IMPROVING ECOLOGICAL FORECASTING WITH HYPERSPECTRAL DATA: A DATA ASSIMILATION SYSTEM FOR THE COMMUNITY LAND MODEL

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Ecological forecasting

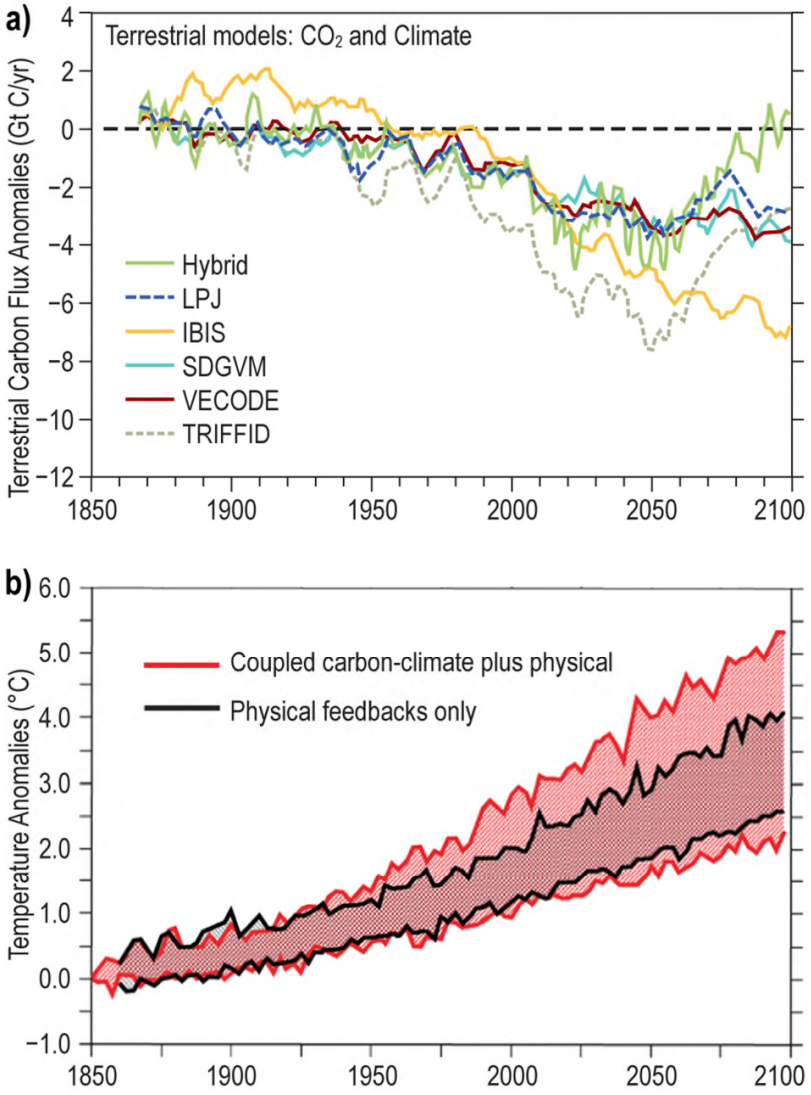
1. **Predicting the most likely future state of an ecological system**
   i. Relevant for short-term forecasts
   ii. Systems own dynamics most strongly govern change over time
   iii. i.e. forecasting the likely spread of invasive species

2. **Predicting the most likely future state, given a decision today**
   i. Relevant when alternate management actions or scenarios are considered
   ii. i.e. forecasting likely impacts on biodiversity from alternate wildfire mitigation schemes

Coupled carbon-climate models

- Uncertainty in carbon cycle feedbacks roughly doubles climate uncertainty for any given emission pathway
- Most of this uncertainty is associated with responses of the terrestrial biosphere

- This uncertainty stems from
  - i. **Structural uncertainty**
  - ii. **Parameter uncertainty**
  - iii. **Initial conditions uncertainty**
  - iv. **Boundary conditions uncertainty**



Is biodiversity of vegetation a problem?

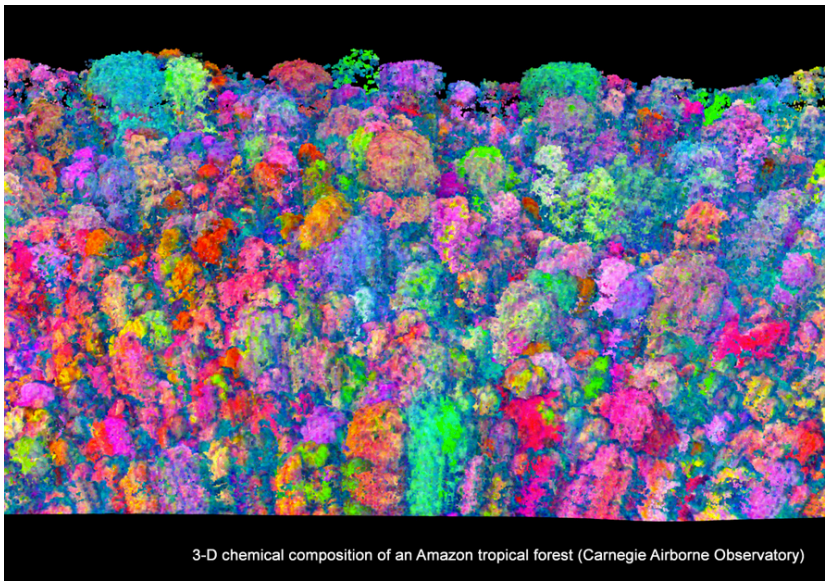
- The c. 300,000 vascular plant species represented by c. 20 plant functional types (PFTs)
- Hyperspectral remote sensing allows us to potentially classify many thousands of vegetation categories
- Reveals the detailed biological, functional and structural diversity

i. **Leaf nitrogen** – nutrient status and photosynthetic potential

ii. **Specific leaf area** – fundamental tradeoff in leaf construction and light interception

iii. **Lignin/Cellulose** – Foliar recalcitrance, decomposability and nutrient cycling

iv. $\mathbf{V_{cmax}}$ – photosynthetic capacity of vegetation



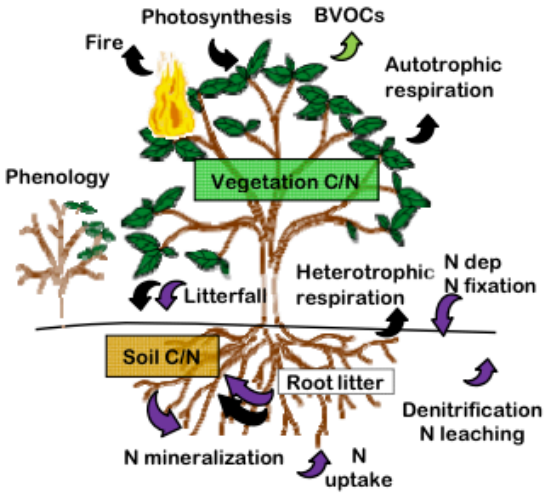
3-D chemical composition of an Amazon tropical forest (Carnegie Airborne Observatory)

Canopy parameters control biogeochemistry

Photosynthesis

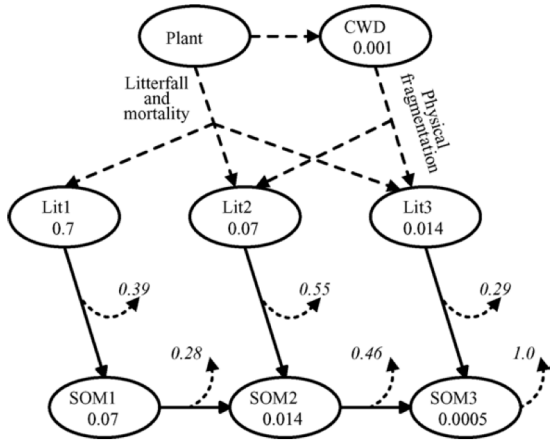
$$V_{cmax} = f(N_a F_{LNR})$$
$$N_a = f(CN_L SLA)$$

- N_a - Leaf nitrogen concentration
- F_{lnr}– Fraction of leaf N in rubisco
- CN_L – Leaf C:N ratio
- SLA – Specific leaf area: top of canopy

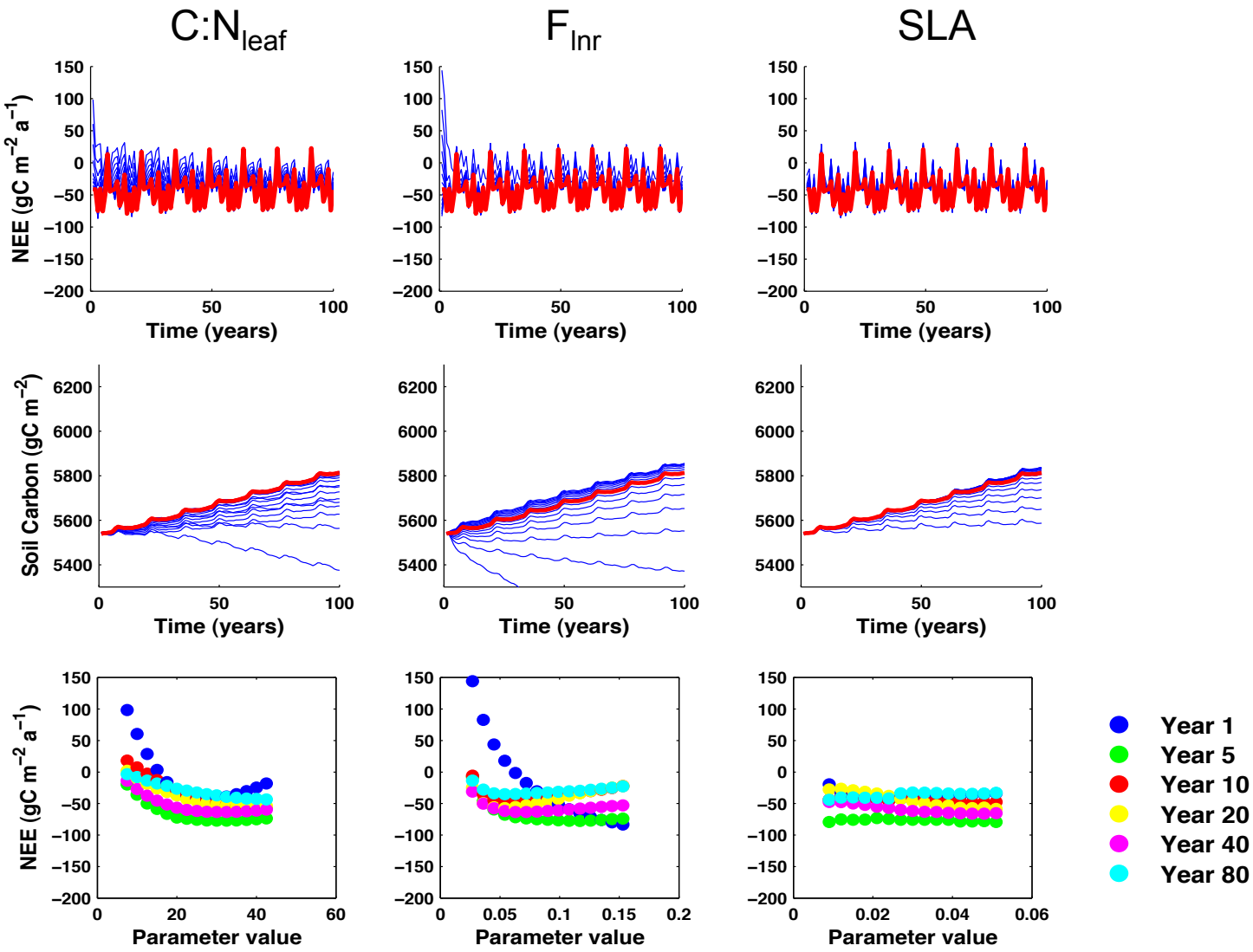


Respiration

- 3 litter pools, 3 soil organic matter pools and coarse wood debris pool in converging cascade
- Approximate labile, cellulose and lignin
- LF_{flig} – leaf litter lignin fraction
- LF_{fcel} – leaf litter cellulose fraction

