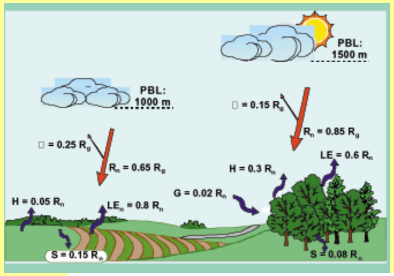
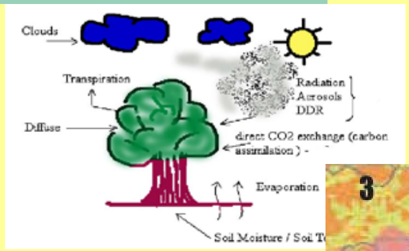
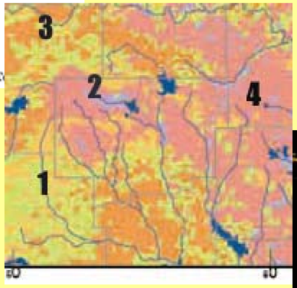
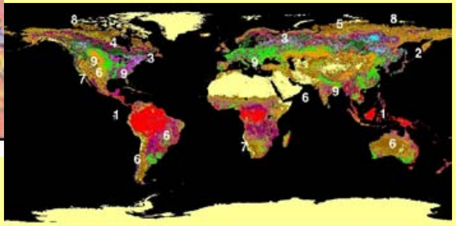
INTEGRATED REGIONAL CLIMATE STUDY WITH A FOCUS ON THE LAND-USE LAND-COVER CHANGE AND ASSOCIATED CHANGES IN HYDROLOGICAL CYCLES IN THE SOUTHEASTERN UNITED STATES

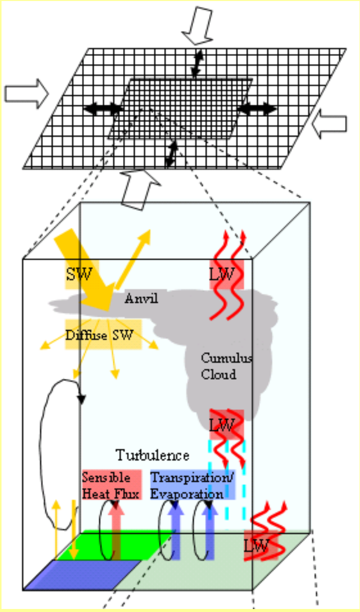
Dev Niyogi
Dept. of Marine, Earth, Atmos. Sciences
N. C. Agricultural Research Services
North Carolina State University
Raleigh, NC 27695

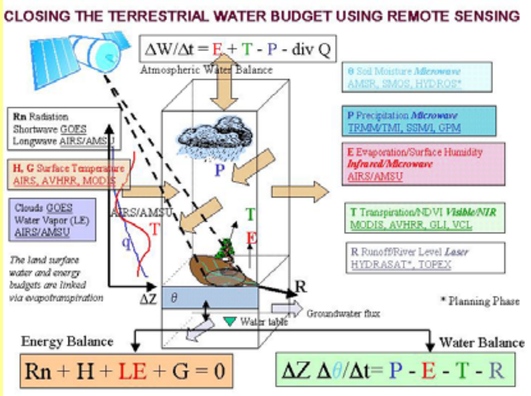












INTEGRATED REGIONAL CLIMATE STUDY WITH A FOCUS ON THE LAND-USE LAND-COVER CHANGE AND ASSOCIATED CHANGES IN HYDROLOGICAL CYCLES IN THE SOUTHEASTERN UNITED STATES

Collaborative, interdisciplinary project to resume under IDS

Roger Pielke Sr.[1]

Christian Kummerow[1]

Toshihisa Matsui[1]

Michael B. Coughenour[2],

[1]Dept. Atmos. Sci.,

[2]Natural Resources Lab.

Colorado State University

Dev Niyogi

Souleymane Fall

Hsin-I Chang

Dept. MEAS,

NC Ag Research Serv.,

North Carolina State University

Introduction….

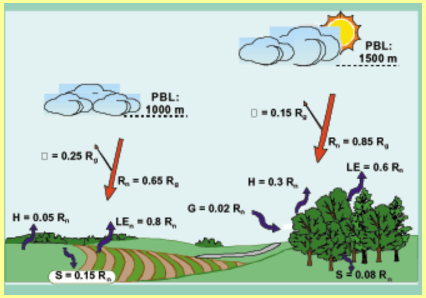
Study LULC/ biospheric processes in weather and climate models under effect of different forcings simultaneously

General Questions

- What are the different biogeophysical processes that are critical for environmental problems affecting life and economy at short term (few hours) to a long term (decades)?
- How can these processes be integrated in the environmental studies ranging from short term weather forecasting to long lead climate assessments?'

- Example Publications …
- The Influence of Land-Use Change and Landscape Dynamics on the Climate System – Relevance to Climate Change Policy Beyond the Radiative Effect of Greenhouse Gases, *Philosophical Transactions Royal Society London A: Mathematical, Physical & Engineering,* vol 360, 1705 – 1719.
- The climatic impacts of land surface change and carbon management, and the implications for climate -change mitigation policy, *Climate Policy*, 3, 149 - 157.

IDS LCLUC /Hydrology Project Objectives

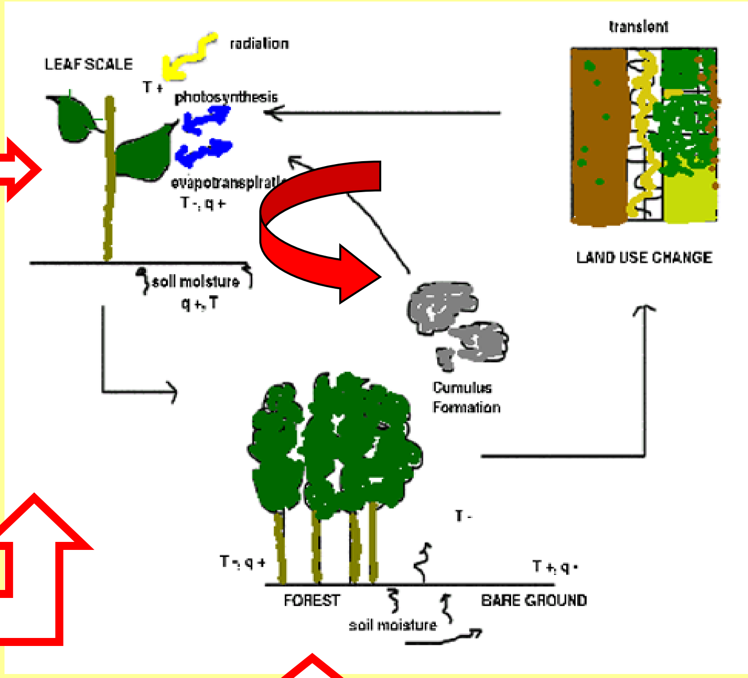


- Variability in surface latent heat flux (evaporation and transpiration) and hence the regional hydrological cycle
  - Variability due to LCLUC, cloud-precipitation process, and terrestrial ecosystem processes
  - Examine the individual, as well as the combined effect
  - Investigate the feedbacks under drought and non-drought conditions
  - Use detailed process models, remote-sensed satellite data and products

Coupled Terrestrial Biosphere Atmosphere Interactions

$Qnet = H + LE + G$

$Qnet = SW\,(1-\alpha) + (1 - \varepsilon)\,LW + \sigma.\varepsilon.T^4$



Albedo, emissivity change with LULC, surface

SW, LW change as coupled feedbacks

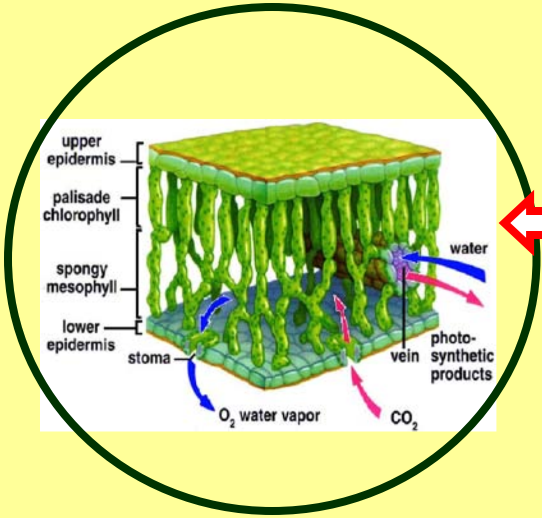
=> Need for a coupled, integrative analysis

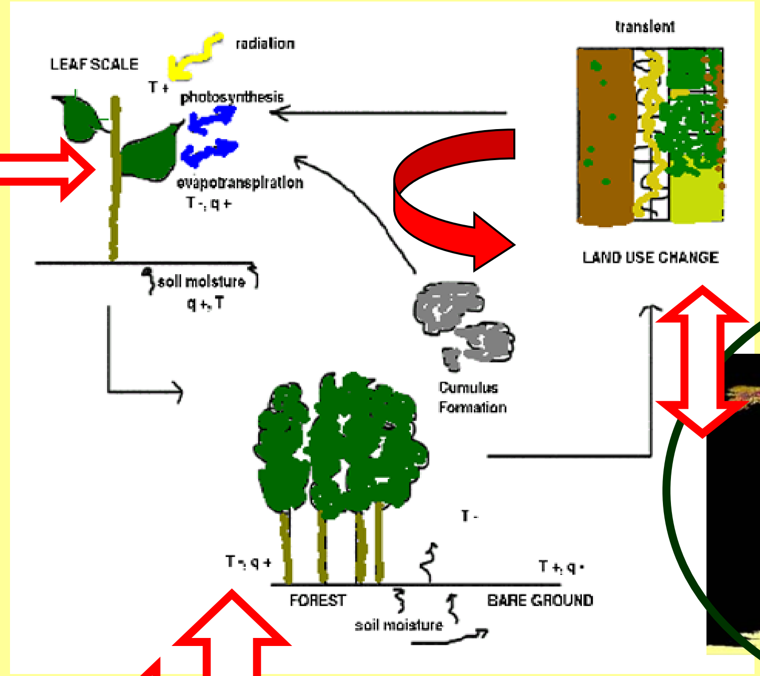
LCLUC feedbacks are coupled at different spatial and temporal scales

