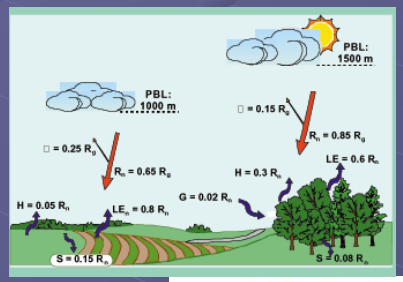
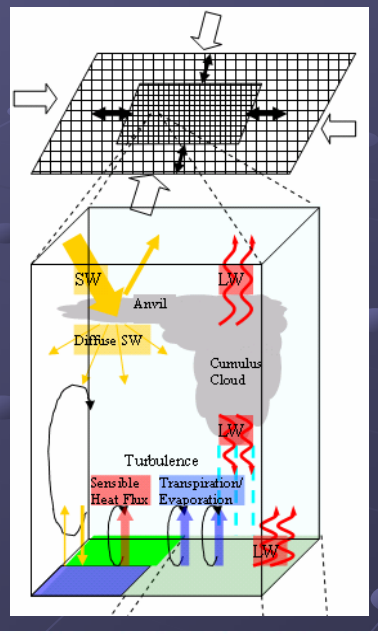
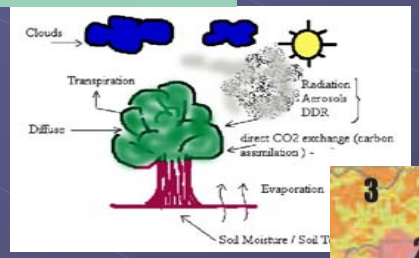
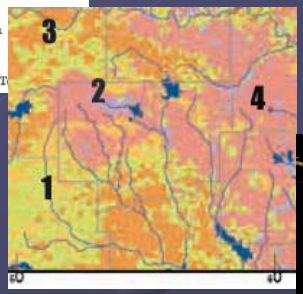
INTEGRATED REGIONAL CLIMATE STUDY WITH A FOCUS ON THE LAND-USE LAND-COVER CHANGE AND ASSOCIATED CHANGES IN HYDROLOGICAL CYCLES IN THE SOUTHEASTERN UNITED STATES

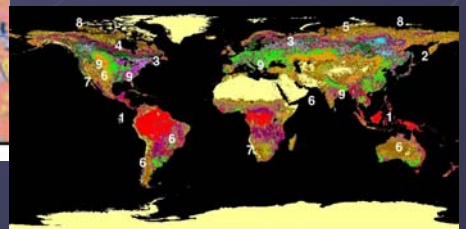


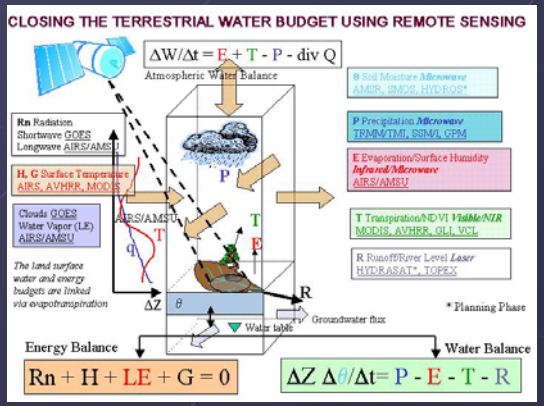
Presented at the NASA Land-Cover and Land-Use Change Science Team Meeting, UMUC Inn and Conference Center, College Park, Maryland. January 11-13, 2005.











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 initiated under IDS

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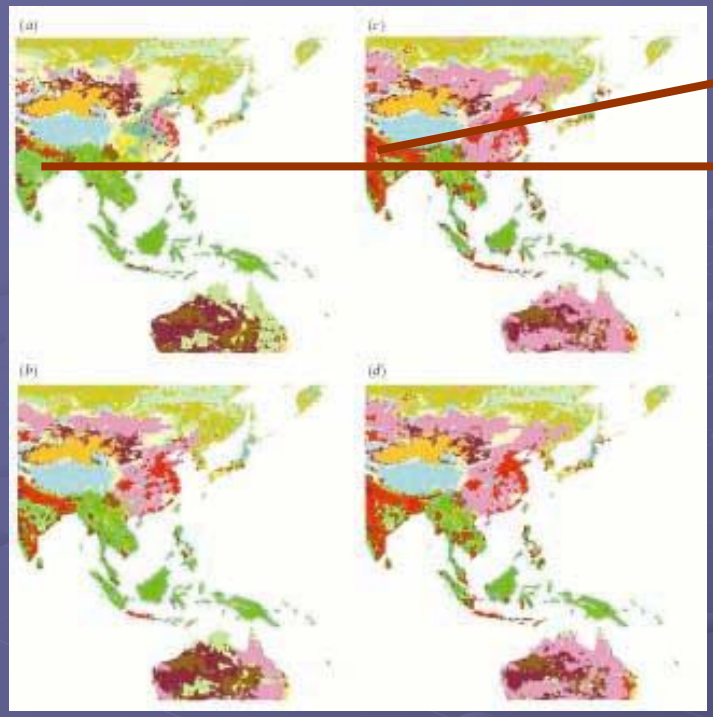
Introduction….