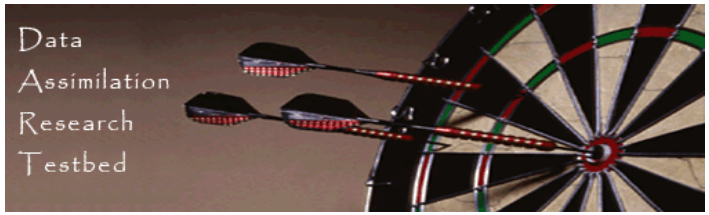


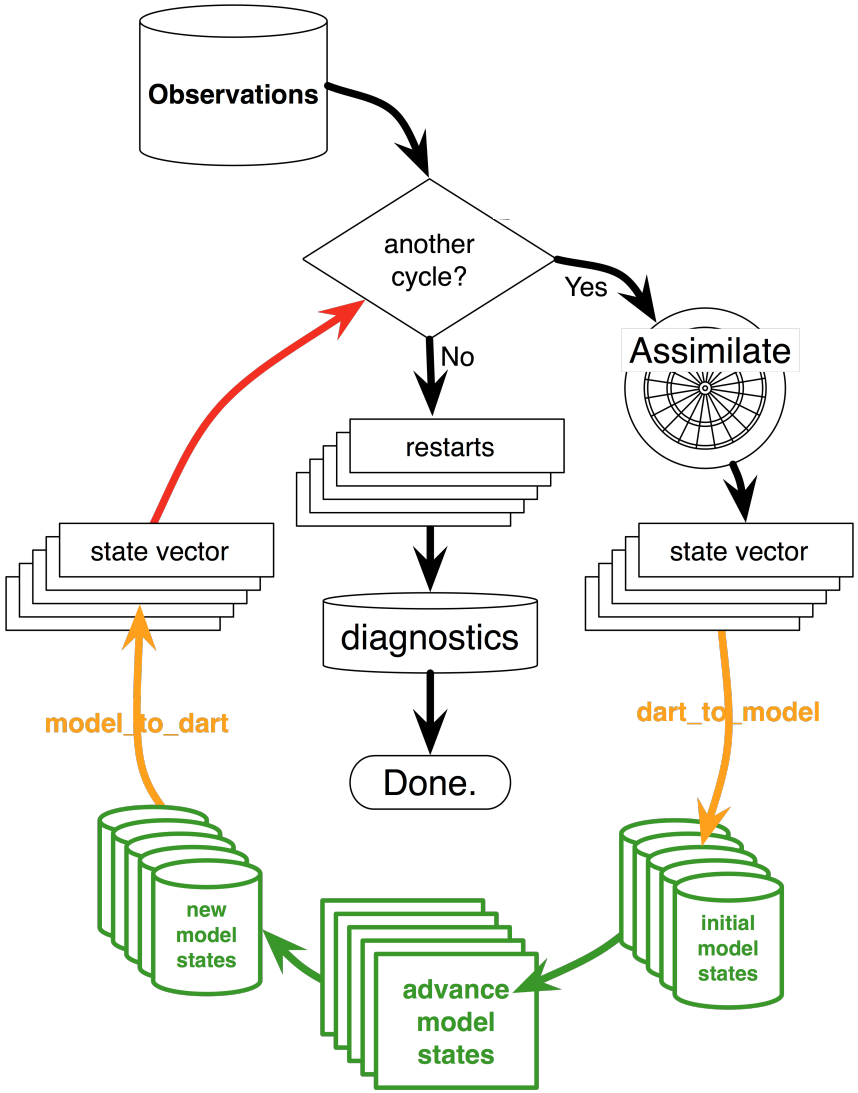
Sensitivity to canopy chemistry parameters



Data Assimilation Research Testbed (DART)

- DART is a community facility for ensemble DA
- Uses a variety of flavors of filters
  - Ensemble Adjustment Kalman Filter
- Many enhancements to basic filtering algorithms
  - Adaptive inflation
  - Localization
- Uses new multi-instance capability within CESM



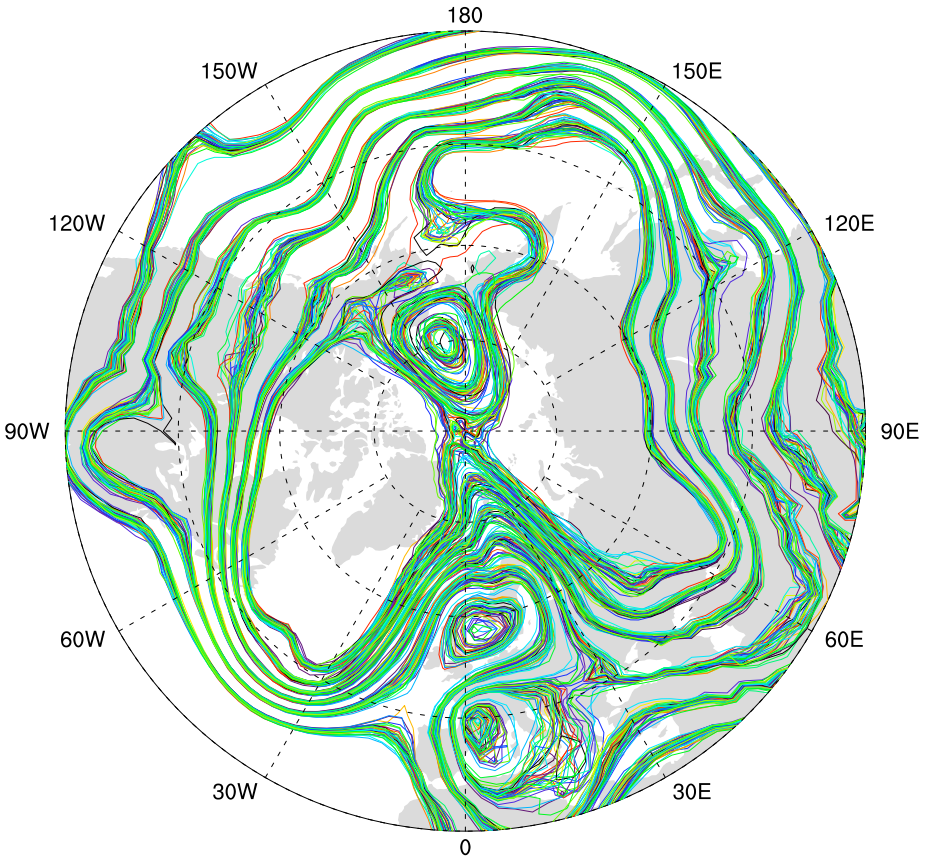


Observing system simulation experiment

- 80 member, 6 hourly climate reanalysis available, 1998 – 2010
- Each forces separate CLM ensemble member at 1° x 1°
- Generates spread in the land model states
- At 60 NEON sites observe:

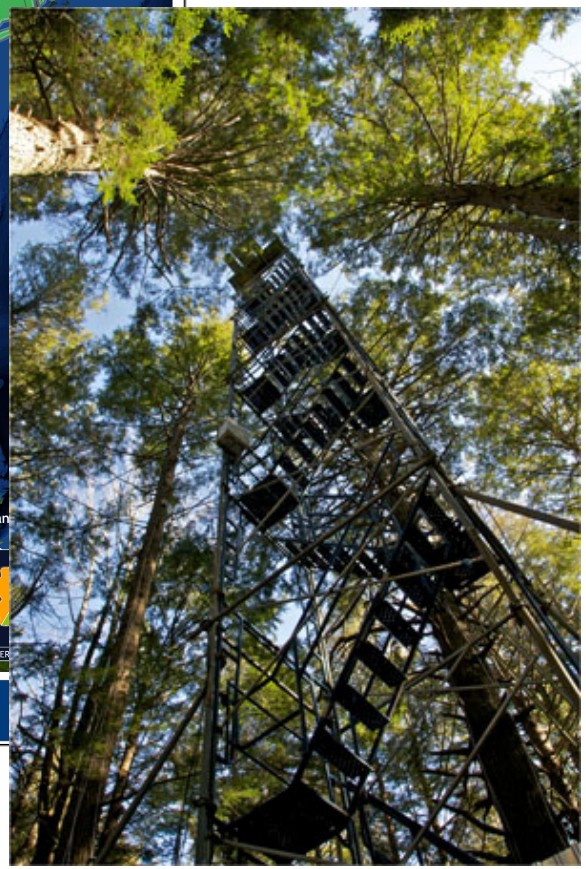
i. **Leaf area index**
ii. **Leaf nitrogen concentration**
iii. **Net Ecosystem Productivity**
iv. **Evapotranspiration**