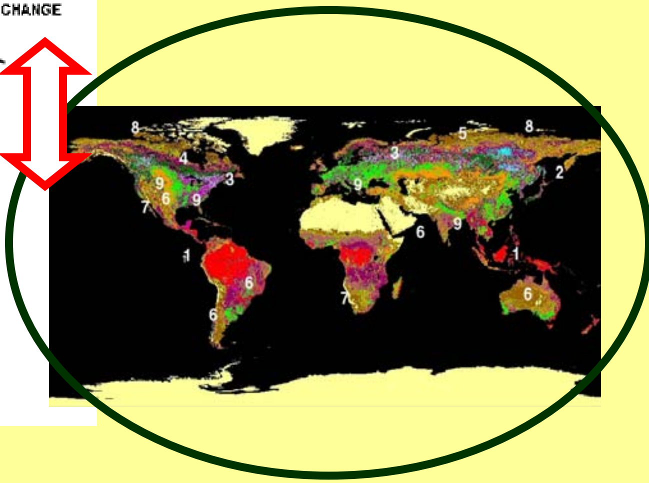
Land use Land Cover Change as a Hydrological and Climate Change Driver

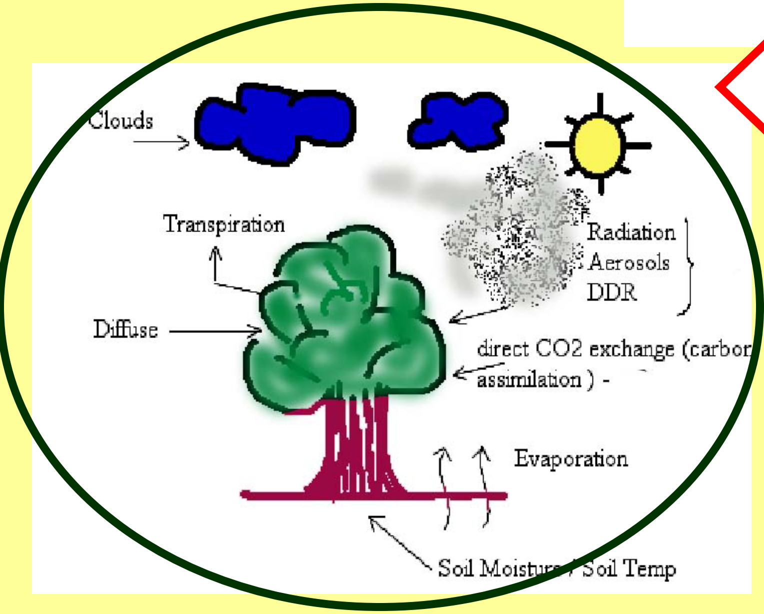
Why Feedback Scenarios are CRITICAL?

- Logical / Process Flow....
- LULC Change (albedo, vegetation characteristics)
- Leads to Surface Energy Balance Change
- Leads to surface temperature changes
- Associated with evapotranspiration and surface hydrological changes
- Leads to terrestrial NPP / carbon assimilation rates
- Leads to vegetation characteristics / LULC changes
- Go to 1......





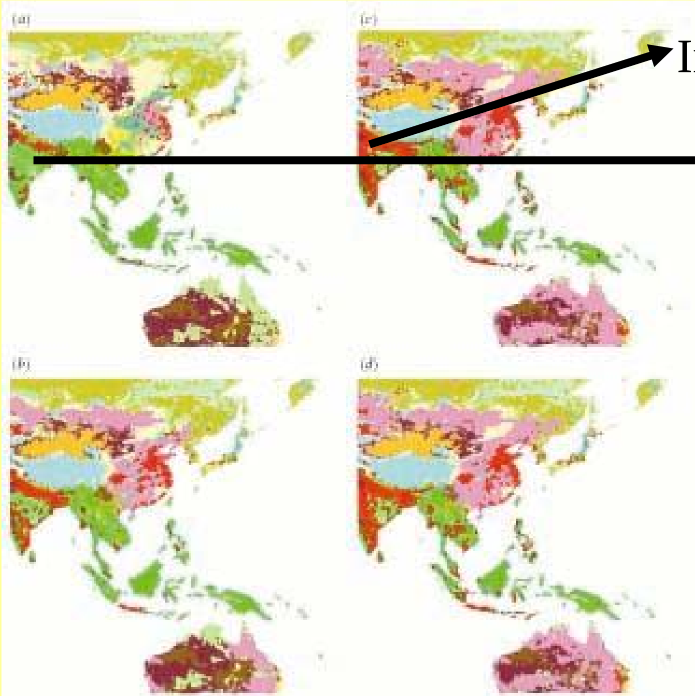




Coupled Feedback are important from leaf to landscape to a continental scale.

