Seasonal-interannual prediction of ecosystems and the global carbon cycle using NCEP/CFS

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Atmosphere

- Organic aerosol processes
- Cloud processes
- Photo-oxidant processes

Carbon Cycle
- CO₂
- Biological particles and VOC emissions
- Disturbances: Insect outbreaks

Water & Energy Cycles
- Latent and sensible heat
- Water vapor
- Precipitation and solar radiation

Nitrogen Cycle
- NOₓ
- NH₃
- Ozone and N deposition
- Agriculture

Gas/oil production

Water-limited Biosphere
Why predicting eco-CO2: targets

• Predicting atmospheric CO2 concentration and growth rate. Atmospheric CO2 can be a ‘climate index’ indicating anomalies in the global ecosystem

• Predict spatial patterns and temporal variability of carbon fluxes and pool size ➔ Example: biosphere productivity, fire, CO2 flux, crop harvest

• Stepping stone for Earth system analysis and modeling

• Including vegetation dynamics to improve short-term climate prediction, such as warm season US?

• In a carbon trading market, there will be a strong need for monitoring and anticipating the carbon pool changes
Foundation of dynamical eco-carbon prediction
CO2 as a “climate index”

- SOI

Lagged Correlations

3-6 months lag Hydrology/SOI
Corr = 0.6

Seasonal cycle:
Northern Hemisphere biosphere growth and decay

Interannual variability:
ENSO, drought, fire, Pinatubo
Seasonal-interannual CO2 variability is largely driven by climate variability: ENSO, Pinatubo, drought and other signals.
El Niño 97/98

VEGAS
(model driven by observed climate variability)

Inversion
Roedenbeck 2003
Seasonal-interannual Prediction of Ecosystems and Carbon Cycle

Made possible by two strands of recent research

• Significantly improved skill in atmosphere-ocean prediction system, such as NCEP/CFS and NASA/GMAO

• Development of dynamic ecosystem and carbon cycle models that are capable of capturing major interannual variabilities, when forced by realistic climate anomalies

A pilot hindcast study joint at UMD, NCEP and NASA:

Feasibility study using a prototype eco-carbon prediction system
dynamical vs. statistical

N. Zeng, J. Yoon, A. Vintzileos, G. J. Collatz, E. Kalnay, A. Mariotti,
A. Kumar, A. Busalacchi, S. Lord
The VEgetation-Global Atmosphere-Soil Model (VEGAS)

Atmospheric CO2

Photosynthesis

NPP = 60 PgC/y

Autotrophic respiration

Heterotrophic respiration

NEE = Rh – NPP = ± 3 (Interannual)

5 Plant Functional Types:
- Broadleaf tree
- Needleleaf tree
- C3 Grass (cold)
- C4 Grass (warm)
- Crop/grazing

Deciduous or evergreen is dynamically determined

5 Vegetation carbon pools:
- Leaf
- Root (fine, coarse)
- Wood (sapwood, heartwood)

6 Soil carbon pools:
- Microbial
- Litterfall: metabolic, structural
- Fast, Intermediate, Slow

Atmospheric CO2
The VEgetation-Global Atmosphere-Soil Model (VEGAS)

Gross Primary Productivity (GPP)

$C_{\text{leaf}} \ (1y)$

$C_{\text{wood}} \\{ \text{Sapwood (5y)}, \text{Heartwood (75y)} \}$

$C_{\text{root}} \\{ \text{Fine root (1y)}, \text{Coarse root (75y)} \}$

Autotrophic Respiration ($R_a$)

Heterotrophic Respiration ($R_h$)

$\text{CO}_2/\text{CH}_4$

Human Animals
Insects
Fungi
Microbes

Decomposers

$C_{\text{lmeta}} \ (0.5y)$

$C_{\text{sfast}} \ (1.5y)$

$C_{\text{smed}} \ (20y)$

$C_{\text{sslow}} \ (750y)$

Direct Oxidation (Fire)

$C_{\text{vege}} = C_{\text{leaf}} + C_{\text{woods}} + C_{\text{woodh}} + C_{\text{rootf}} + C_{\text{rootc}}$

$C_{\text{soil}} = C_{\text{lmeta}} + C_{\text{lstru}} + C_{\text{dcmp}} + C_{\text{sfast}} + C_{\text{smed}} + C_{\text{sslow}}$

Turnover

Erosion
Forecasting Procedure

CFS (9mon, 15 members)