- **175,000 observations a month**

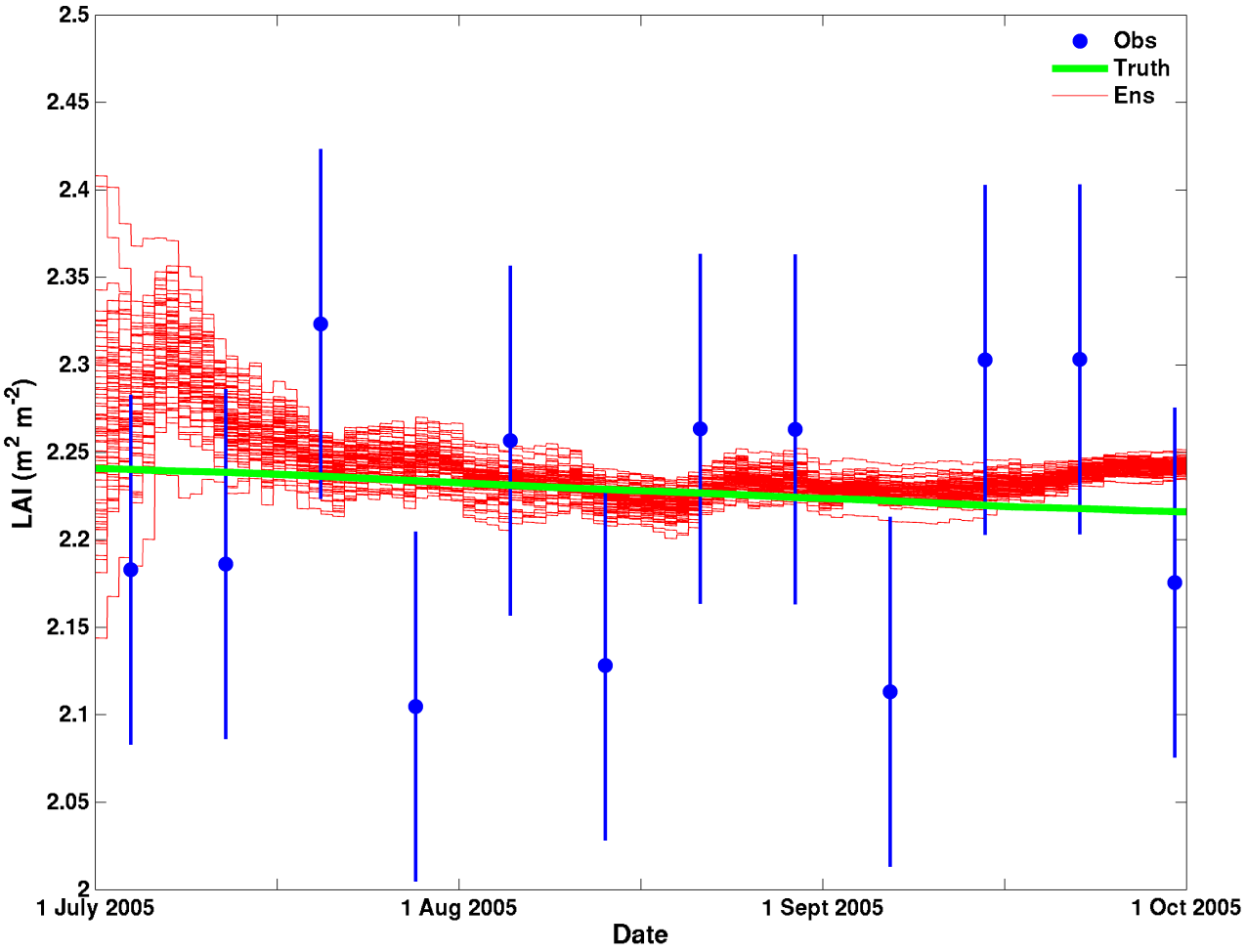


500 hPa GPH
Feb 17 2003

NEON sites and Harvard forest flux tower



LAI – observations every 8 days



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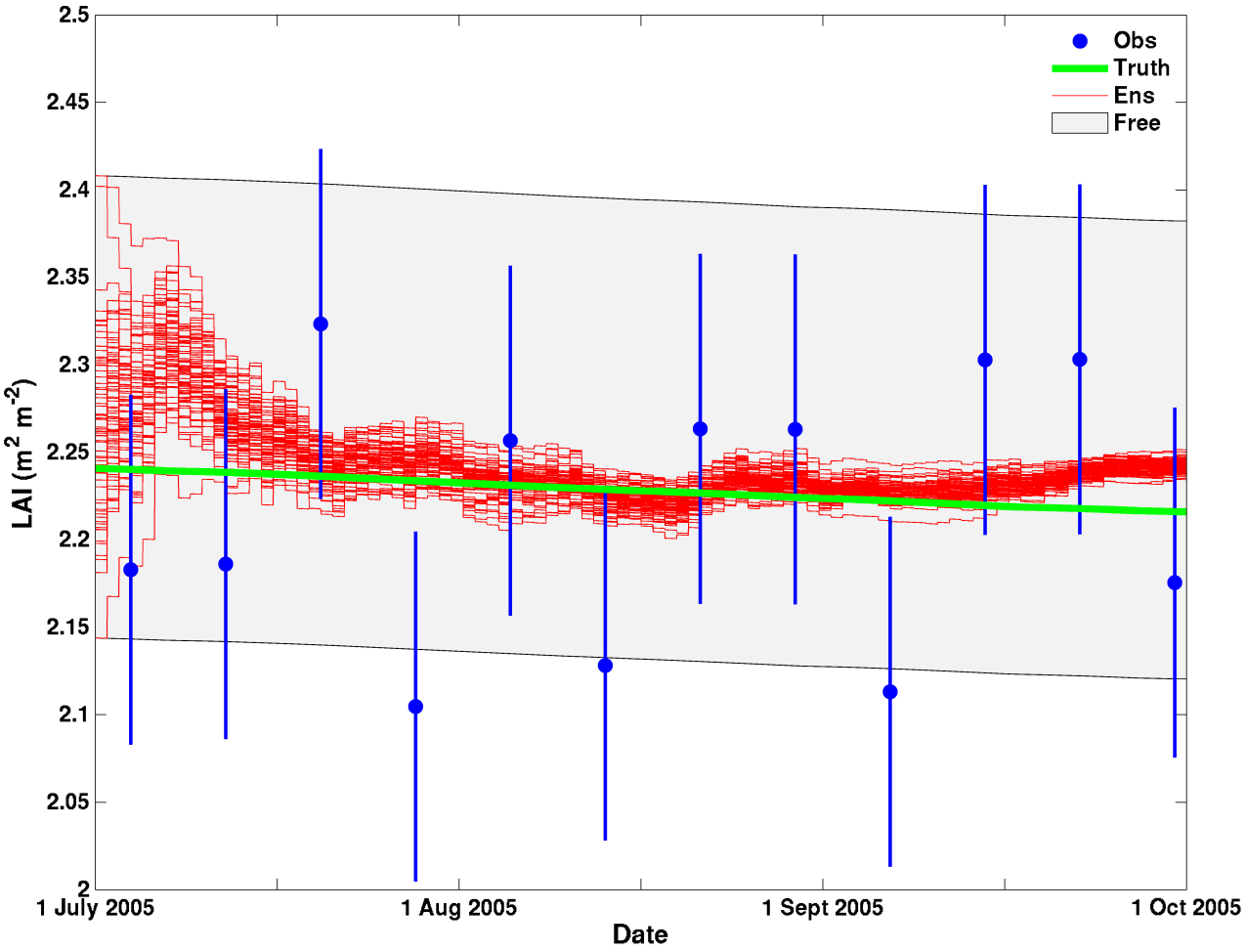
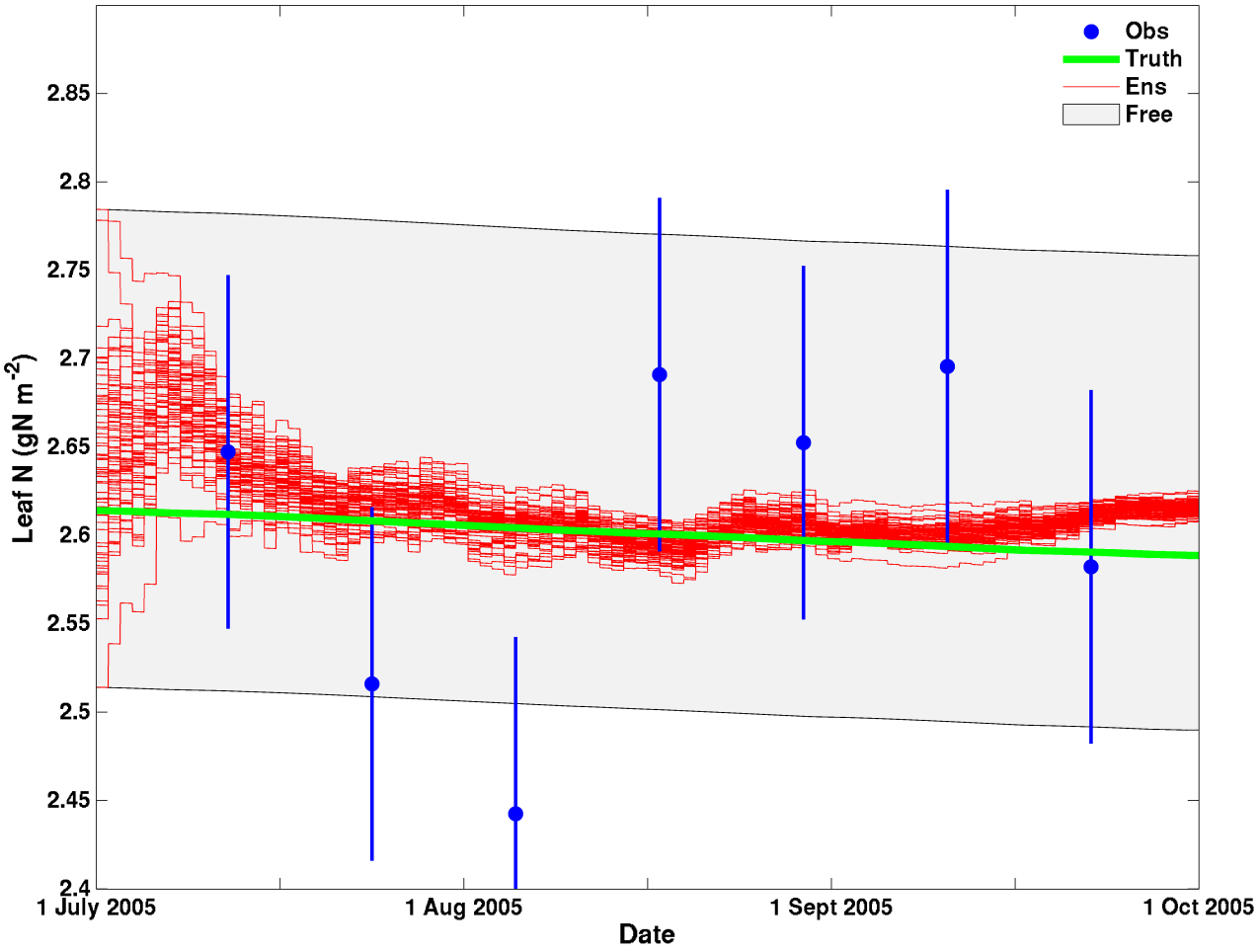
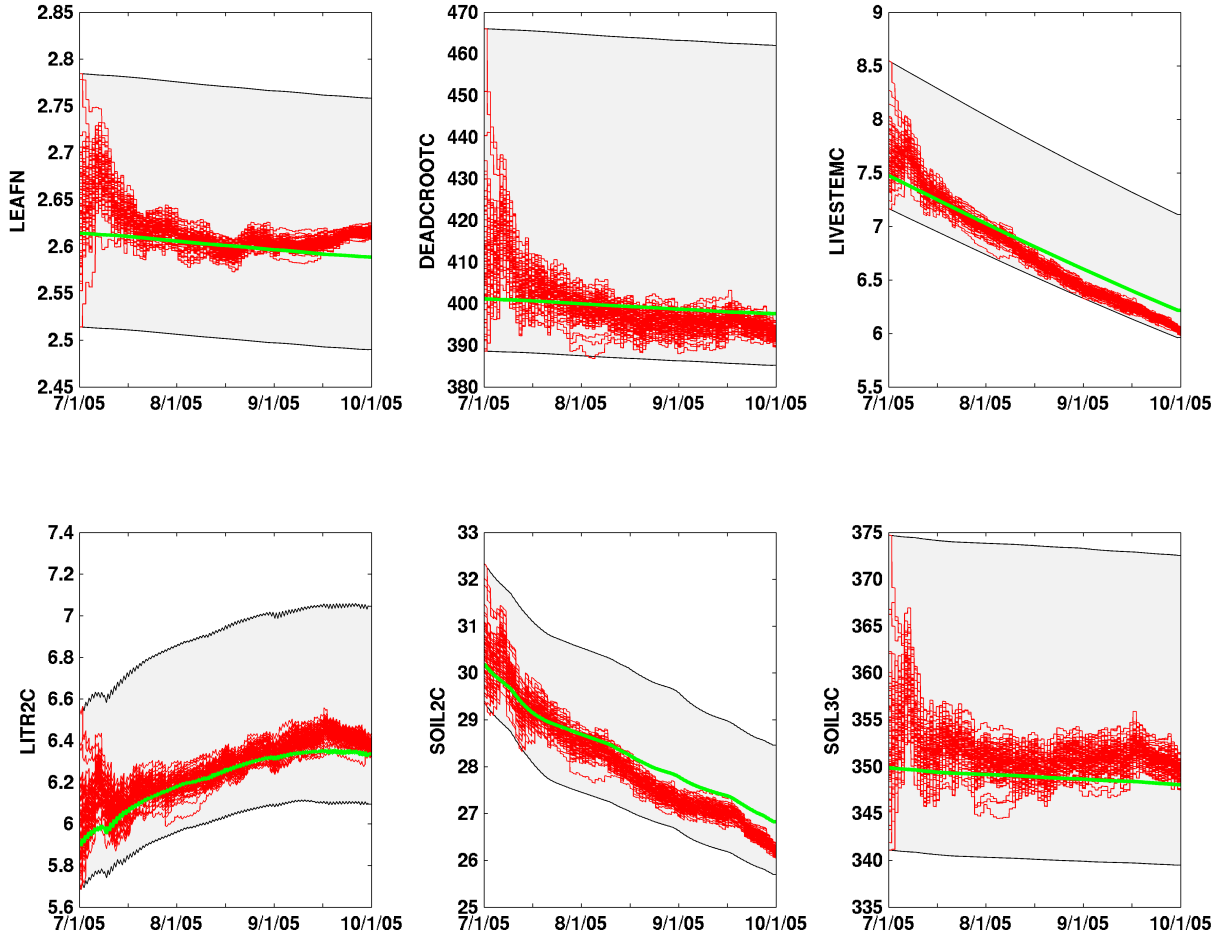