LCLUC affects regional and global climate

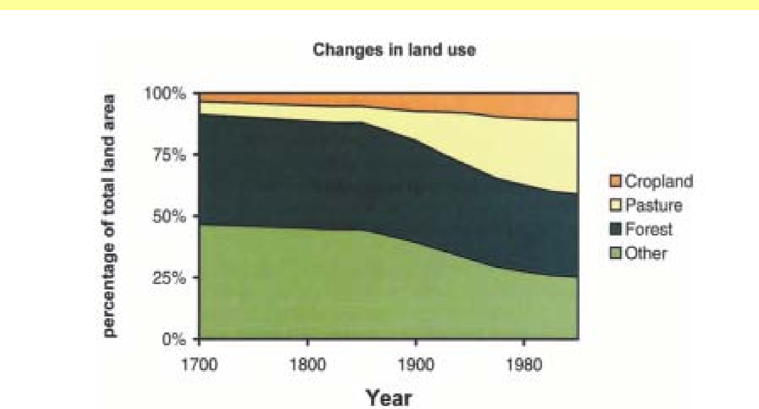
1700 1900



Intensive Crop Land

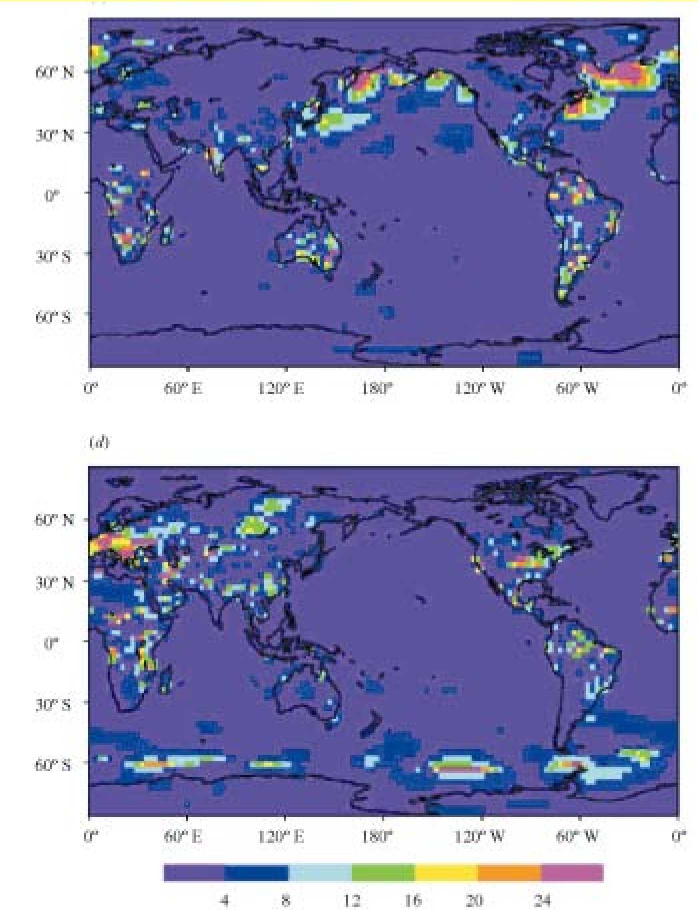
Mixed Forest Grassland, Agriculture

1970 1990

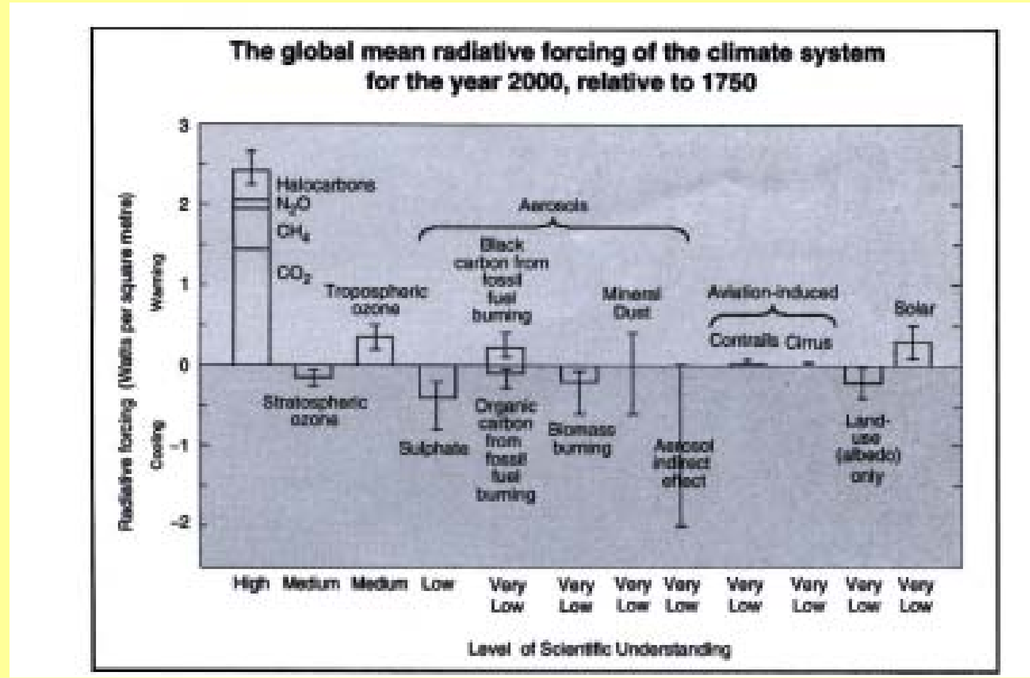


Reduction in rainforest and moist deciduous forest from 1981 - 1990

country	rainforest extent in 1990 (kha)	decrease 1981–1990 (%)	moist deciduous forest extent in 1990 (kha)	decrease 1981–1990 (%)
Brazil	291 597	6	197 082	16
Indonesia	93 827	20	3 366	20
Dem. Rep. Congo (Zaire)	60 437	12	45 209	12
Columbia	47 455	6	4 101	38
Peru	40 358	6	12 299	6
Papua New Guinea	29 323	6	705	6
Venezuela	19 602	14	15 465	36
Malaysia	16 339	36	0	0
Myanmar	12 094	24	10 427	28
Guyana	11 671	0	5 078	6
Suriname	9 042	0	5 726	4
India	8 246	12	7 042	10
Cameroon	8 021	8	9 892	12
French Guiana	7 993	0	3	0
Congo	7 667	4	12 198	4
Ecuador	7 150	34	1 669	34
Lao People's Dem. Rep.	3 960	18	4 542	18
Philippines	3 728	62	1 413	54
Thailand	3 082	66	5 232	54
Vietnam	2 894	28	3 382	28
Guatemala	2 542	32	731	0
Mexico	2 441	20	11 110	30
Belize	1 741	0	238	0
Cambodia	1 689	20	3 610	20
Gabon	1 155	12	17 080	12
Central African Republic	616	14	28 357	8
Cuba	114	18	1 247	18
Bolivia	0	0	35 582	22



10-yr avg SHF changes as a result of land use change. Jan (top); July (bottom)



The only effect of LCLUC used in Climate Assessment is related to the Thermal (albedo) feedback.

Hydrological Feedbacks are even more profoundly important.

OUTSTANDING SCIENCE QUESTION

How does the change in radiative forcing associated with the LCLUC and cloud radiative-precipitation process affect the terrestrial biogeochemical, the hydrological cycles, and the surface energy budget?

Focus is on Southeastern US

(i) Historical changes in LULC and associated plant canopy density are significant and well documented

(ii) seasonal biogeochemical cycles (e.g., over deciduous forest) are large and significantly affect the surface physical process

(iii) Plant phenological cycles have been monitored for a long term by satellites and ground observations, which allow us to implement an extensive calibration/validation work for the regional climate modeling as well as the remote sensing algorithm

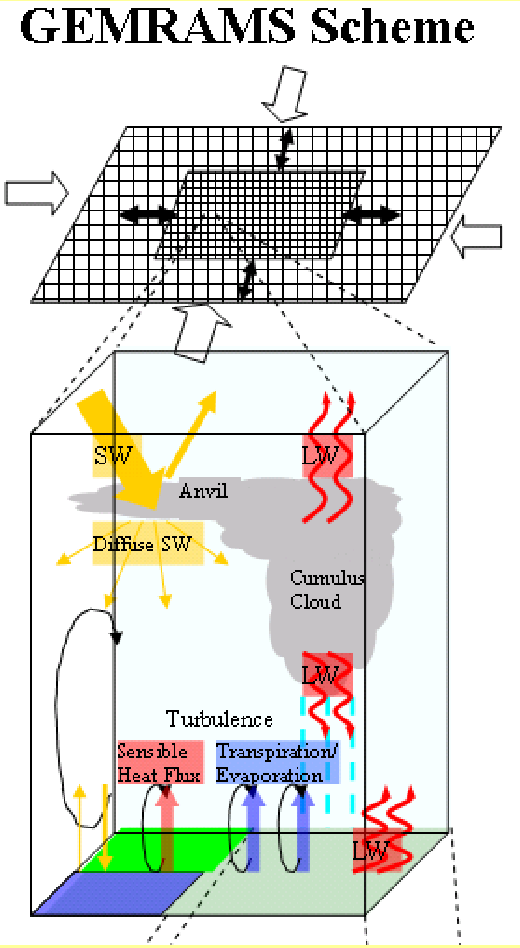
(iv) Different seasonal and interannual hydrological cycles, under drought and non-drought conditions, affect the regional agricultural productivity and economy,

(v) The region has relatively high temporal and spatial resolution remotely-sensed data sets (e.g., TRMM) with relatively less interference from topographical variability

Remotely-sensed satellite datasets to be used in the research

Satellite	Sensors	Data	Spatial / Temporal Scale	Reference Algorithm	Organization
TRMM (1998~)	VIRS	Cloud mask , Atmospheric Optical Depths	2 km / daily and monthly	Minnis et al. 1999 Roger and Vermote 1997	**DAAC
	TMI/PR	Precipitation latent heat flux	0.5 degree / daily and monthly	Tao et al. 2001a,b	NASA GSFC
	PR/TMI	Soil moisture index	0.25 degree daily	Oki et al. 2000 Bindlish et al. 2003	Tokyo Univ. USDA
TERRA (2000~)	MODIS	LAI, albedo	0.05 -0.25 degree 16day - monthly	Myneni et al., 2002	EOS U. of Boston
	CERES	Net radiation SRF, OLR	2.5 degree/ daily and monthly	Wielicki et al. 1996	NASA Langley
NOAA (1980~)	AVHRR	LAI ,Albedo	8 km /bi-weekly, monthly	GIMMS	U. of Boston

Additionally, the coupled model system uses several 'default' datasets for soils, landuse, biophysics, LDAS products.



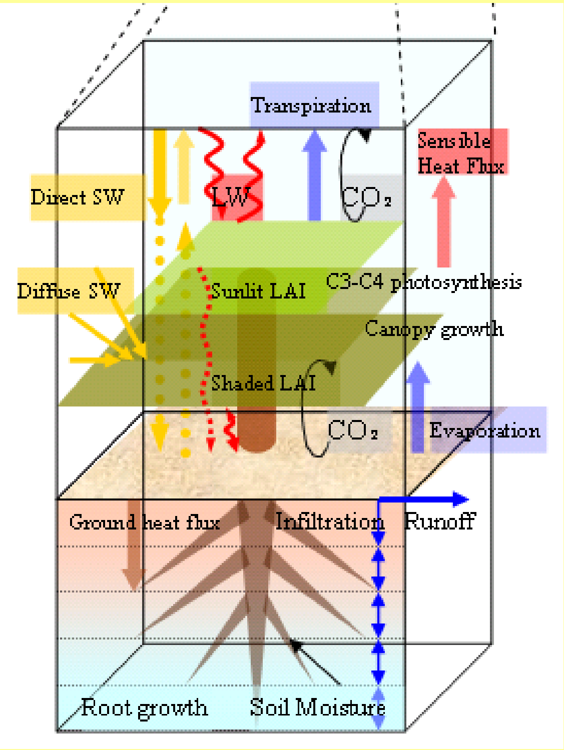
Coupled Modeling System

-GEMTM and RAMS based

-Several interactive processes

-Surface and satellite data ingestion

-Process based assessment possible



Matrix of supplementary data sites that can be analyzed for insitu / surface validation

Land Cover Classes	Coverage over SE US (sq.mi, %)	Representative AmeriFlux Site	Flux Data	Soil Data	Diffuse radiation	AERO-NET Site
Deciduous Forest	59172, 21%	TN Walker Branch Watershed, Oak Ridge 35 57' N, 84 17' W	1995-1999	1995-1999	1995-1999	Walker_ Branch
Evergreen Forest	57434, 20%	NC Duke Forest - loblolly, Durham36N, 79W	1997-2002	1997-2002		
		FL Gainesville (Austin Carey) slash/longleaf pine 30N,82W	1998-2000	1998-2000		Okefenokee NWR
Mixed Forest	35536, 12.5%	TN Walker Branch Watershed, Oak Ridge 35 57' N, 84 17' W	1995-1999	1995-1999	1995-1999	Walker_ Branch
Row Crops	33640, 12%	IL Bondville, Illinois 40 N, 88 17.512' W	1996-2002	1996-2002	1995-2002	Bondville
Woody Wetlands	31829, 11%	FL Gainesville - cypress wetland 30N,82W				Okefenokee NWR
Mixed Forest	35536, 12.5%	WI Park Falls 35.57N, 84.17W	2000-2002	2000-2002	2000-2002	Chequamegon
Temperate Forest	31829, 11%	WI Willow Creek, 45N, 90W	2000-2002	2000-2002	2000-2002	Chequamegon
Grassland/ herbaceous	5580, 2%	MO Fort Peck, 48N, 105W	1999-2002	1999-2002	1995-2002	

- Six sites available that have information on optical depths, latent heat flux, radiation for calibration and algorithm testing

Willow Creek, WI

Lost Creek, WI

(mixed forest,00,01)

Ponca, OK

(wheat 98,99)

Bondville, IL (agriculture, C3 / C4, 98-02)

Barrow, AK (grassland 99)

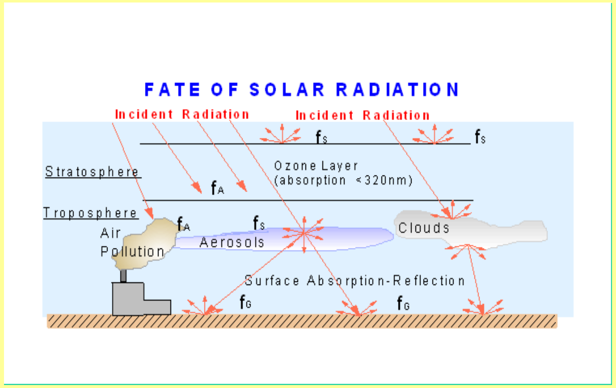
Walker Branch, TN (mixed forest 2000)

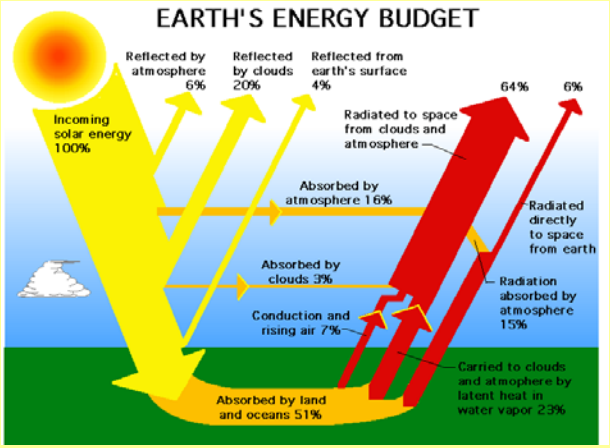
Task 1 Calibration/Evaluation of Biogeochemical Process in the GEMRAMS Model

- How are regional water cycles responding to the variation of radiative forcing under cloud cover?

