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A Global, 1-km Vegetation Modeling System for NEWS
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Final Report

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Abstract

We have developed, parameterized, and evaluated, and published a global modeling system for simulating land-atmosphere exchanges of water, energy, and carbon that has been applied in a prognostic climate model (Community Climate Model, CCSM). The model is based on improvements to the Community Land Model (CLM3) with extensions for prognostic phenology, ecosystem competition, subgrid-scale water redistribution, and physiological stress. The model was parameterized using satellite products documenting fractional absorption of photosynthetically-active radiation (FPAR). Model evaluation at multiple spatial scales was performed using local measurements of micrometeorological fluxes and storage of water and carbon, stream discharge from instrumented catchments, and regional information about snow cover and water storage. The modeling system and related data sets was delivered to the CCSM community through structured collaborations, and to the larger climate modeling community through the peer-reviewed literature.

Background

Climate models simulate land-atmosphere interactions and require a realistic representation of changing distributions of transpiring leaves in response to seasonal, interannual, and longer-term changes in climate. Vegetation and climate interact dynamically therefore a two way coupling of phenological and physiological responses will lead to a better prediction of the terrestrial water cycle for short-term weather forecast, seasonal climate prediction and future climate change assessments.

Our aim was therefore to build and explore a vegetation modeling system which in particular includes the capability for prognostic vegetation phenology. The project explores the strong spatial heterogeneity, the seasonal and interannual variabililty of vegetation phenology and the associated biophysical parameters like the leaf area index within the terrestrial water and energy cycle.

Approach

The project involved the following steps:

1. **Evaluate** existing vegetation modeling systems based on the biogeochemical models CLM3/CN/DGVM (NCAR) and SiB 2.5/3 (CSU) by use of a integrative framework of ground-based (FluxNet, Phenology Networks) and satellite-based (MODIS, AVHRR) measurements: seasonal and interannual variation in predictions of leaf phenology and water, heat, momentum and carbon exchanges are assessed for the full range of global vegetation types.
2. **Improve** the prediction of global leaf phenology by merging existing phenology schemes to a generally-applicable scheme. Train the phenology scheme parameters so that they hold for global applications by using satellite-derived vegetation indices and data assimilation approach (Ensemble Kalman Filter).
3. **Apply** this prognostic phenology scheme in a coupled climate model (Community Climate System Model, CCSM). Test and provide this new model on global scale and provide both the model and the results to the climate modeling community.

Accomplishments

1. Linking land surface models, remote sensing and ecosystem observations

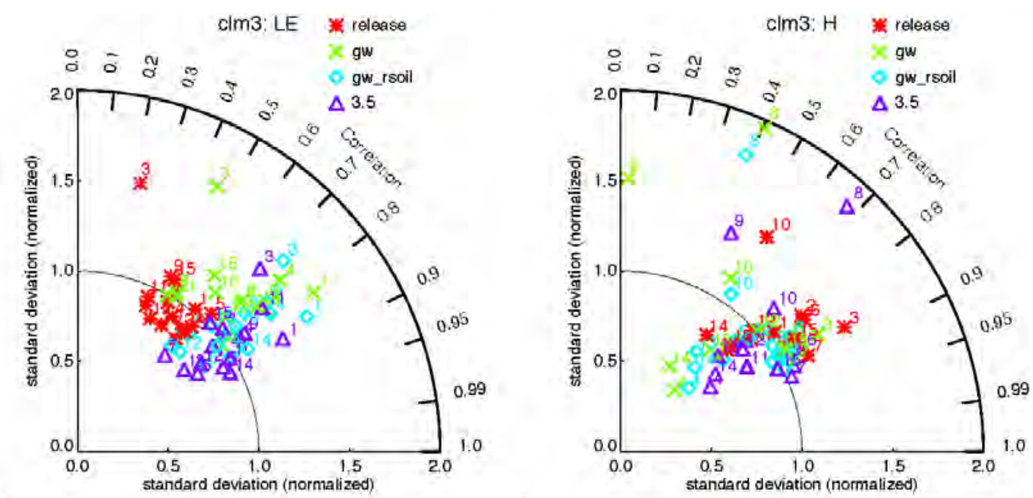
The Community Land Model Version 3 using prognostic phenology (DGVM, and CN) has been integrated into a land surface modeling framework (Model Farm) which now includes six LSM's of three model generations (Bucket, BATS 1E, SiB 2/2.5/3, TERRA, CLM3 and JULES), around 70 Ameriflux, 65 CarboEurope, and 8 LBA flux towers with multi-year observations, and four global satellite-based diagnostic phenology datasets (EFAI-NDVI, GIMMSg, FASIR-NDVI and MODIS). This framework allows the offline evaluation of model performance against measured phenology and surface turbulent fluxes at wide range of vegetation types as covered in a global coupled climate model simulation.