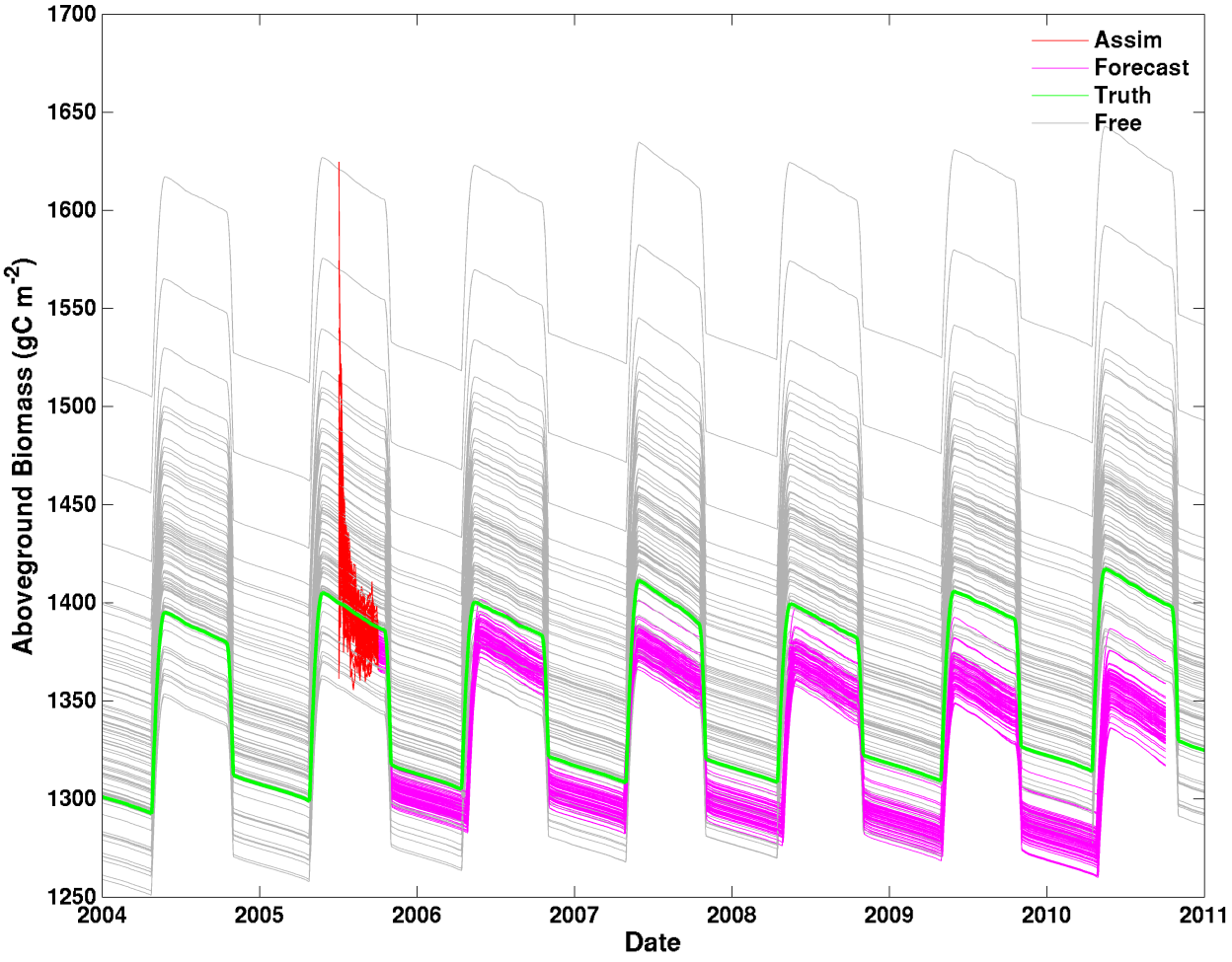
Leaf Nitrogen – observations every 12 days



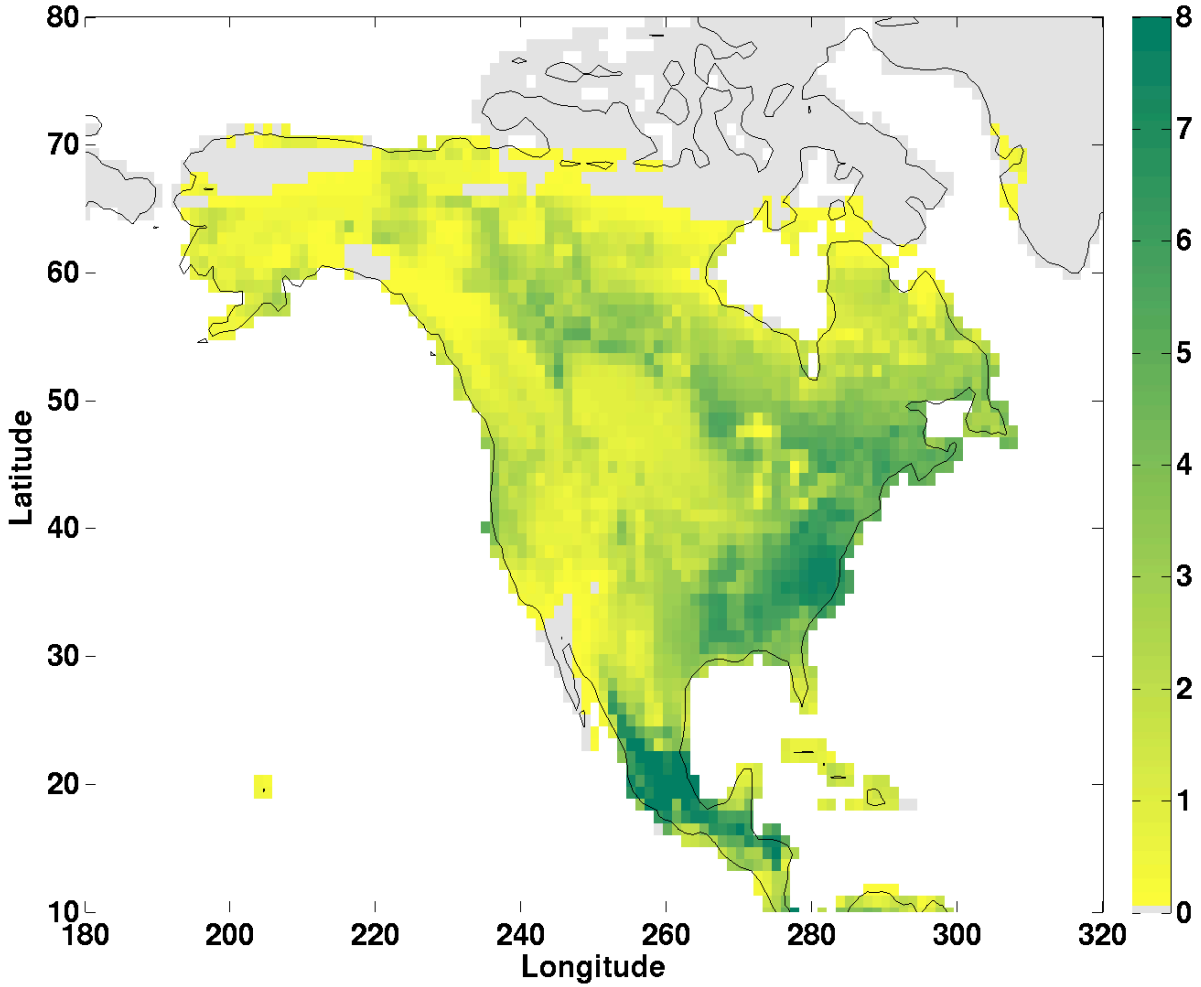
Examples of other N and C pools- unobserved