- What is the effect of the variation in the radiative forcing on plants and regional landscapes regulated by the soil moisture anomalies?

Clouds – Radiation – LULC – Hydrology Feedback

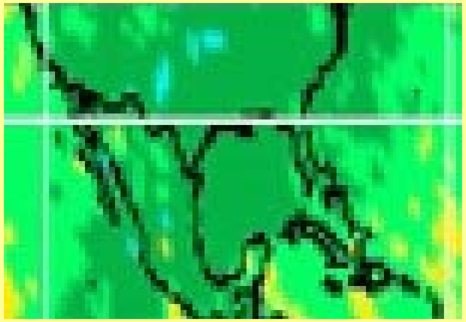




The main reason cloud- radiation interactions impact hydrology is due to changes in the radiative forcing.
Total solar radiation = Diffuse solar radiation+Direct solar radiation

For increased Cloud Cover or increased cloud optical depth,
Diffuse Component Increases. This changes the DDR (Diffuse to Direct Ratio) of Radiation.

We hypothesize that,
increase in the DDR will impact the Terrestrial Land surface Processes, Water Cycle through Transpiration and Evaporation flux changes.



Mean April Cloud droplet effective radius in 1998, derived from TRMM VIRS (Source: Minnis et al. 1999)

CDER = Ratio of third to second moment of droplet size

South – Southeastern US has high concentration due to CCN availability

8.0 km 5.0 km 2.0 km

Monthly mean atmospheric latent heating at 8 km, 5 km and 2 km AGL, derived from Goddard Convective-Stratiform Heating (CSH) algorithm using the TRMM products . (Tao et al. 2001a).

CCN (aerosols, haze,...), clouds each affect the characteristics of global radiation (increase diffuse radiation fraction, ...)

<u>Coupled feedbacks are still active</u>

Process Flow

- How are regional water cycles responding to the variation of radiative forcing under cloud cover?

1.1 Establish relationship between the MODIS LAI and albedo product for each vegetation type

1.2 Compute the top-of-canopy albedo as a function of LAI for each vegetation type via a multi-canopy radiative transfer model in GEMRAMS

1.3 Compare 1.1 and 1.2 to calibrate the GEMRAMS biophysical configuration.

Process Flow

•What is the effect of the variation in the radiative forcing on plants and regional landscapes regulated by the soil moisture anomalies?

2.1 Examine the sensitivity of the surface radiative feedback including sunlit and shaded LHF calculations under clear, hazy, and cloudy conditions.

2.2 Separately test effect of ambient temperature and relative humidity on the vegetation's productivity

2.3 Repeat sensitivity under drought and non-drought situations.

Task 2 Evaluation of the Cloud-Radiative and Precipitation Process in the GEMRAMS

- What is the impact of introducing a modified Kain-Fritsch convection parameterization embedded with a fairly sophisticated two-way radiation scheme?

- How well do microphysics represent shortwave cloud radiative forcing?

Process Flow

•Month- to season-long control simulations in both a wet and dry year to evaluate/calibrate

i) precipitation and ensuing diabatic latent heating, and
ii) CDER and associated shortwave CRF

**Though Kain-Fritsch convection scheme has been used and tested in coupled models; its use application embedded with the explicit microphysics to predict cloud droplet effective radius (CDER) and associated shortwave CRF has not been done.

Task 3 GEMRAMS sensitivity experiments

•How do local LCLUC scale-up to affect the regional climate and hydrological cycle?

•How do cloud radiation-precipitation processes feedback with respect to LCLUC?

•How does the presence of drought and non-drought conditions affect the results for above two questions?

Process Flow

- Investigate the seasonal “evaporation-minus-precipitation” to examine the regional hydrological cycles and water recycling

- Evaluate seasonal net radiation that is accompanied by the changes in surface albedo and shortwave CRFs, and

- Review seasonal green LAI (or NPP) for better understanding of important changes in terrestrial ecosystems as they respond to the integrated effects of multiple stressors.

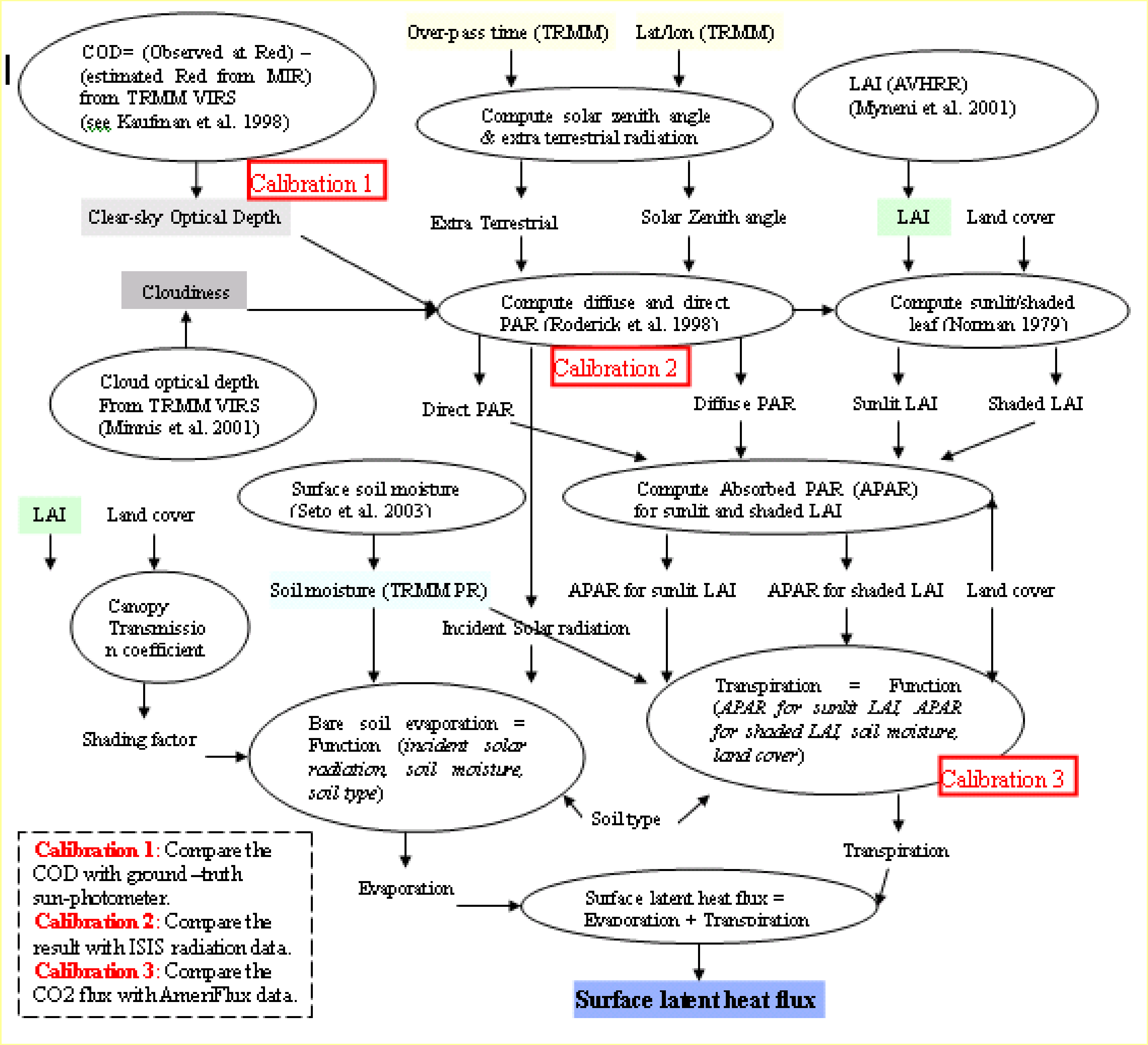
Task 4 Mapping and Retrieval Algorithm for Surface Latent Heat Flux from Multi TRMM products

- Calibration and evaluation with surface cloud optical depth measurements using sun photometers (AERONET)

- Calibration and evaluation with surface radiation data (CERES, ISIS)

- Calibration and evaluation with surface latent heat flux observations (AmeriFlux, Fluxnet)

Retrieval Algorithm for Surface Latent Heat Flux Mapping from Multi TRMM products

