A Global Vegetation Modeling System for NEWS

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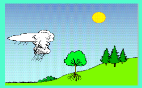
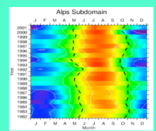
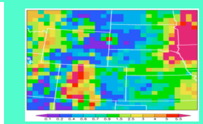


1. Hypothesis

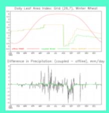
- Strong seasonal and inter-annual variability of leaf area index (LAI) and its vegetation-dependent spatial heterogeneity are observed.
- Including realistic description of heterogeneous vegetation phenology influences the seasonal climate prediction.
- Prognostic simulation of land-atmosphere interaction with respect to climate variability and change requires realistic representation of changing distributions of transpiring leaves in response to diurnal, seasonal, inter-annual, and longer-term changes in weather and climate.



Interannual and seasonal variability as observed in the 20-year period from 1982 to 2001 for Alps sub-domain. The black dashed line show the area-averaged start and end of the growing season. (Stockli and Vidale, 2004)



Derived LAI spatial distribution for Central U.S. for average year 1989. (Lu and Shuttleworth, 2002)



LAI response of CENTURY is different after harvest when run in coupled mode. The coupled model gives a response in modeled precipitation (Lu et al, 2001)

2. Objectives

Build a multi-scale vegetation modeling system with prognostic vegetation phenology that can address the strong spatial heterogeneity, the seasonal and inter-annual variability of vegetation distribution and its associated biophysical parameters (such as leaf area index) within the terrestrial water and carbon cycle.

3. Technical Approach and Methods

I. **Evaluate** existing vegetation modeling systems based on the biogeochemical models CLM3/CN/DGVM (NCAR) and SiB 2.5/3 (CSU) by using an integrative framework of ground-based (FluxNet, Phenology Networks, LTER sites) and satellite-based (MODIS, AVHRR) measurements: seasonal and inter-annual variation in predictions of leaf phenology and water, heat, momentum and carbon exchanges are assessed for the full range of global vegetation types. We'll first focus on process scales and aggregating to increasingly large area.

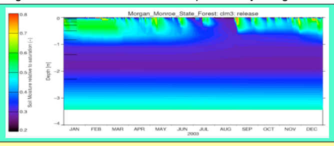
II. **Improve** the prediction of global leaf phenology by merging existing phenology schemes to a generally-applicable scheme. Train the phenology scheme parameters to hold for global applications by using satellite-derived vegetation indices and data assimilation approach (Ensemble Kalman Filters).

III. **Apply** the trained prognostic phenology scheme in both the coupled climate model (Community Climate System Model, CCSM) and the global operational offline land model (Land Information System). Test and provide this new model at global scale, and provide both the model and the results to the climate modeling community.

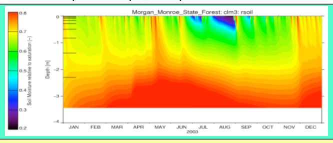
4. Results

4.1 Improving Hydrological Cycle in CLM3

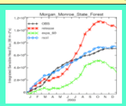
release: released CLM3 code;
expa_60: Gue-Yue Niu and Zong-Liang Yang's ground water treatment using seasonal soil water storage and ground water recharge;
rsoil: limiting CLM3's excessive bare soil evaporation by using Sellers' FIFE-derived soil resistance on top of the expa_60 improvements.

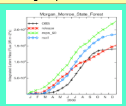


From released CLM3 code: rainfall events produce surface runoff but inhibit vertical soil water transfer, resulting impermeable dry layers in deeper soil.



rsoil version of the CLM3 hydrology improves the ground water treatment and soil resistance parameterization, allows effective vertical and later horizontal (Stockli) soil moisture transfer, and seasonal variations of ground water storage.

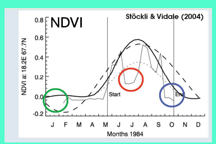




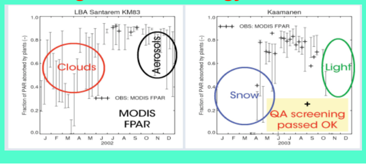
1. New hydrology schemes (version rsoil) of CLM3 improve surface fluxes prediction, especially during the dry season.
2. Higher infiltration and prognostic water storage lead to more latent heat flux during dry period.