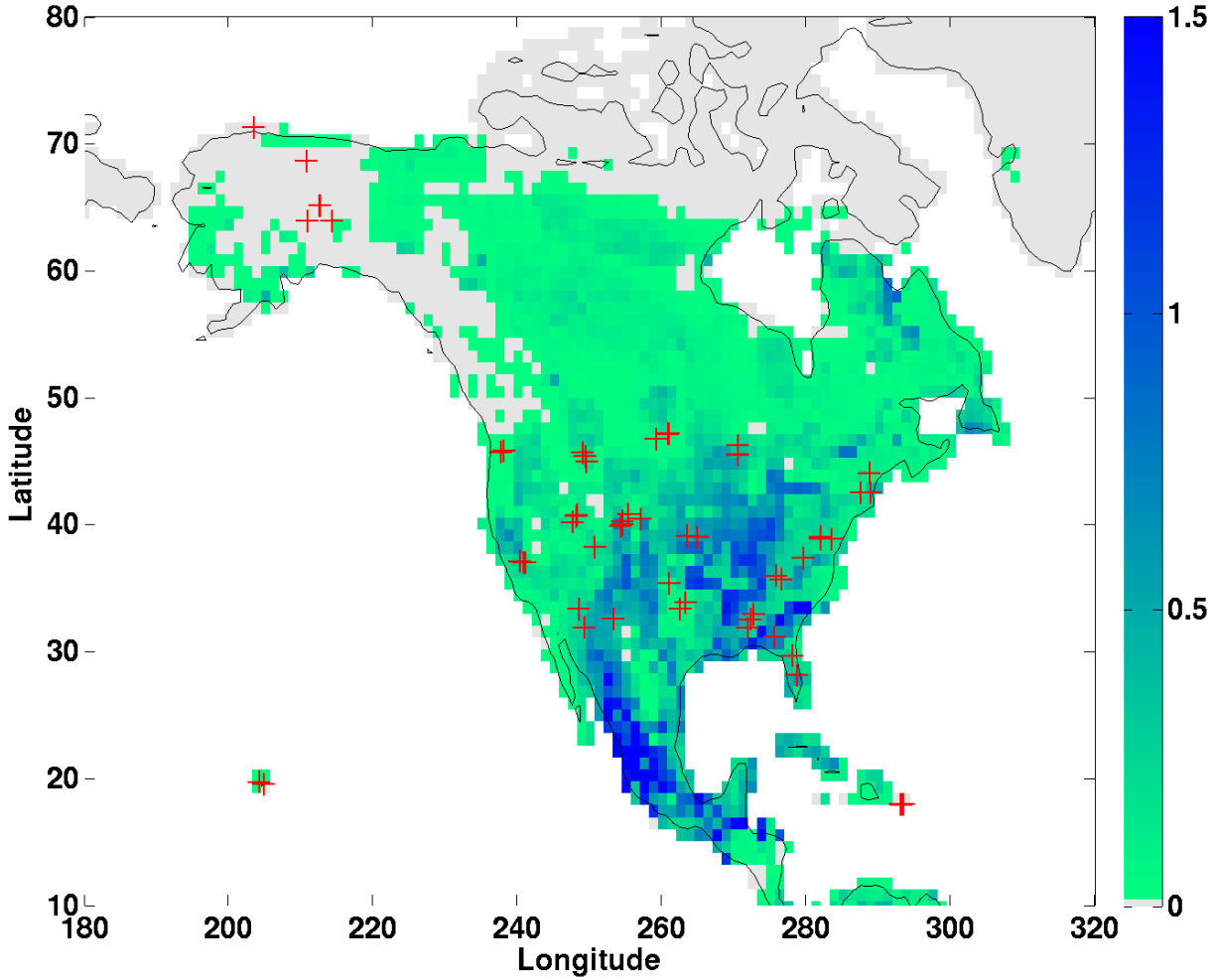
Impact on forecast - biomass



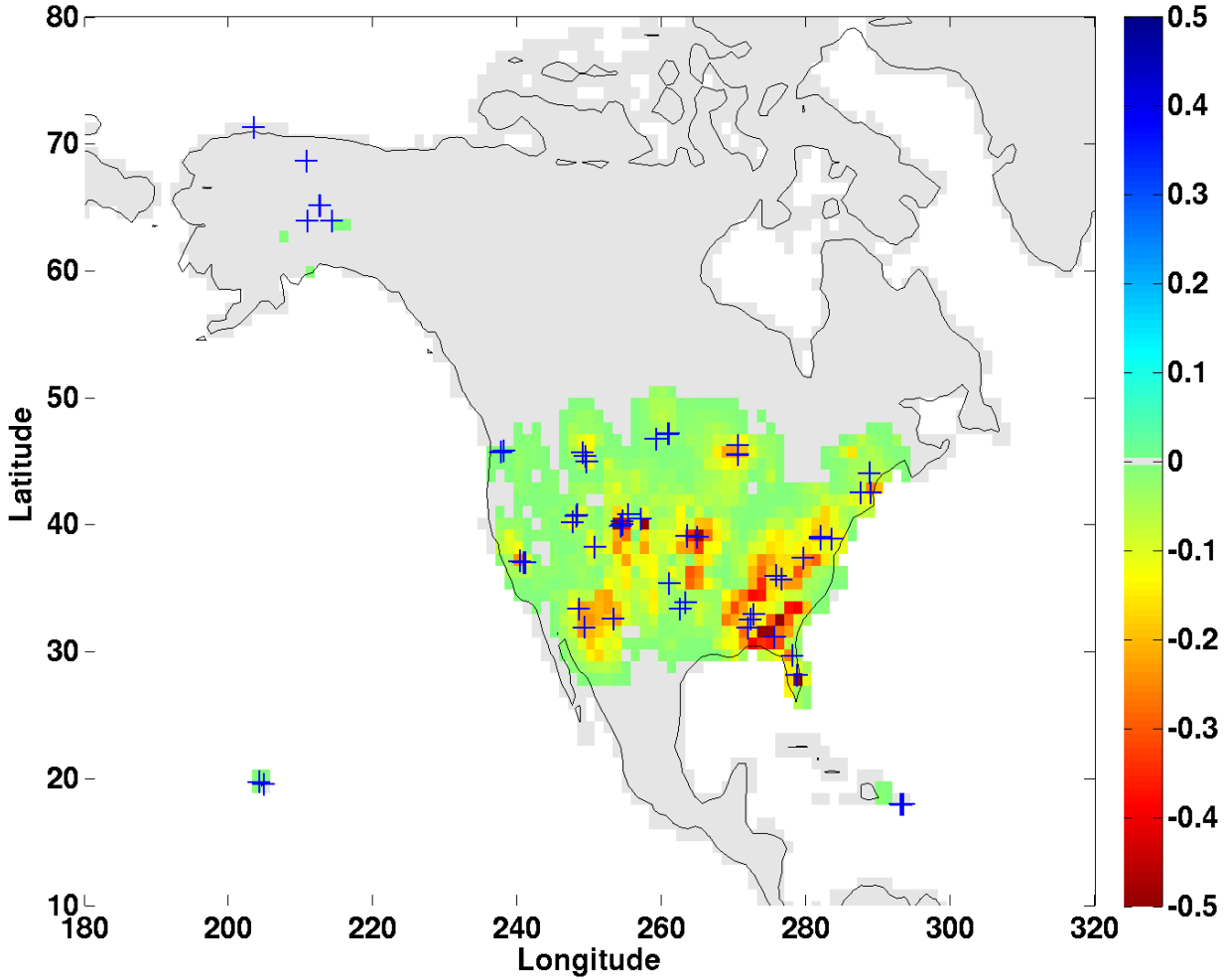
Mean LAI from 80 ensemble members



LAI spread from 80 ensemble members



Reduction in LAI ensemble spread



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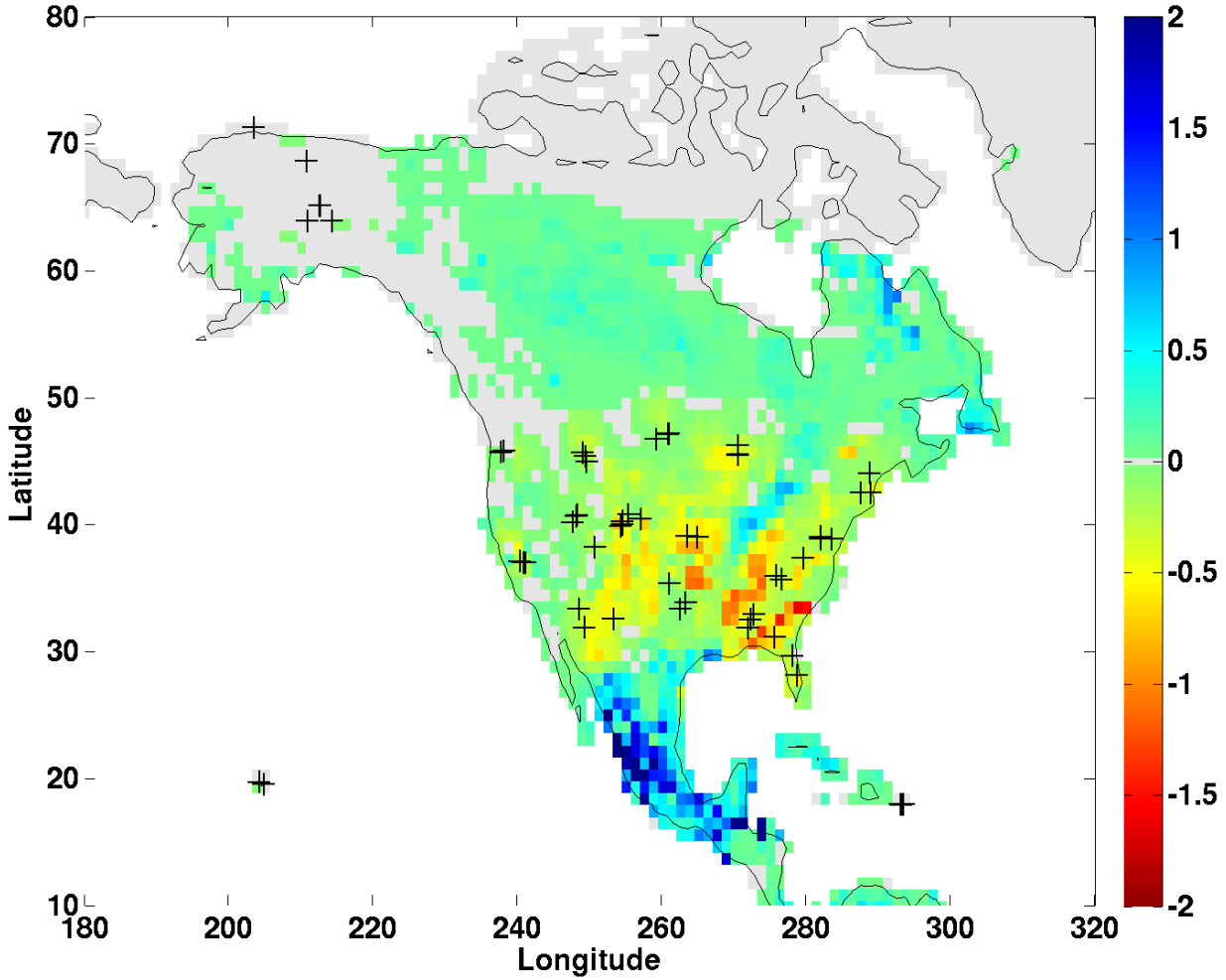
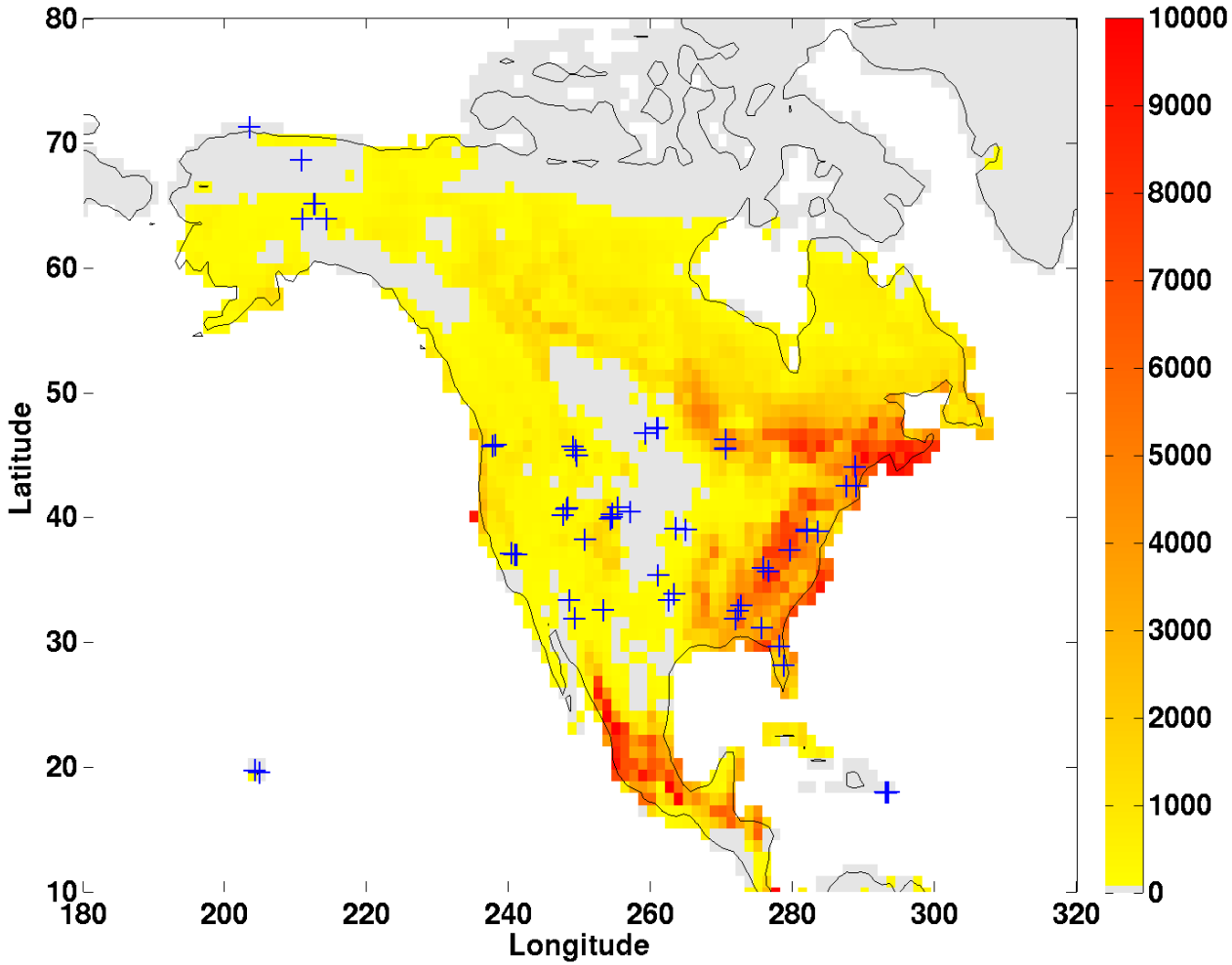
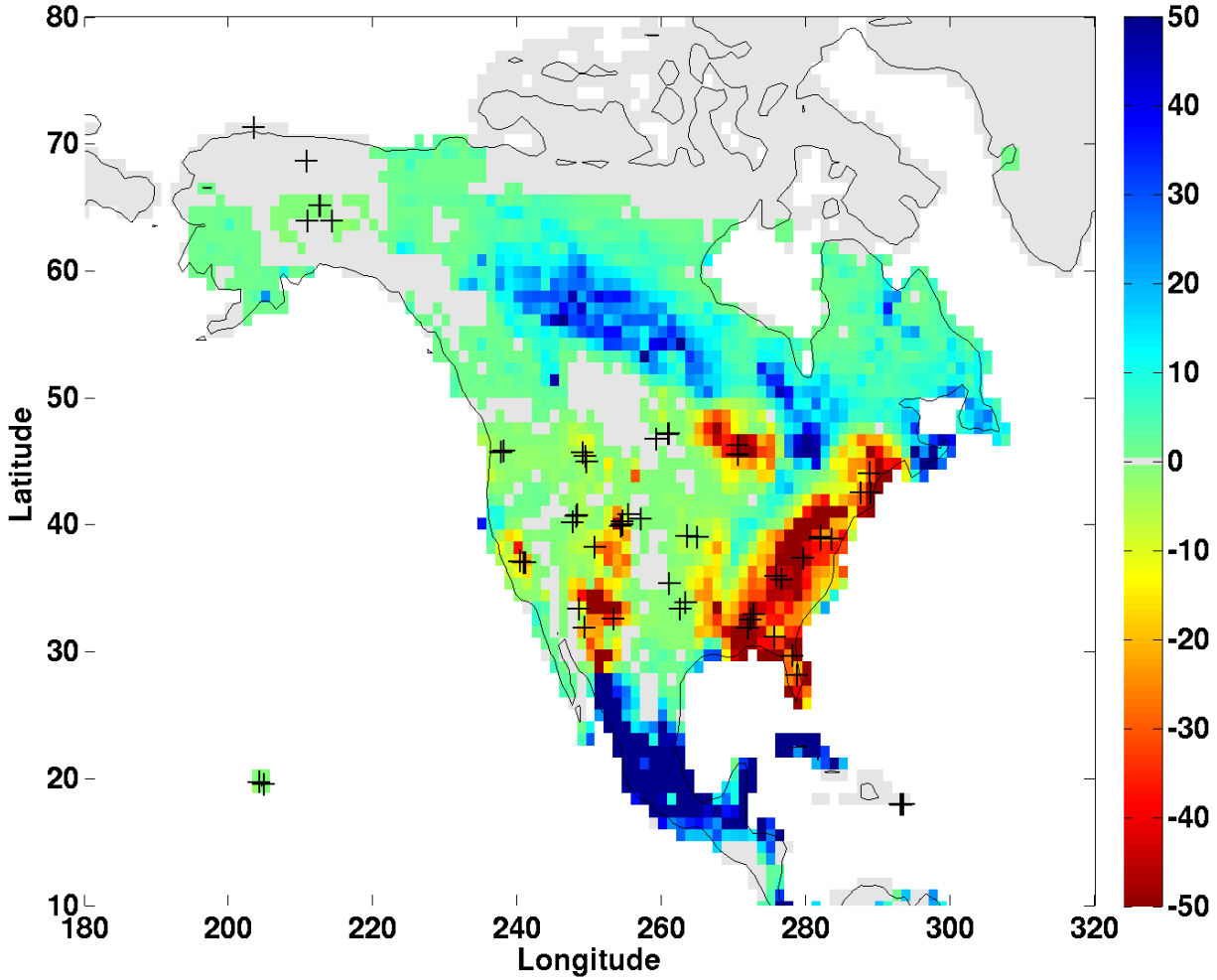