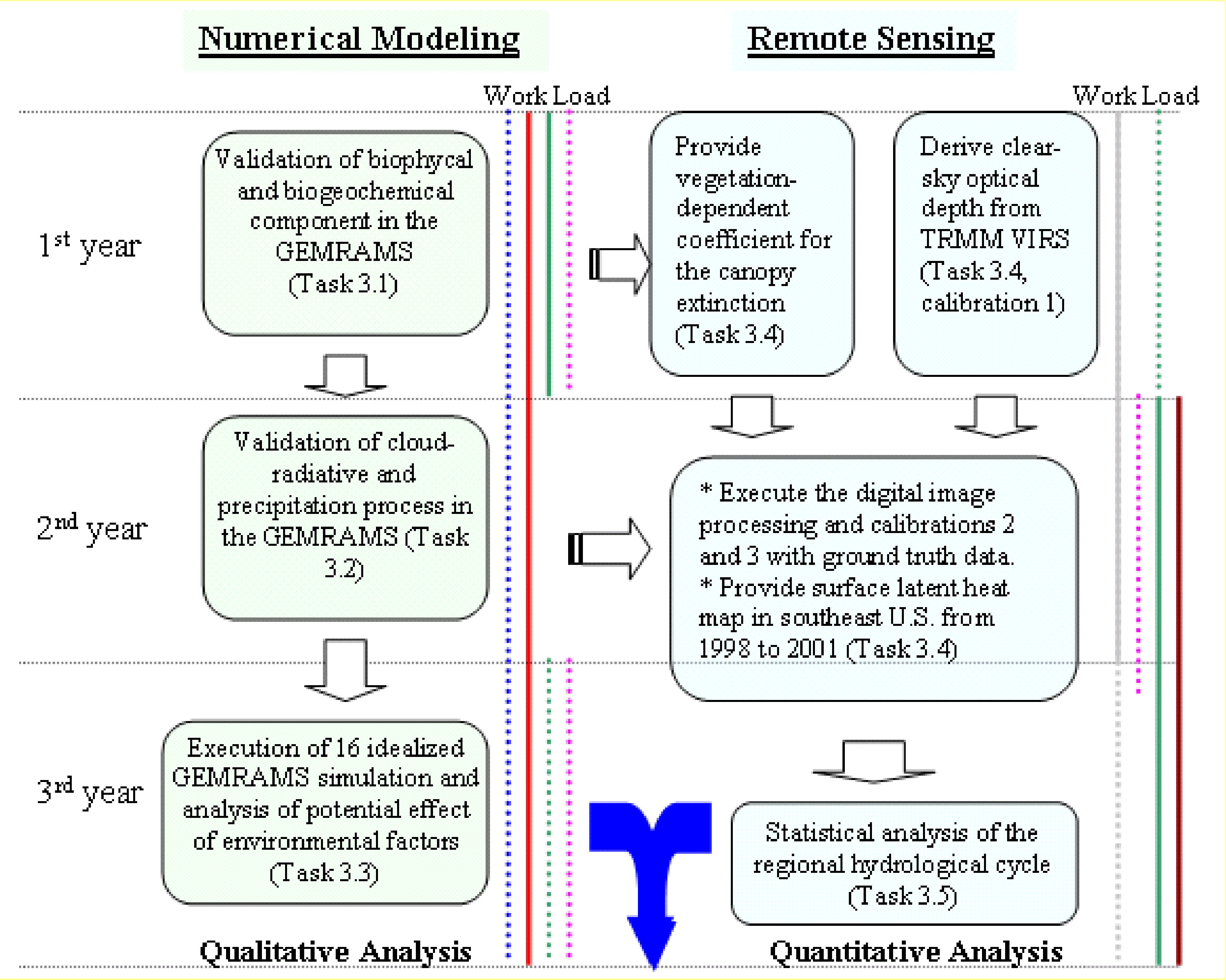


Task 5 Analysis of regional hydrological cycle over Southeastern United States

- How does the regional water budget vary seasonally and annually?

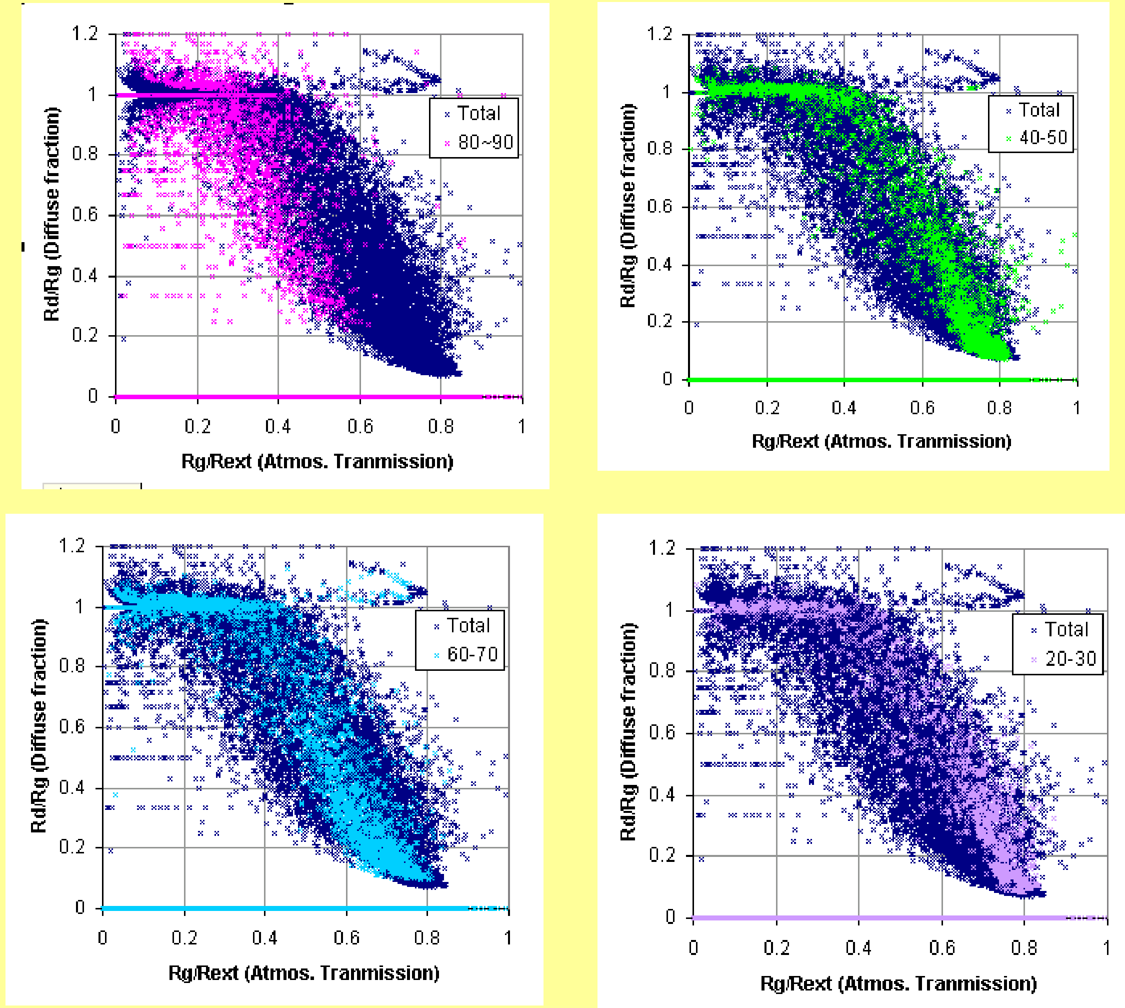
- 4 year (1998 – 2002) water budget analysis for Precipitation, Evaporation, Transpiration, with TRMM/ Total Runoff Integrating Pathway (TRIP) algorithm

- Compare results with VIC-LDAS ; GSFC- LDAS estimates

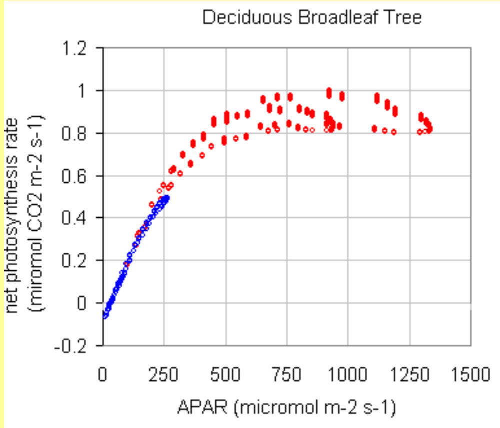


Numerical Modeling
Remote Sensing
Work Load
Work Load
1st year
2nd year
3rd year
Validation of biophycal and biogeochemical component in the GEMRAMS (Task 3.1)
Validation of cloud-radiative and precipitation process in the GEMRAMS (Task 3.2)
Execution of 16 idealized GEMRAMS simulation and analysis of potential effect of environmental factors (Task 3.3)
Provide vegetation-dependent coefficient for the canopy extinction (Task 3.4)
Derive clear-sky optical depth from TRMM VIRS (Task 3.4, calibration 1)
* Execute the digital image processing and calibrations 2 and 3 with ground truth data.
* Provide surface latent heat map in southeast U.S. from 1998 to 2001 (Task 3.4)
Statistical analysis of the regional hydrological cycle (Task 3.5)
Qualitative Analysis
Quantitative Analysis