2. Improving the hydrological cycle of land surface models

The evaluation of CLM 3 using the above framework revealed shortcomings in the representation of the seasonal and interannual heat and water exchange processes for tropical and semi-arid climates. In collaboration with our research collegues from NCAR (Gordon Bonan, Samuel Levis, Keith Oleson, Dave Lawrence and Peter Thornton), University of Texas (Robert Dickinson,Guo-Yue Niu, Zong-Liang Yang), we successfully solved numerical and physical issues in CLM's soil hydrology. A number of parameterizations from SiB have already been or are going to be integrated in CLM (e.g. soil resistance and prognostic canopy air space). Both schemes, CLM and SiB are also updated with a prognostic ground water table (Guo-Yue Niu) and TOPMODEL-based subgrid-scale lateral soil water fluxes. Model improvements were evaluated against a suite of eddy covariance data collected in North America, Europe, and Brazil (Table 1). The improved model was found to exhibit dramatically improved correlation to variations in water and energy fluxes (Stockli et al, 2008a; Figure 1).

Table 1. Flux Towers used in this study. Biome types: mixed forest (MF), evergreen needleleaf forest (ENF), deciduous broadleaf forest (DBF), tundra (TUN), evergreen broadleaf forest (EBF), grasslands (GRA)

No.	Site	Lon [°E]	Lat [°N]	Altitude (Mesurement height) [m]	Biome type	Soil type	Years	Climate zone
				CarboEurope				
1	Vielsalm	6.00	50.30	450 (40)	MF	loam	1997–2005	Temperate
2	Tharandt	13.57	50.96	380 (42)	ENF	loam	1998–2003	Temperate
3	Castel Porziano	12.38	41.71	68 (25)	EBF	loamy sand	2000–2005	Mediterranean
4	Collelongo	13.59	41.85	1550 (32)	DBF	silt loam	1999–2003	Mediterranean
5	Kaamanen	27.30	69.14	155 (5)	TUN	loam	2000–2005	Arctic
6	Hyytiälä	24.29	61.85	181 (23)	ENF	loamy sand	1997–2005	Boreal
7	El Saler	-0.32	39.35	10 (15)	ENF	loamy sand	1999–2005	Mediterranean
				LBA				
8	Santarem KM83	-54.97	-3.02	130 (64)	EBF	sandy clay	2001–2003	Tropical
9	Tapajos KM67	-54.96	-2.86	130 (63)	EBF	sandy clay	2002–2005	Tropical
				Ameriflux				
10	Morgan Monroe	-86.41	39.32	275 (46)	DBF	clay loam	1999–2005	Temperate
11	Boreas OBS	-98.48	55.88	259 (30)	ENF	clay loam	1994–2005	Boreal
12	Lethbridge	-112.94	49.71	960 (4)	GRA	silt loam	1998–2004	Boreal
13	Fort Peck	-105.10	48.31	634 (4)	GRA	sandy loam	2000–2005	Temperate
14	Harvard Forest	-72.17	42.54	303 (30)	DBF	sandy loam	1994–2003	Temperate
15	Niwot Ridge	-105.55	40.03	3050 (26)	ENF	clay	1999–2004	Sub-alpine



a) b)

Figure 1. Performance of four CLM3 model versions at 15 Fluxnet towers (numbers 1-15). Statistics in the Taylor diagram are derived from hourly simulated and observed LE and H fluxes. Legend: observations: black plus signs; release code: red asterisks; gw code: green crosses; gw_rsoil code: cyan diamonds; final 3.5 code: violet triangles. In the release code H is off-scale for the two tropical sites 8 and 9 (and therefore not shown).

3. NASA's EOS satellite phenology assimilation

Direct use of MODIS phenology products (e.g., FPAR/LAI) into vegetation and climate models can lead to pathological representation of seasonal and interannual variations due to interference from clouds, atmospheric aerosol, or snow (Fig 2). We therefore developed a system for assimilation of these data into a prognostic model of leaf area using an Ensemble Kalman Filter (EnKF).