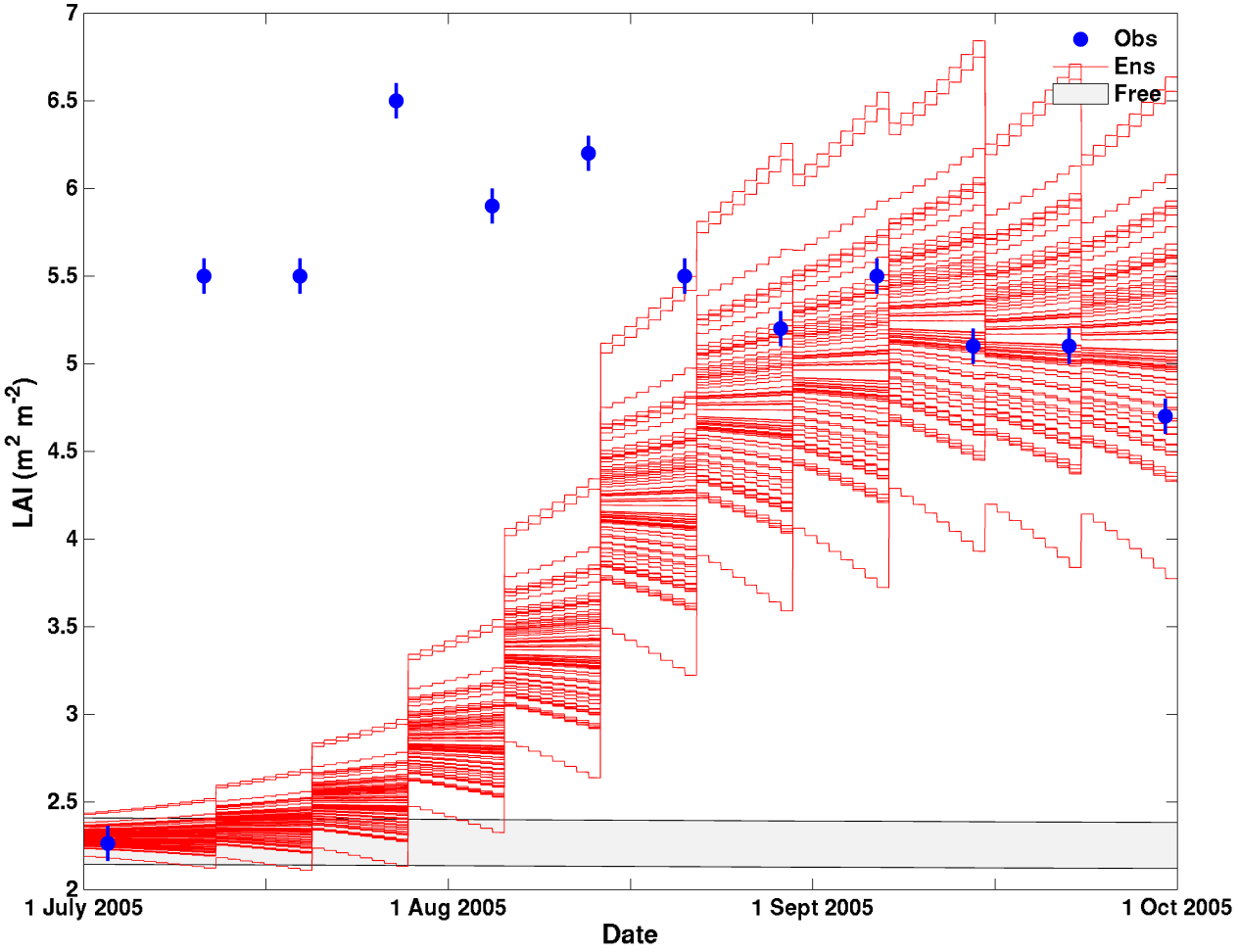
Mean biomass from 80 ensemble members



Change in biomass ensemble spread



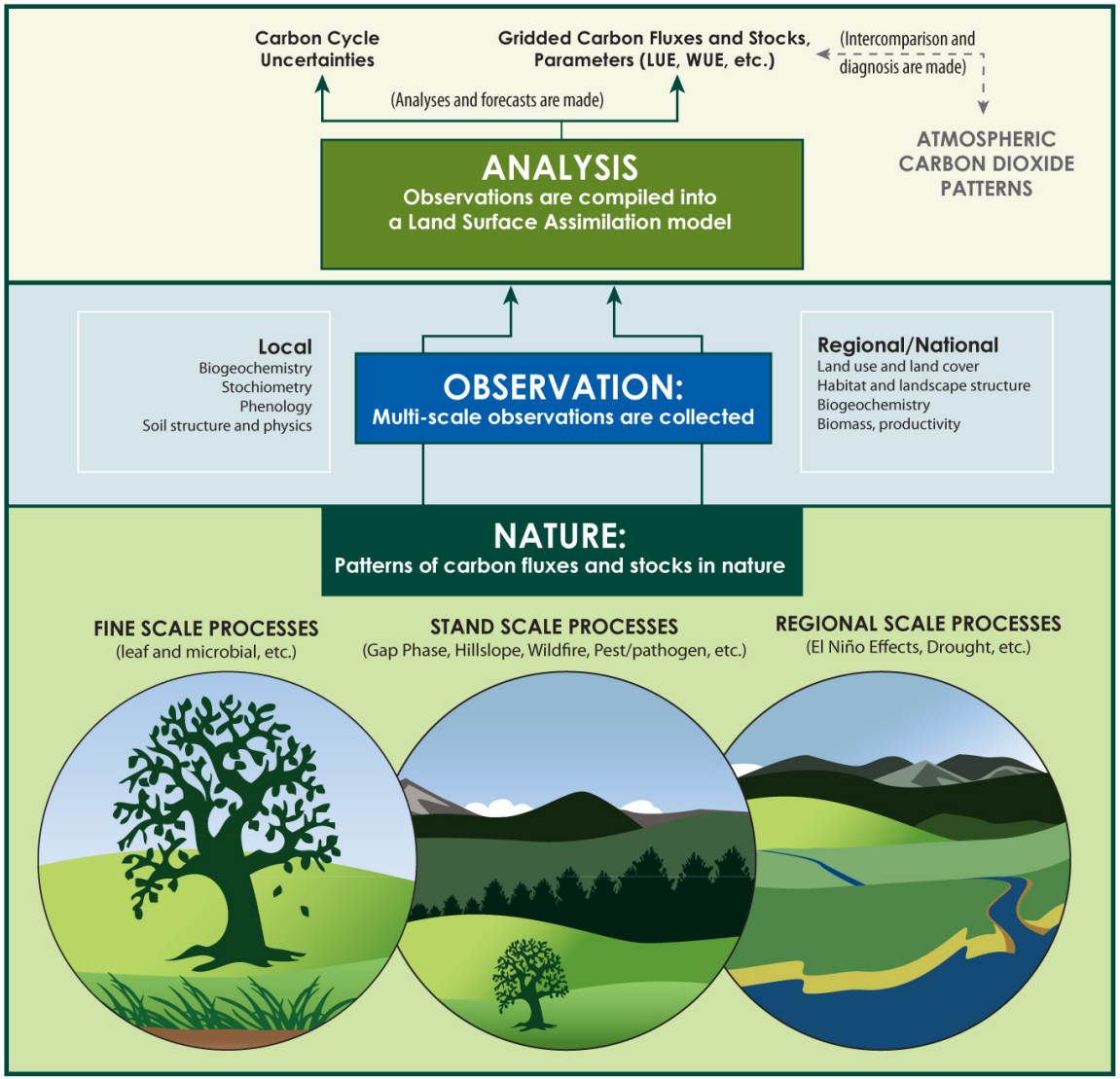
“Real observations” - MODIS LAI



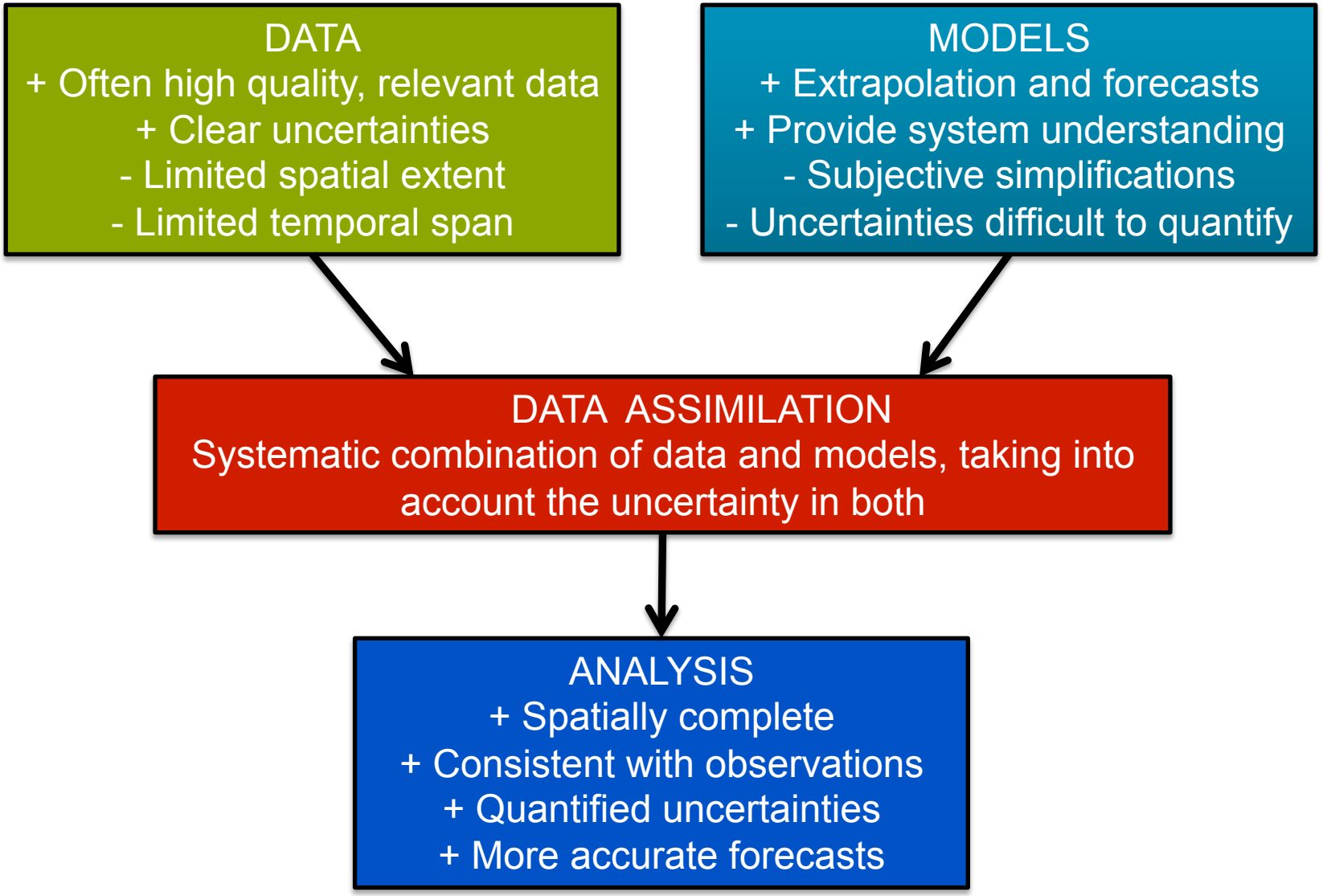
Summary

- Ecological forecasting is essential to advancing scientific understanding and is a useful societal application of knowledge
- Ecological forecasting requires deterministic knowledge of process, but forecasts should be probabilistic and provide and estimate of uncertainty on future state
- Hyperspectral remote sensing provides detailed biological, functional and structural diversity
- It can classify vegetation, but also provides key information about these categories
- But using this information in complex BGC models is challenging. “Direct replacement” is unlikely to work
- Ensemble data assimilation can account for uncertainties in model and observations, providing probabilistic estimates of future states
- But need to make sure the models are ready for the data