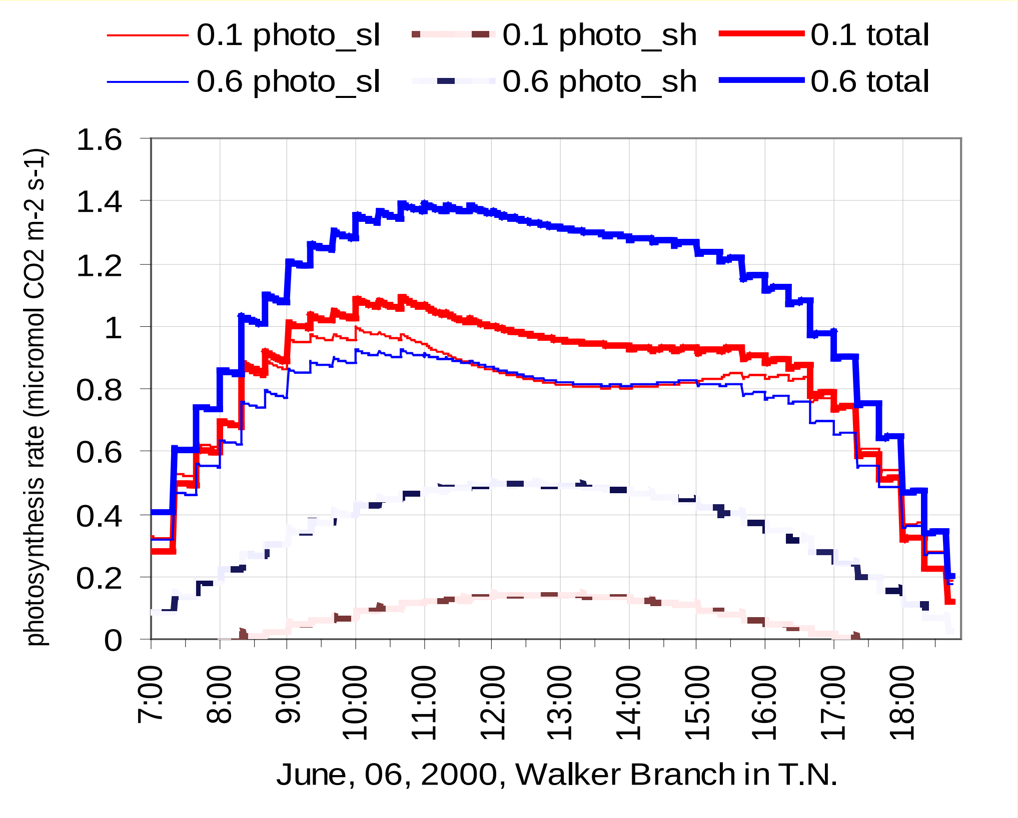
Year 1 Project activity / coordination has resumed



Relationship between diffuse fraction and atmospheric transmission as a function of solar zenith angle derived from the ISIS radiation observation at Walker Branch, TN.

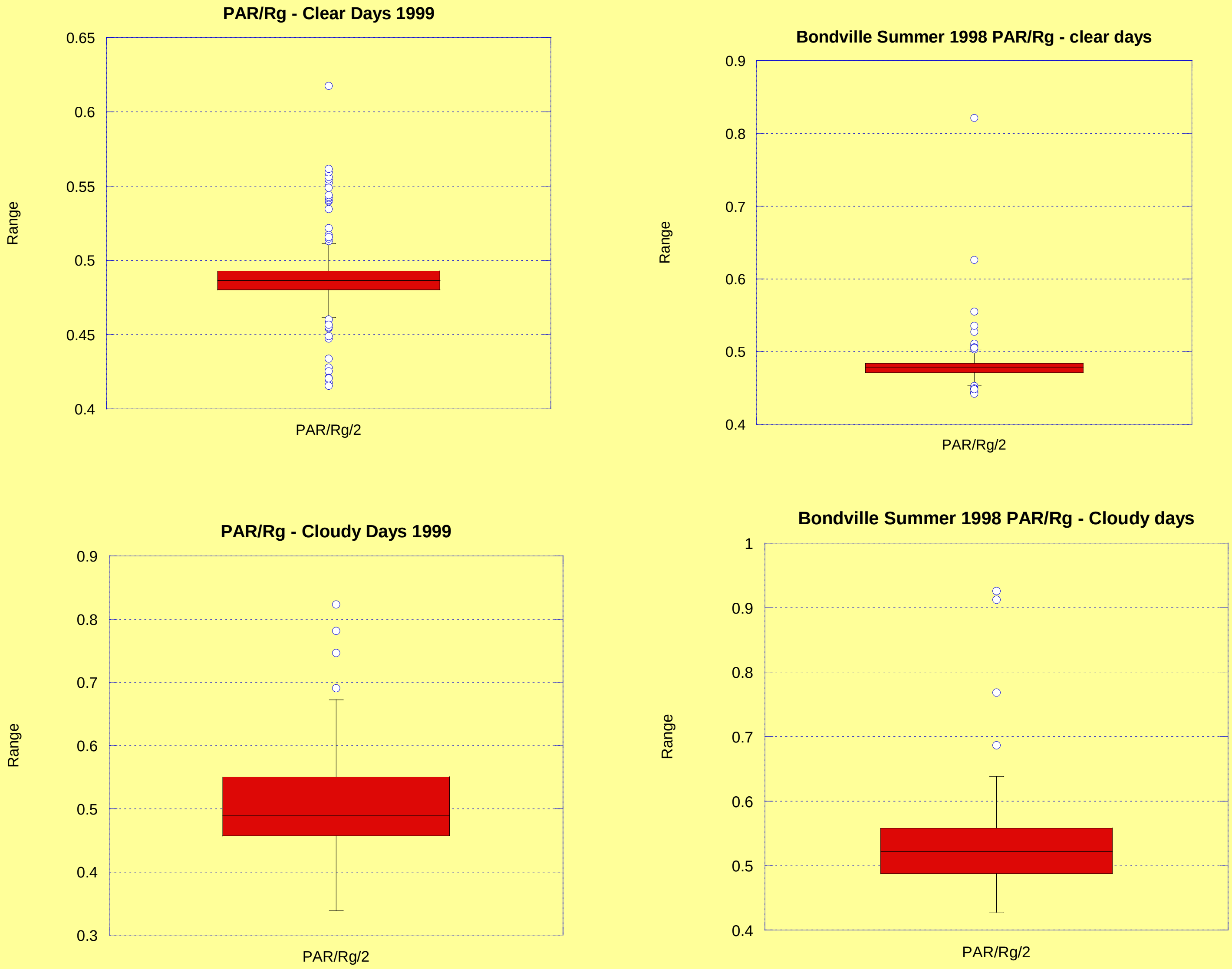


Relationship between APAR and net photosynthesis simulated by GEMRAMS. (Red = sunlit leaves , Blue = shaded)



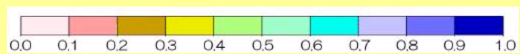
0.1 and 0.6 diffuse fraction; Total = sunlit (sl) + shaded (sh) in coupled GEMRAMS

PAR estimation from global radiation

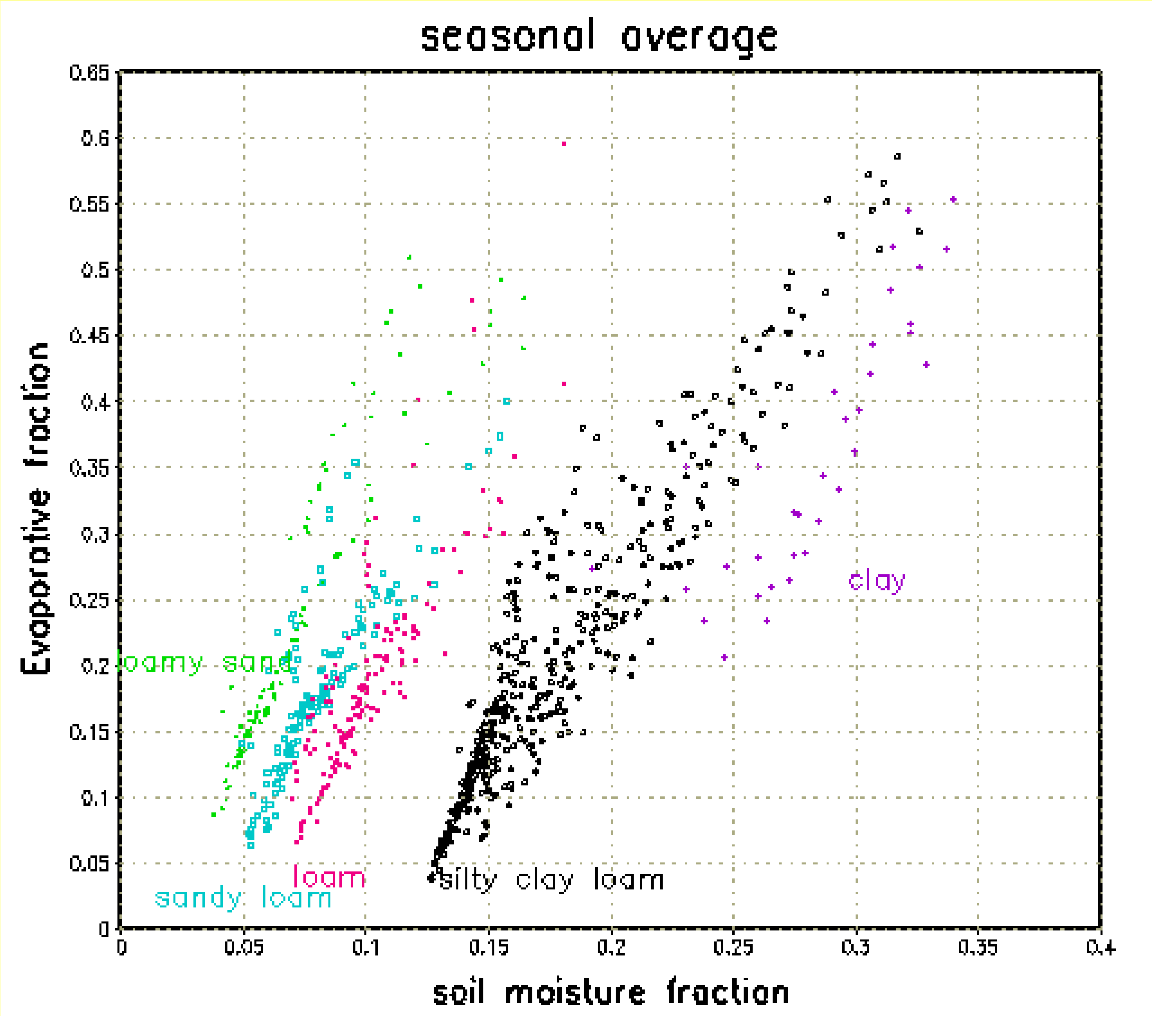


February

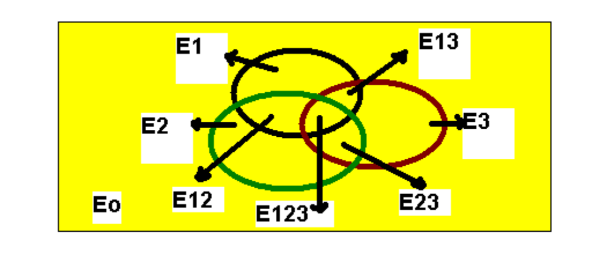
May



Monthly mean soil moisture index (0~1 from dry to wet) in 1998 derived from TRMM PR (Oki et al. 2000). The variations are consistent with observations from surface and drought monitor reports.