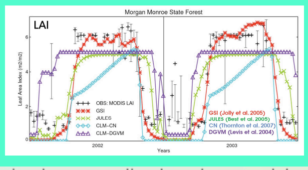
Discussion: 1) Can CLM3 roots use ground water? 2) Overestimate off-season ground evaporation.

4.2 Remote Sensing Data Assimilation to Improve a Prognostic Vegetation Phenology Model



Satellite Phenology
Benefits:
global, seasonal to interannual
Limitations:
Clouds, Aerosols, Snow, Sunlight, Gap-filling algorithm





Existing Phenology Models from empirical (GSI) to full BGC(CN) respond dynamically to climate variability, but not always consistent with satellite observations

A simple prognostic phenology model

$$GSI = f(VPD)\cdot f(T)\cdot f(R_g)$$

$$f(R_g) = \frac{R_g - R_{gmin}}{R_{gmax} - R_{gmin}}$$

$$f(T) = \frac{T - T_{min}}{T_{max} - T_{min}}$$

$$f(VPD) = 1 - \frac{VPD - VPD_{min}}{VPD_{max} - VPD_{min}}$$

Growing Season Index (GSI) Phenology Model Jolly et al. 2005

$$\Delta GSI = GSI - P$$

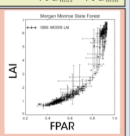
$$\frac{\partial P}{\partial t} = \gamma \cdot \Delta GSI \cdot P \cdot (1-P)$$

$$P_{t+1} = P_t + \frac{\partial P_t}{\partial t}\Delta t$$

Prognostic GSI Model -> FPAR and LAI

$$FPAR = \frac{P - FPAR_{min}}{FPAR_{max} - FPAR_{min}}$$

$$LAI = \frac{\ln(1 - FPAR/FPAR_{max})}{\ln(1 - FPAR_{sat})} LAI_{max} FPAR_{max}$$



Data assimilation framework (EnKF)

$x = (FPAR, LAI)$ — 2 States

$\theta = (\gamma, T_{min}, T_{max}, VPD_{min}, VPD_{max}, R_{gmin}, R_{gmax}, FPAR_{min}, FPAR_{max}, LAI_{max}, FPAR_{sat})$ — 11 Parameters

$u = (T, VPD, R_g) + \zeta, \quad \zeta \sim N(0, \Sigma^u)$ — 3 Forcings

$d = (FPAR, LAI) + \epsilon, \quad \epsilon \sim N(0, \Sigma^m)$ — 2 Obs Streams

Ensemble Kalman Filter (Evensen 2003)

$$\psi = f(x, u, \theta)$$

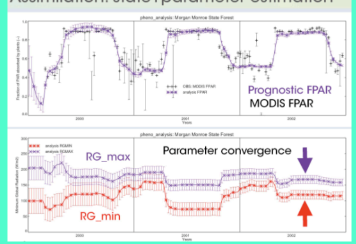
$$\mathbf{A} = (\psi_1, \psi_2, ..., \psi_N) \in \Re^{n\times N} \qquad n = 10 \text{ (state+parameters)}$$

$$\mathbf{D} = (d_1, d_2, ..., d_N) \in \Re^{m\times N} \qquad m = 49 \text{ (observations)}$$

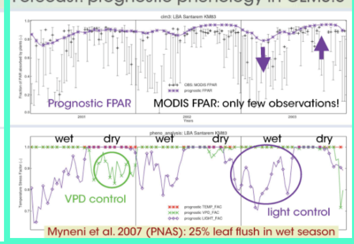
$$N = 1000 \text{ (ensemble size)}$$

$$\mathbf{A}^a = \mathbf{A}^f + \mathbf{K}(\mathbf{D} - \mathbf{H}\mathbf{A}^f)$$

Assimilation: state+parameter estimation



Forecast: prognostic phenology in CLM3.5



5. Conclusion and Outlook

- EnKF improves prognostic phenology model which inherits global statistics of satellite observations
- Need further quantification of uncertainty in satellite data: MODIS QA flags
- Deliverables & Outlook: 1) 1981-2007 phenological reanalysis dataset; 2) Prognostic phenology model for LSMs; 3) Use MODIS to constrain CLM-CN phenology parameters by PFT

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