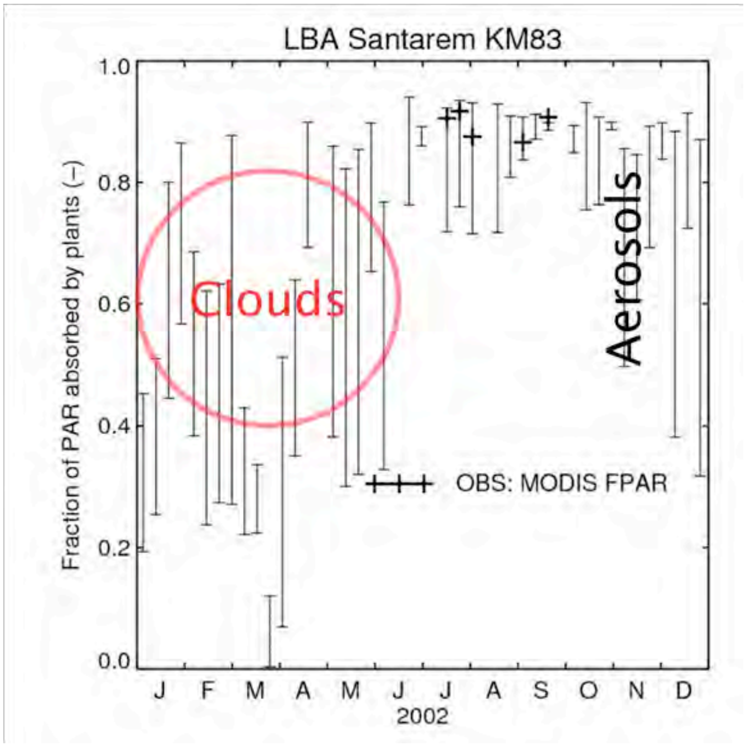


Figure 2: Seasonal variations of FPAR derived fromMODIS data for a tropical forest pixel near Santarem, Brazil. Local observations show almost no seasonal variation, but satellite data are heavily impacted by clouds and smoke aerosol.

Assimilating MODIS LAI/FPAR (2000-2006) and AVHRR LTDR NDVI (1981-1999), the vegetation states and parameters are estimated jointly, and the spatial and temporal statistics of observed global satellite phenology are incorporated into our process-based phenology model (Stockli et al, 2008b; Fig 3). The strict quality filtering and uncertainty estimation are performed for MODIS/AVHRR data before data assimilation. This method overcomes limitation of "interpolation" methods for satellite phenology (e.g. TimeSat, BISE, FASIR etc.), and predicts future vegetation dynamics. This prognostic phenology scheme is generally applicable for any LSM; it performs better than many current phenology models including IBIS, LPJ, TRIFFID.

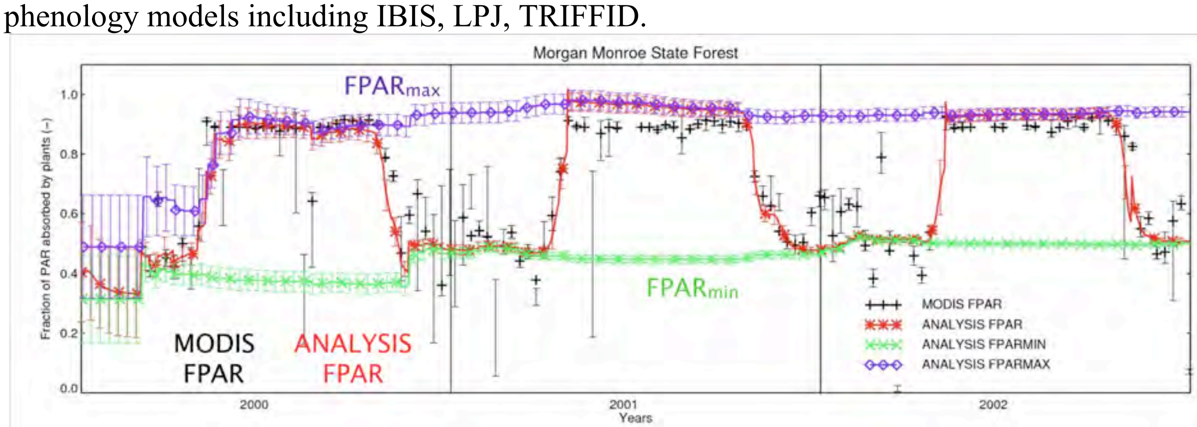


Figure 3: Joint parameter and state estimation by Ensemble Kalman Filter in the prognostic phenology model using MODIS data. Stockli et al (2008b).