Sensitivity of evaporative fraction to the variability of soil moisture and soil type



Eo = Fo = f [CO2 - , Moist -]

F1 = f [CO2 + , Moist -]

F2 = f [CO2 - , Moist +]

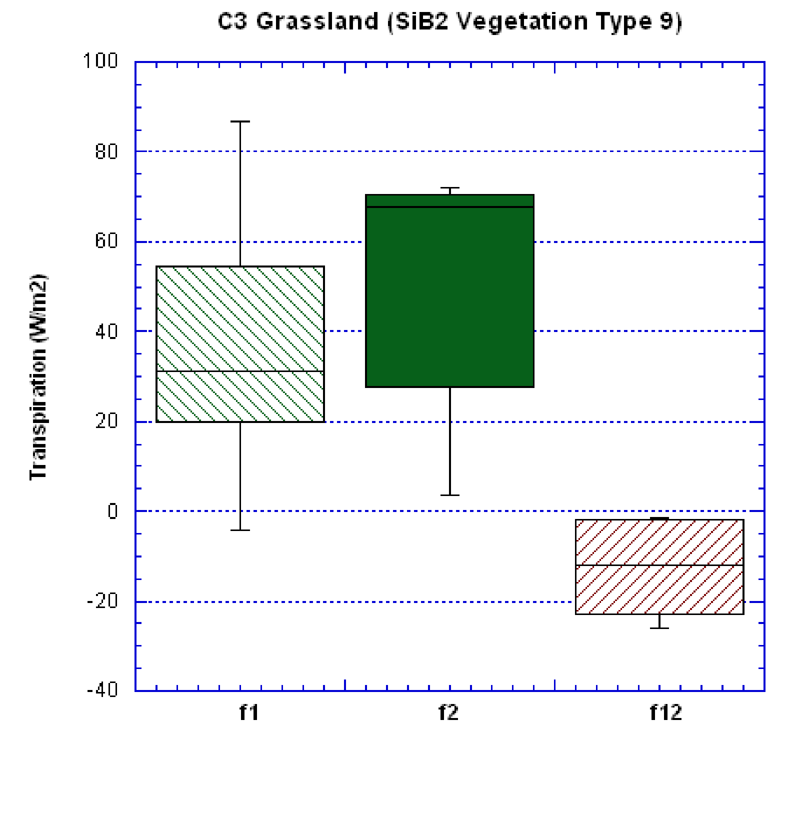
F12 = f [CO2 + , Moist +]

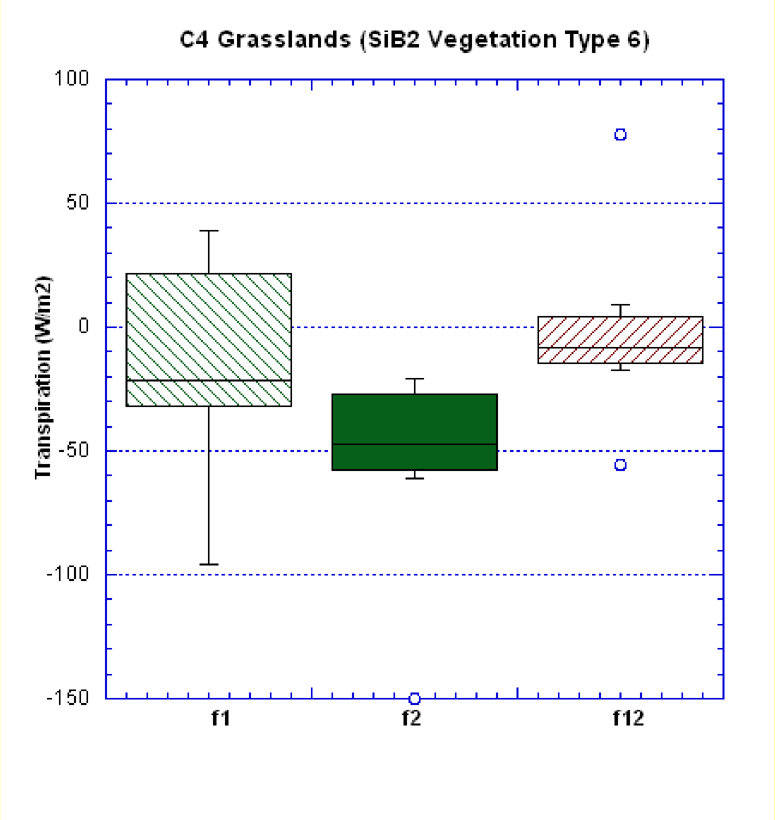
E(CO2) = F1 - Eo

E(SM) = F2 - Eo

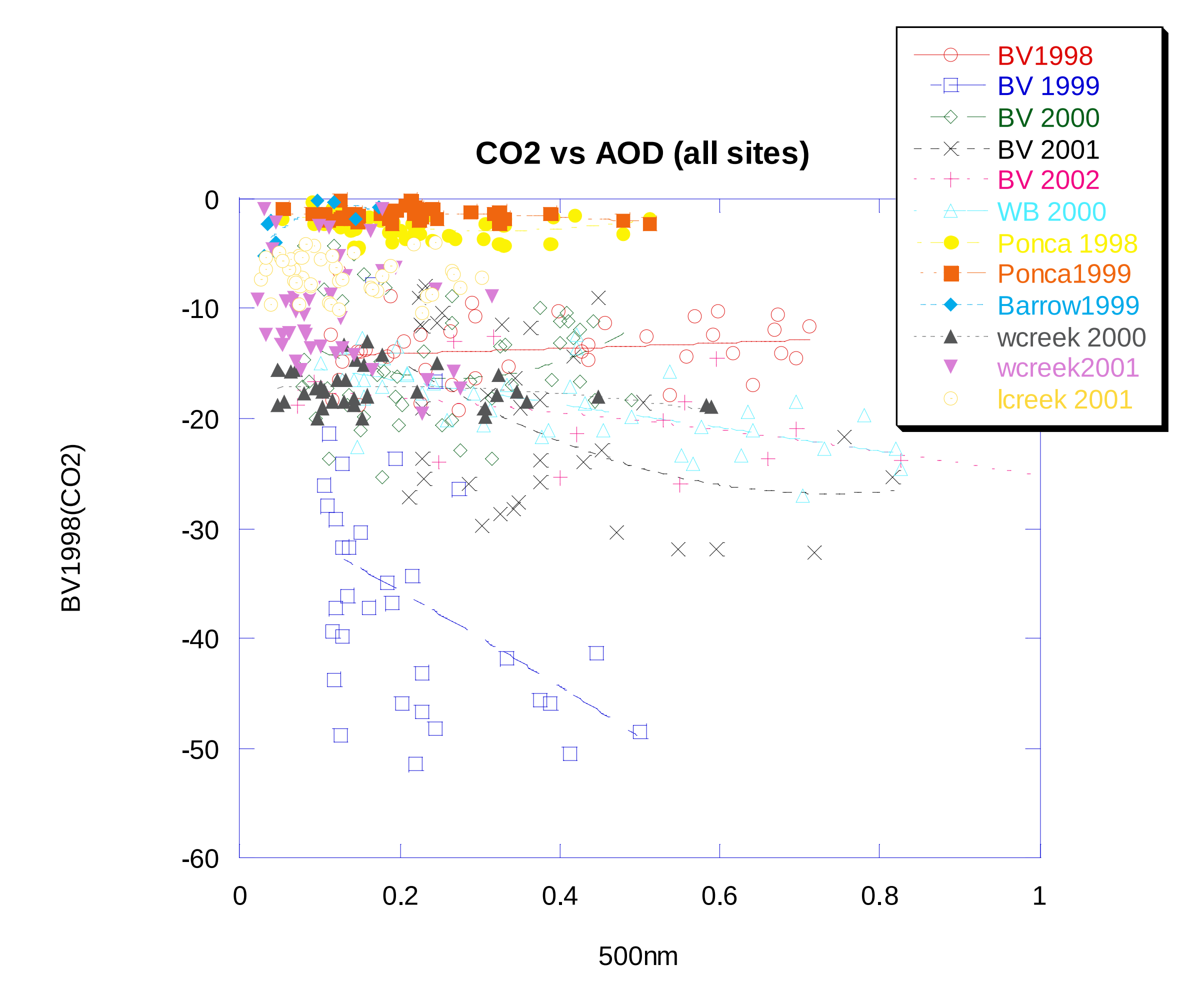
E(CO2:SM) = F12 - (F1+F2) - Fo

Effect of soil moisture availability on transpiration for ambient CO2 changes





Observational analysis of the effect of clouds and aerosol optical depth on plant response



BV = Crop (98,00,02: Corn C4)

(99,01: Soybean C3)

WB = Deciduous Forest(2000)

Ponca(98,99)

