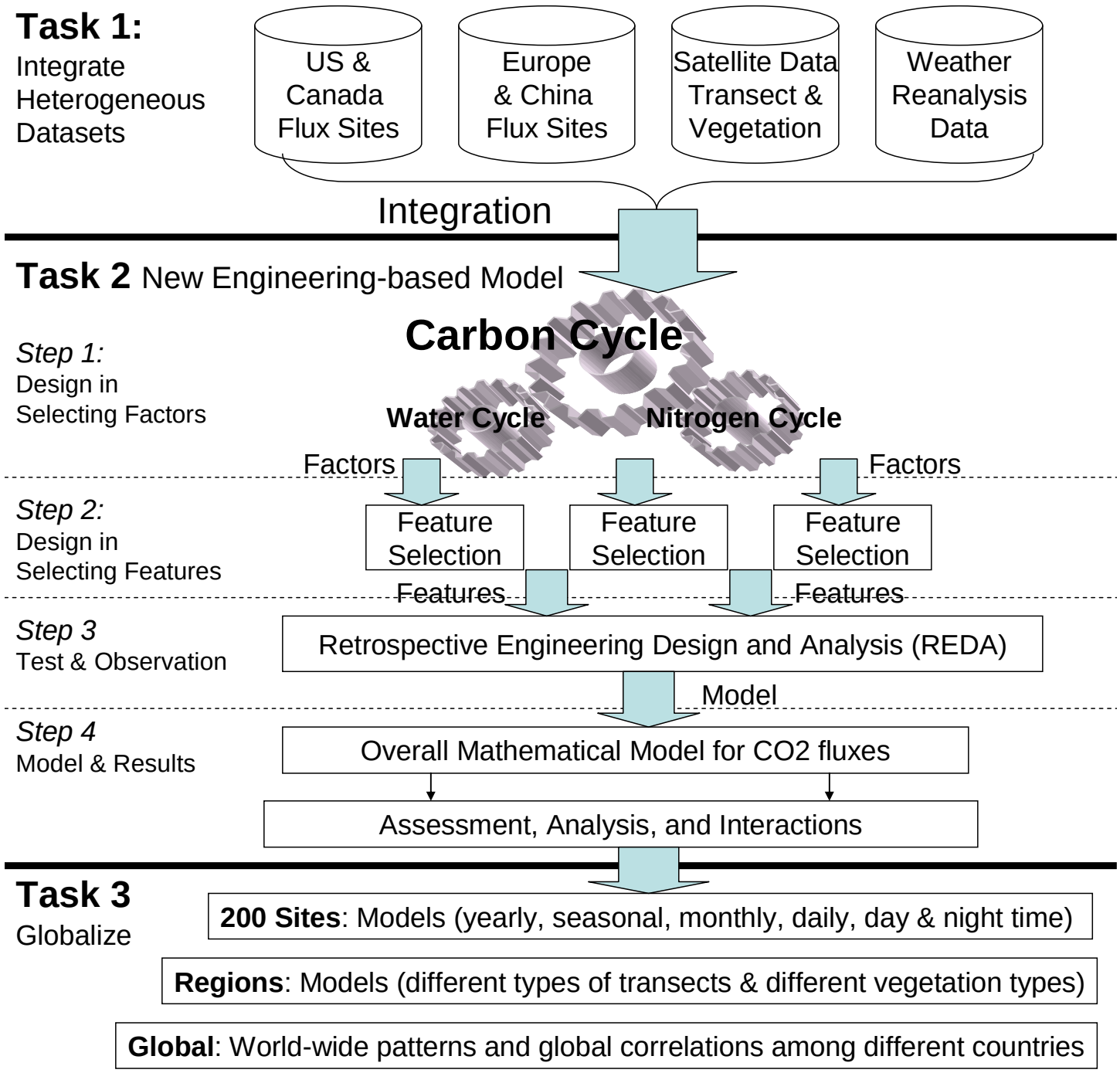


Globalization Results of Spatiotemporal Correlation

- From 2005 Missouri Model to predict the CO2 Fluxes of Morgan Monroe State Forest, 2003



Research Tasks



Sustainability Assessment for Managing CO2

- Sustainability Assessment
  - Effectiveness
    - From the Model to assess the Effectiveness
  - Feasibility
    - From Environments, Economics, Ecology and Politics to evaluate Feasibility
  - Robustness
    - Uncertainty analysis and Sensitivity analysis

Conclusion & Future Work