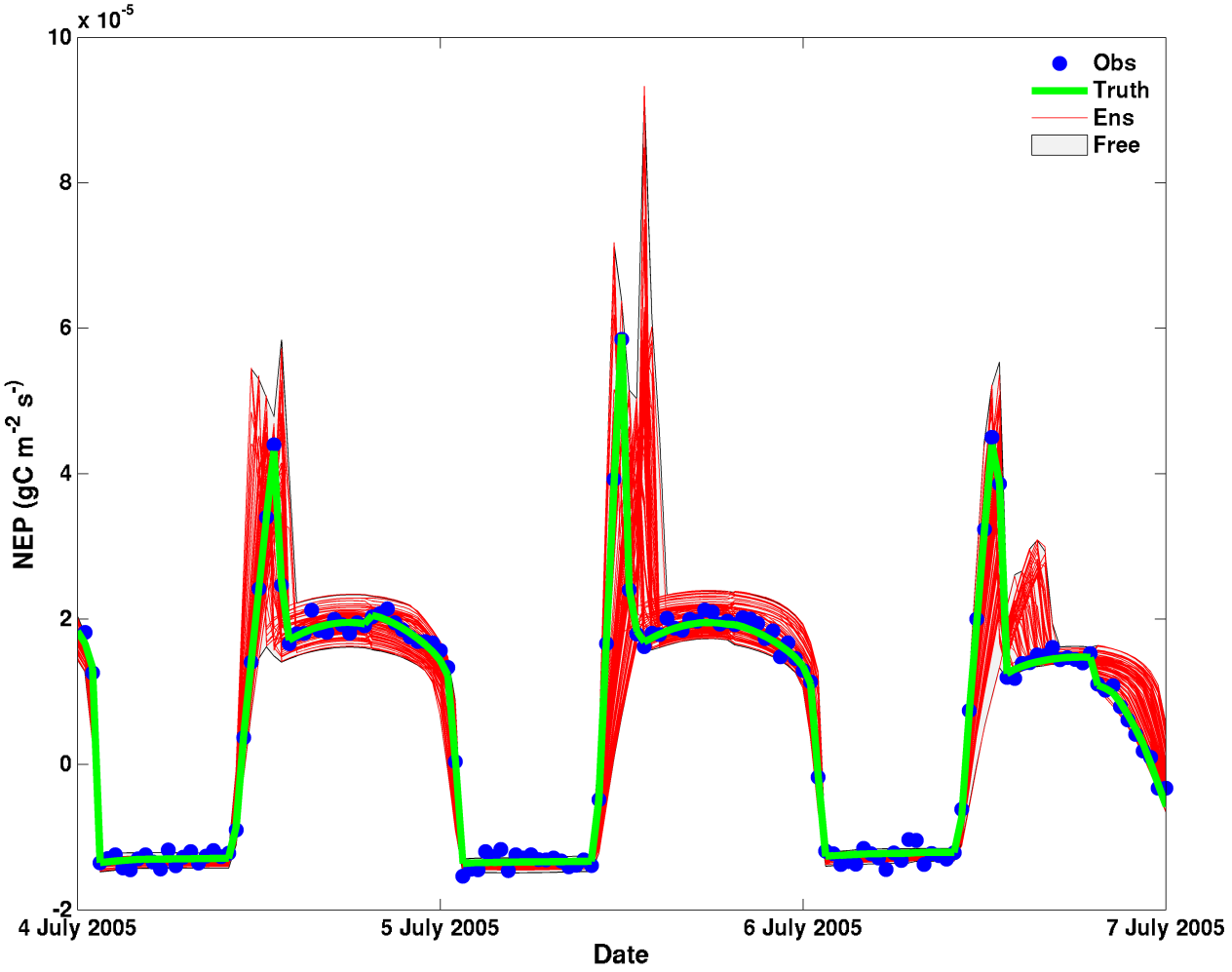
Integrating observations with models



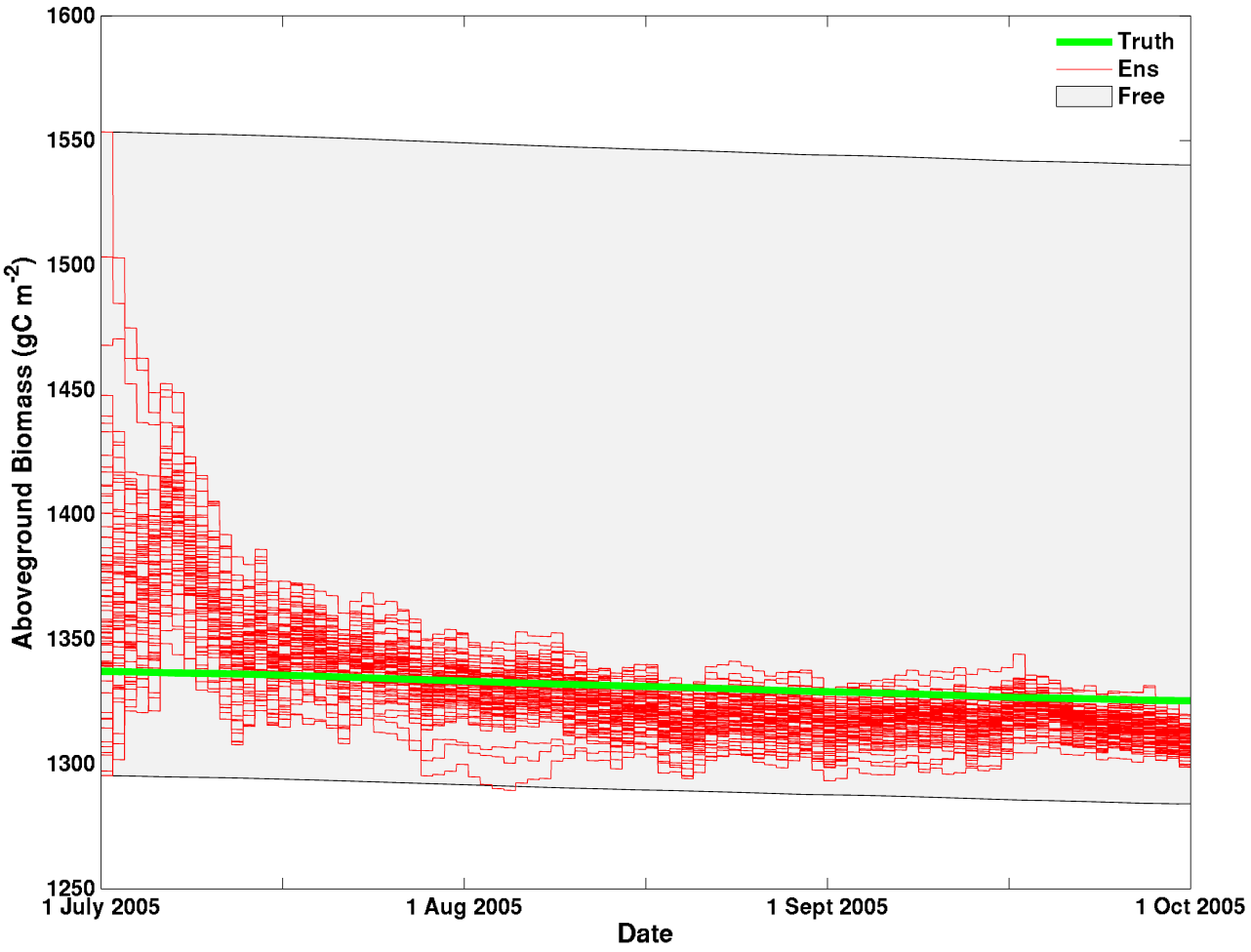
Data Assimilation



NEP – observations every 30 minutes



Above ground biomass - unobserved



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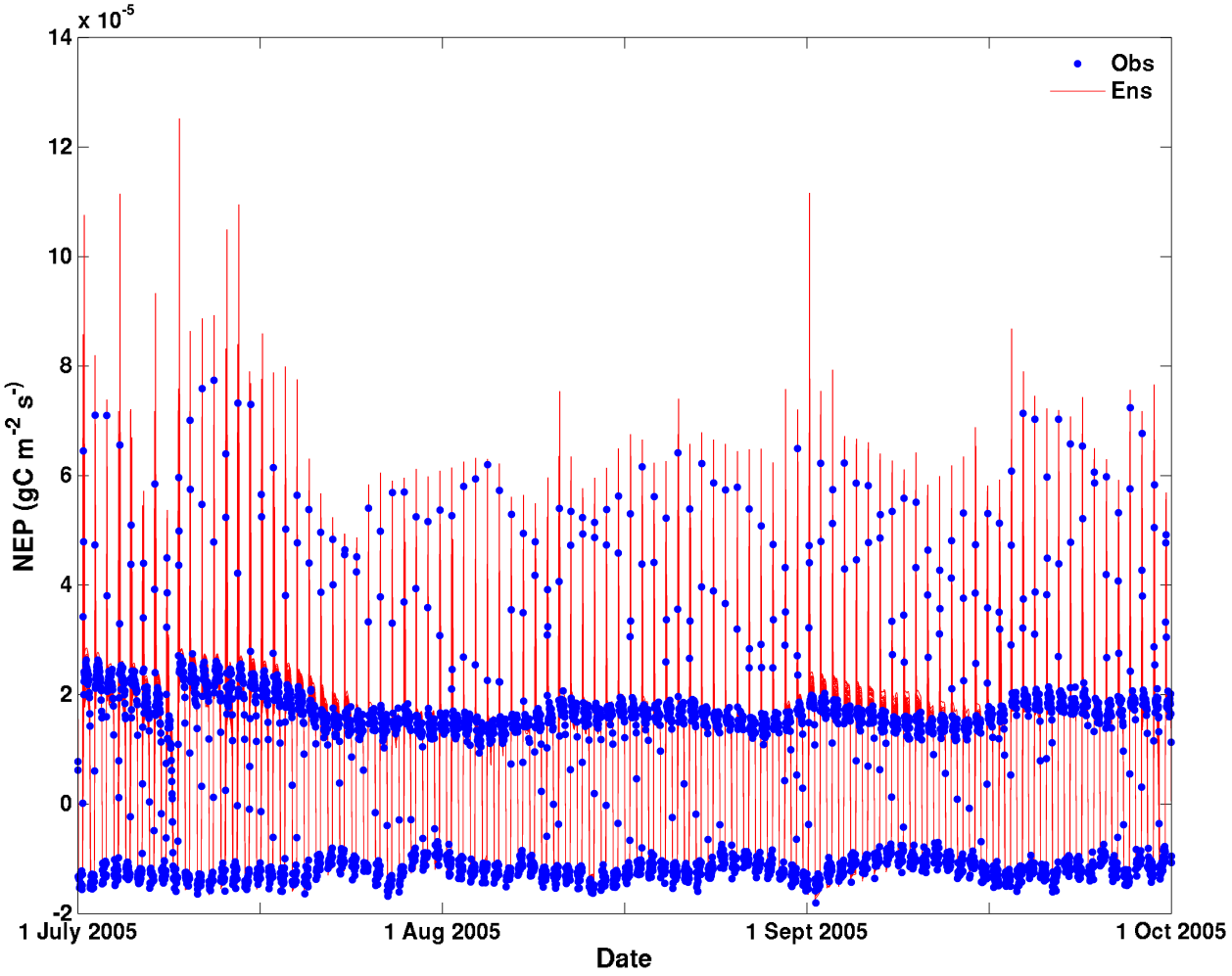