VEGAS

Output
9mon, 15 members

Month 1

Climate Prediction
Spinup
Ecosystem+ Carbon Model

Predicted Eco-carbon

CFS (9mon, 15 members)

Precip Temp

Initialiation

1 mo forecast ensemble mean

Output
9mon, 15 members

Month 2
First look: Productivity (NPP)
Lead times: 1, 3, 6 months

High skills in
- South America
- Indonesia
- southern Africa
- eastern Australia
- western US
- central Asia
Summary of skill for anomaly correlation

Hydroeco/carbon has higher skill than the climate forcings!
Summary of skill for anomaly correlation

(a) Precipitation

(b) Fta
Beyond ENSO:
Drought during 1998-2002

(a) Fta anomaly (Validation)
(b) Fta anomaly (Hindcast L=6)
Fire carbon flux during 1997-98 El Nino

CASA (satellite fire, climate)

Input: satellite fire counts, climate

1997-98 El Nino Anomalies

CFire anomalies 7/97-8/98 minus 9700

VEGAS (climate only)

Input: climate only
Beyond ENSO: Fire in the US
Natural and anthropogenic factors

![Graph showing fire counts over time](image)
Pseudo-operational forecast
Can the drop be caused by reduced FFE due to economic downturn?

An 8% drop in GDP/FFE can explain only 0.05 GtC/y (P. Tans, 2010), too small

So, the model doesn’t get it?
Conclusions

• Ecosystem and carbon cycle prediction is feasible: encouraging results (better than expected)
• Memory in the hydro-ecosystem is important in the enhancement of skill
• several issues such as overestimation at mid-latitude regions

Some major development needs

• Initialization: eco-carbon data assimilation?
  Lack of global eco/carbon data
• Preprocessing/downscaling/postprocessing
• Dynamical + statistical
• Operational
Implications for climate service

• Applications to ecosystem and carbon cycle

• Identifying more clearly society-relevant aspects

• A useful framework for studying eco-carbon response and feedback to climate

• Identifying ways to incorporate eco-carbon dynamics in the next generation of climate prediction models (European GEMS)
Thank you!
Forecasting procedure II

- Ensemble mean

- $L=0$, $t-1$
- $L=1$, $t$
- $L=2$, $t+1$
- $L=3$
Implications of prediction

• Applications to ecosystem and carbon cycle

• A new framework for study eco-carbon response and feedback to climate

• Identifying ways of incorporating eco-carbon dynamics in the next generation of Earth system prediction models
Predicted global carbon flux ($F_{ta}$)

1. CFS/VEGAS captures most of the interannual variability, but
2. Amplitude is underestimated
The NCEP Climate Forecast System (CFS, Saha et al. 2006)

CFS captures major ENSO and other seasonal-interannual variability
Correlation .vs. Regression (Amplitude)
Benchmark Forecast:
Do we need dynamical forecast?

Relaxation or Damping of climate forcing Anomaly at L=0 will persist or damped to zero with decorrelation time scale.
Benchmark Forecast

![Chart showing standardized deviations and correlation for different models. The chart includes symbols for Dynamical, Persistence, Damping, and Initial Condition models, with labeled axes for standard deviations and correlation.]
The NCEP Climate Forecast System (CFS, Saha et al. 2006)

Fig. 2. Anomaly correlation (%) by various methods of the seasonal mean Niño-3.4 SST as a function of lead (horizontal; in months). The results are accumulated for all seasons in the (target) period DJF 1997/98 to DJF 2003/04. Except for CFS, all forecasts were archived in real time at CPC from 1996 onward. CMAP is the previous coupled model, CCA is canonical correlation analysis, CA is constructed analog, CONS is a consolidation (a weighted mean), and MARKOV is an autoregressive method (see text for references).
Benchmark Forecast
Do we need dynamic forecast system?

![Graph showing correlation over lead time (months)]
NEE (land-atmo C flux): VEGAS forced by observed climate (Precip, T)

This will be called ‘validation’ as there is no true observation available.

Ocean contribution smaller, so NEE can be compared with atmo CO2

Using regression of inversion/OCMIP with Nino3.4/MEI?
NEE('validation') and Inversion (from MPI)
First Steps

Analysis of CO2 record: ESRL + MODIS etc?

Forward models forced by a common climate data (P, T, …)

Emissions, ?

A web based forum?