(winter wheat)

lcreek(2001), wcreek(00,01) = Mixed Hardwood Forest

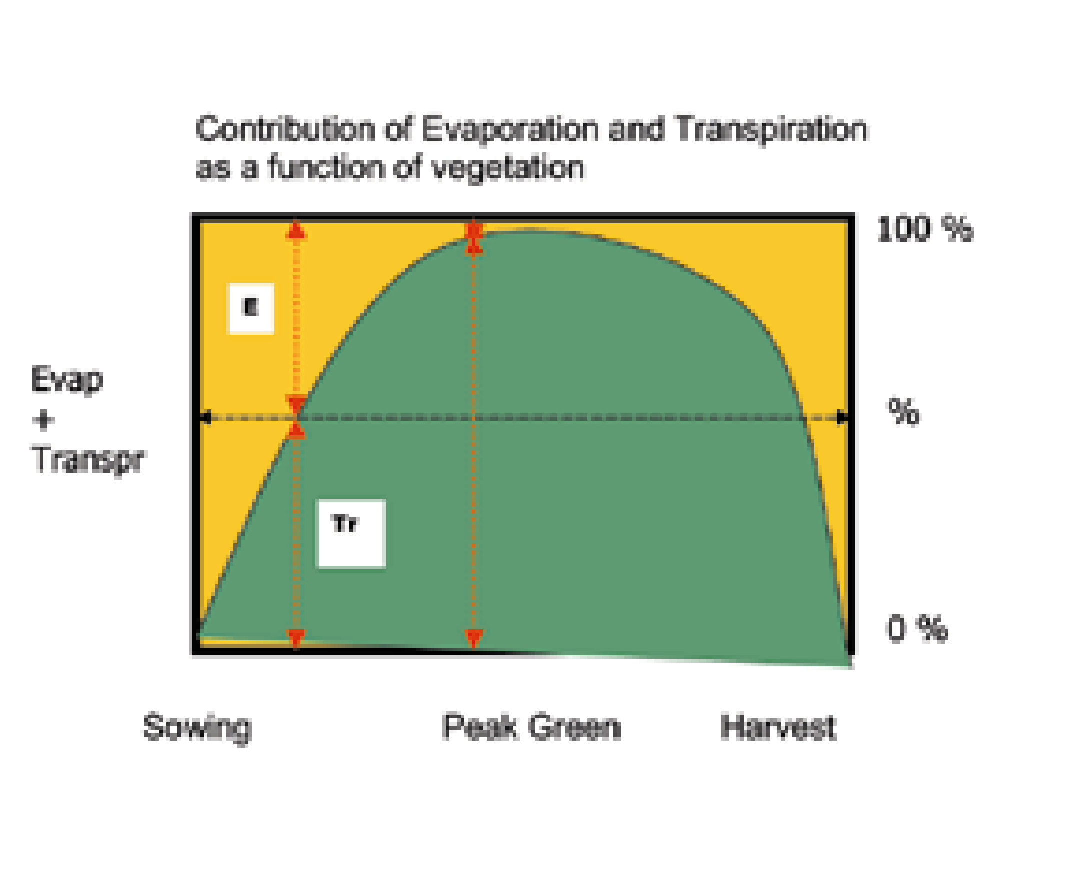
Barrow (2000) grassland

AOD – LHF Relation ; Need for LAI clustering

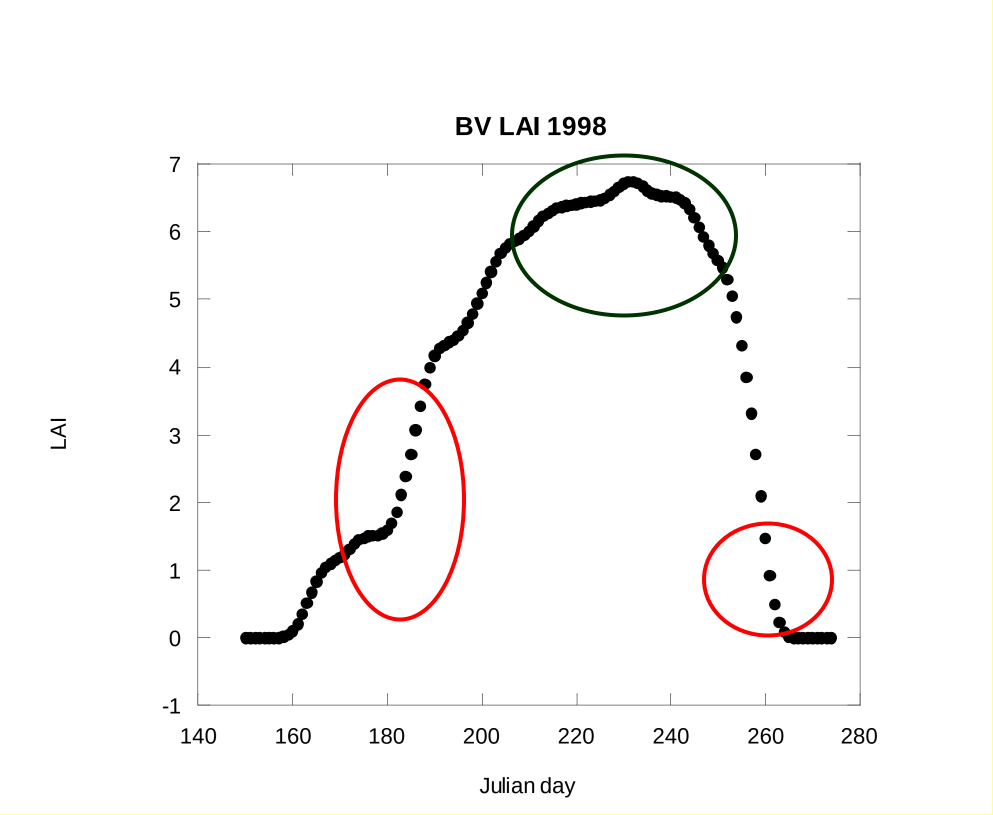
Latent heat flux = evaporation + transpiration

Evaporation is a strongly function of temperature;

Transpiration is directly dependent on plant photosynthesis and radiation.



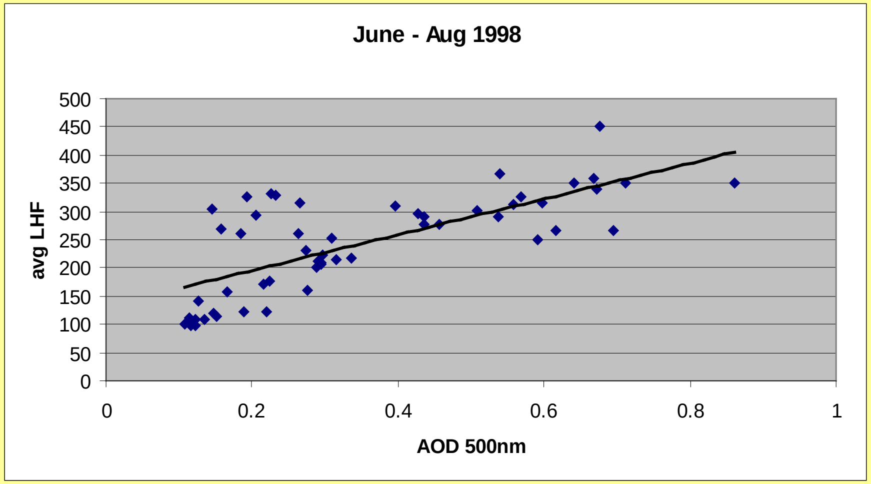
We analyze the LHF – COD relation for high and low LAI conditions

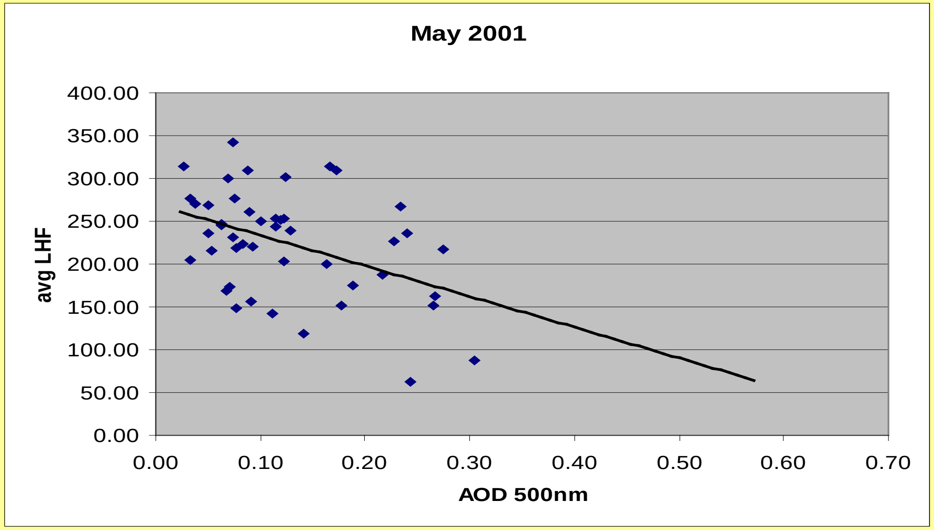


LAI change over Bondville AmeriFlux site

LHF effects are more complex. Transpiration may increase, Evaporation may decrease!!

High LAI case





Low LAI case

Caution: AOD – LHF relations were not consistent across all landscapes

Soil moisture and LAI are very important components as well

The project (LCLUC effects) in a climate perspective..

For climate change, we wont know where we are going until we reach there..
We need to be prepared for diverse scenarios…

Understanding / accounting for the feedback effects and the resulting vulnerability (using models as assessment tools) will help address an integrated assessment on global (climate) change

Any LCLUC -even with the best of management and mitigation interests in mind- may prove to be a failure and even harmful unless we explicitly consider the feedback processes affecting the hydrological interactions for an effective resilient policy

What could the results yield?

-Generate defensible and testable results considering feedbacks

-Incorporate LCLUC as a critical driver for climate change forcing in a hydrological framework (beyond current thermal feedback)

- Scaling (time and space based) still remains the biggest disconnect and the multisensor – calibration / model algorithm mapping could be an approach

Thank you