4. Evaluating observed and modeled phenology

The prognostic phenology schemes in CLM's DGVM and CN were evaluated at flux tower sites (Stockli et al, 2008b; Fig. 4) with the following results:

- The two prognostic schemes have a similar timing of leaf-out and senescence like the diagnostic satellite phenology for a temperate deciduous forest
- Boreal evergreen forest in DGVM has a large seasonal cycle due to the inclusion of understory PFT's (plant functional types), while CN keeps the LAI approximately constant (single PFT). During the growing season they match well with the observation. Satellite LAI is more similar to the DGVM LAI since both integrate multiple PFTs.
- Tropical evergreen and Mediterranean phenology agree poorly between models and observations, potentially due to the poor representation of drought in the prognostic schemes but also due to large uncertainties in the satellite observations.
- Simulated heat and water fluxes were less susceptible to drought when either the CN or DGVM prognostic phenology scheme was used compared to simulations with prescribed (diagnostic) phenology.

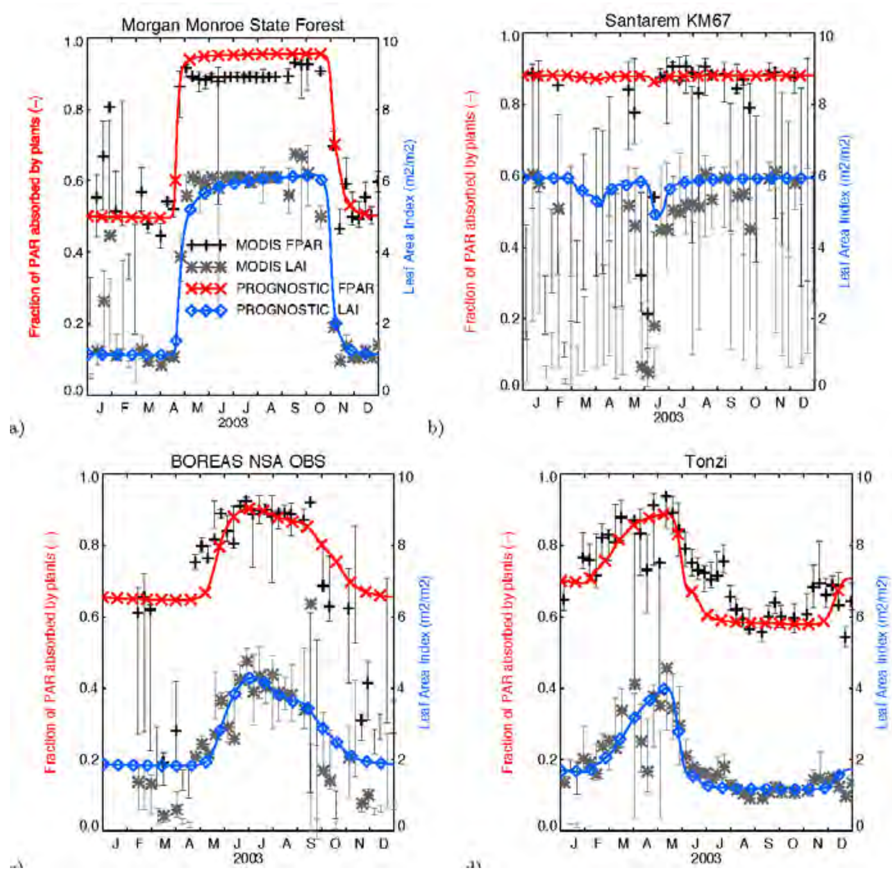


Figure 4: Prognostic phenology compared to MODIS data for four eddy covariance sites (a) temperate deciduous, (b) tropical evergreen), (c) boreal evergreen, (d) Mediterranean drought-deciduous (Stockl et al (2008b).

The prognostic phenology was also evaluated by comparison to a 50-year phonological record for a forest in Switzerland, far beyond the satellite record used to derive the parameters (Fig 5). Correlation with observed start-of-season was excellent, and shows that the model may be used for prognostic leaf area for either retrospective or future climate simulations.