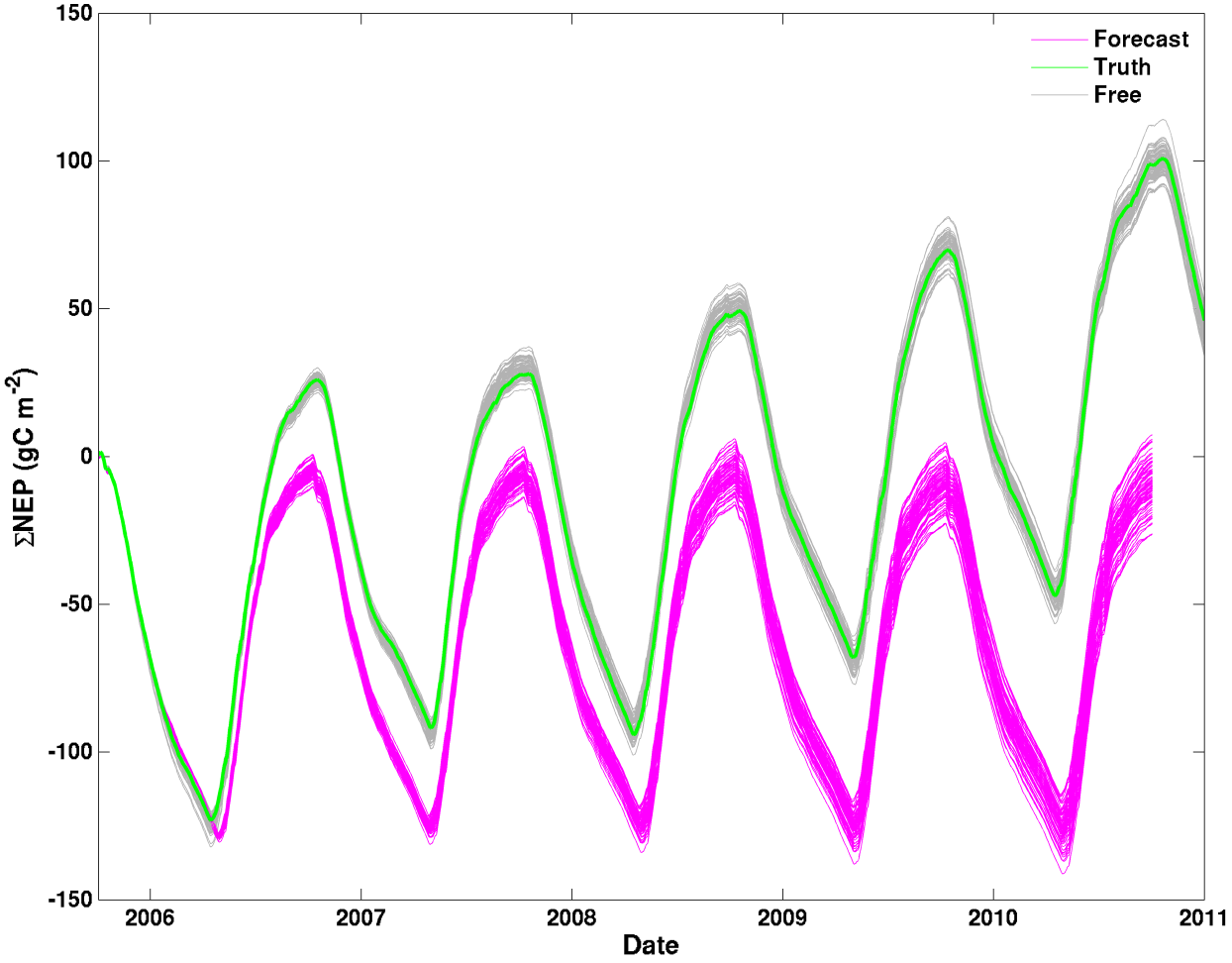
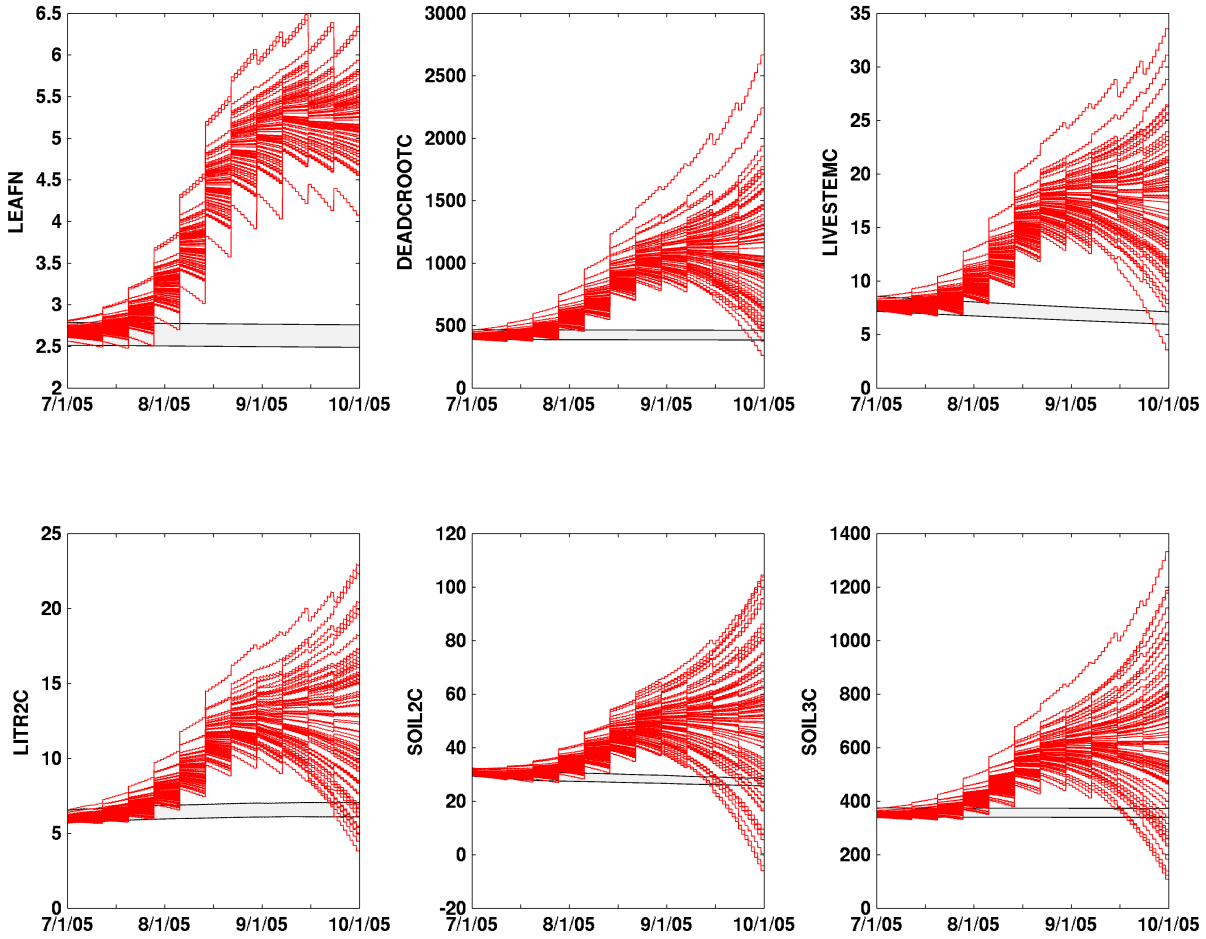


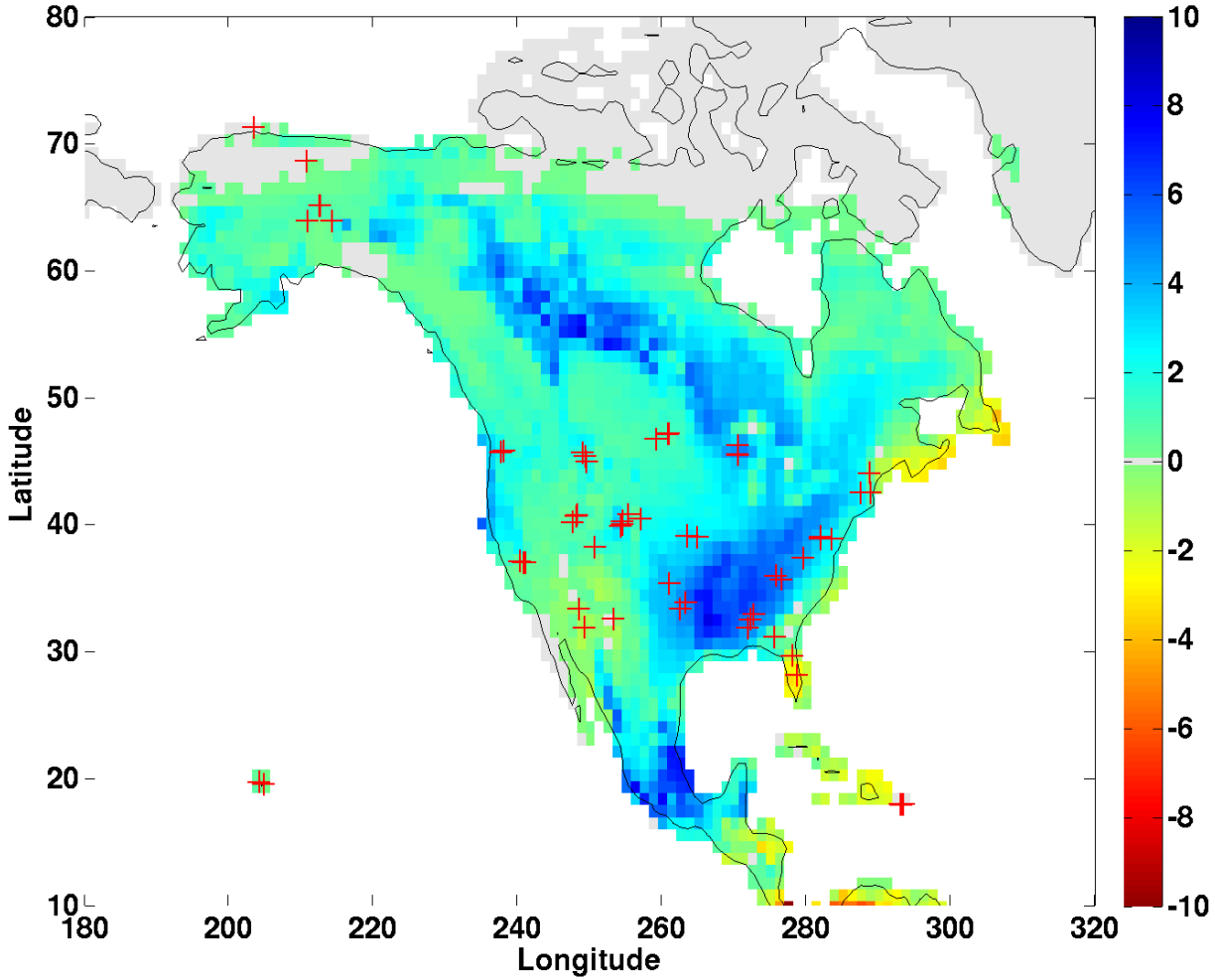
Impact on forecast - ΣNEP



Examples of N and C pools - unobserved



Mean NEP from 80 ensemble members



Change in NEP ensemble spread