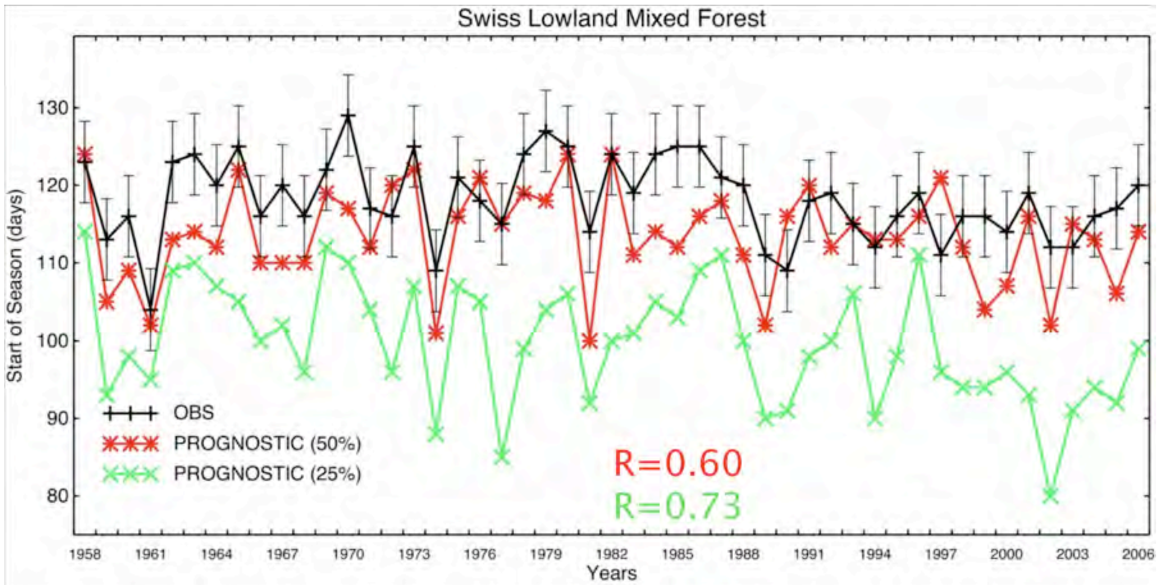


Figure 5: Simulated and observed beginning of growing season from 1957 through 2006 for a phenological field site in a Swiss forest, 1957-2006. The prognostic start-of-season can be defined when leaf area reaches 25% or 50% of its maximum.

Presentations

Stockli, R., Lixin Lu, A.S. Denning, and P. Thornton (April 15, 2007): "Remote Sensing data assimilation for a prognostic model of vegetation phenology", Annual Meeting of the European Geophysical Union, Vienna, Austria.

Lu, L., R. Stockli, and A.S. Denning, 2007: Remote Sensing data assimilation for a prognostic vegetation-phenology model. NASA NEWS PI meeting, September 18-21, 2007, NASA Marshall Space Flight, Center, Huntsville, Alabama.

Stockli, R., T. Rutishauser, L. Lu, A.S. Denning, and P. Thornton, 2007: Remote Sensing data assimilation for a prognostic phenology model. December 10-14, 2007, Fall AGU, San Francisco, CA

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Denning, A. S., R. Stockli, and L. Lu, 2008. Remote Sensing Data Assimilation for a Prognostic Phenology Model. NASA NEWS PI Meeting, November 4, 2008, Baltimore, MD.

Publications

Stockli, R., P. L. Vidale, A. Boone, and C. Schaar (2007), Impact of scale and aggregation on the terrestrial water exchange: integrating land surface models and Rhône catchment observations., J. Hydrometeorol., 8(5), 1002–1015.

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Improvements to the Community Land Model and their impact on the hydrological cycle, J. Geophys. Res., 113, G01021, doi:10.1029/2007JG000563.
Stockli, R., D. M. Lawrence, G.-Y. Niu, K. W. Oleson, P. E. Thornton, Z.-L. Yang, G. B. Bonan, A. S. Denning, and S. W. Running, 2008. The use of Fluxnet in the Community Land Model development. *Jour. Geophys. Res.*, **113**, G01025, doi:10.1029/2007JG000562.
Stockli, R., T. Rutishauser, D. Dragoni, P. E. Thornton, L. Lu, and A. S. Denning, 2008. Remote sensing data assimilation for a prognostic phenology model. *Jour. Geophys. Res*. **113**, G04021, doi:10.1029/2008JG000781.