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

LCLUC affects regional and global climate

1700 1900



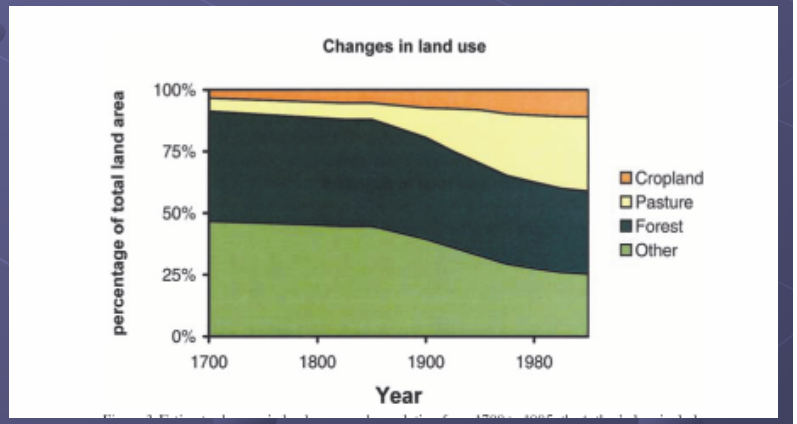
1970 1990

Intensive Crop Land

Mixed Forest Grassland, Agriculture

Reduction in rainforest and moist deciduous forest from 1981 - 1990

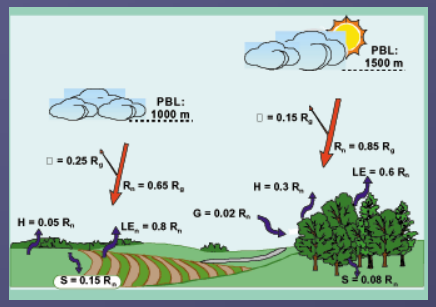
country	rainforest extent in 1990 (kha)	decrease 1981–1990 (%)	moist deciduous forest extent in 1990 (kha)	decrease 1981–1990 (%)
Brazil	291 597	6	197 082	16
Indonesia	93 827	20	3 366	20
Dem. Rep. Congo (Zaire)	60 437	12	45 209	12
Columbia	47 455	6	4 101	38
Peru	40 358	6	12 299	6
Papua New Guinea	29 323	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



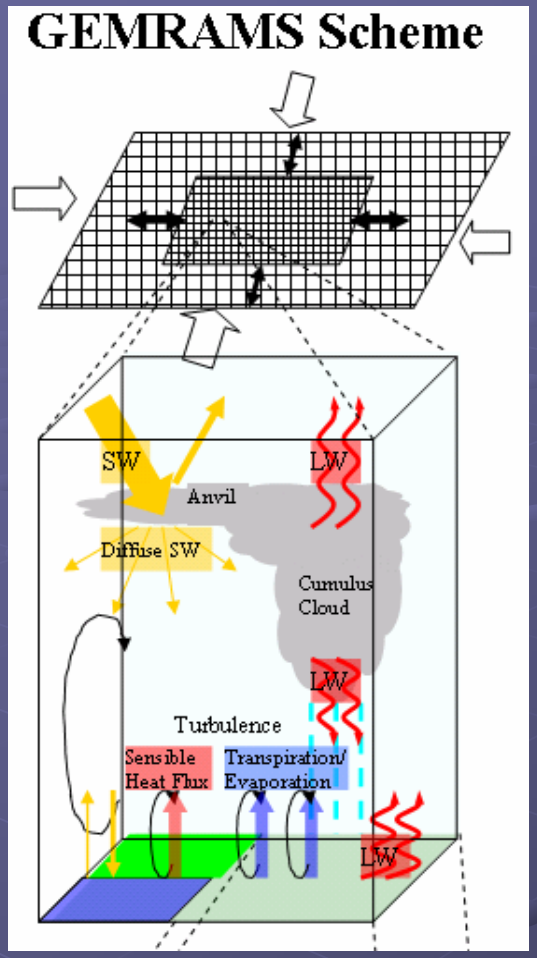
OUTSTANDING SCIENCE QUESTION

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?

IDS LCLUC /Hydrology Project Objectives



- Variability in surface latent heat flux (evaporation and transpiration) and precipitation and hence the regional hydrological cycle
  - Variability due to LCLUC, radiation and 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, in-situ and remote-sensed satellite data and products



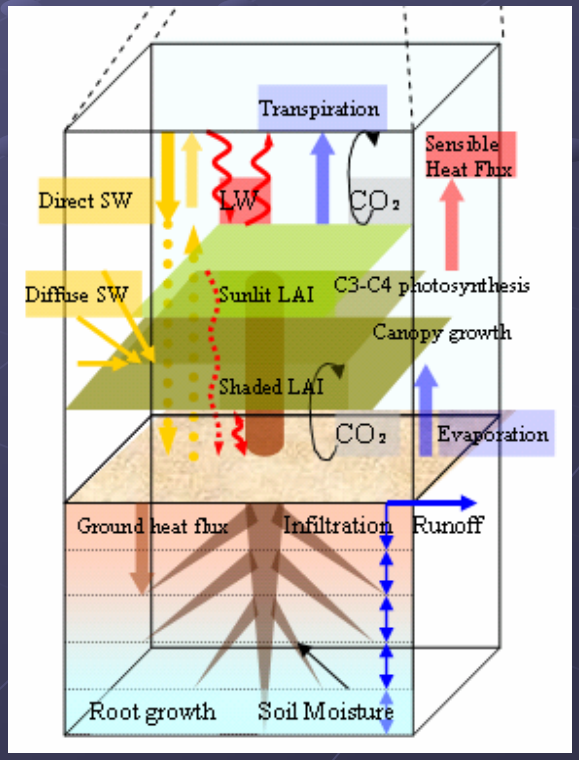
Coupled Modeling System

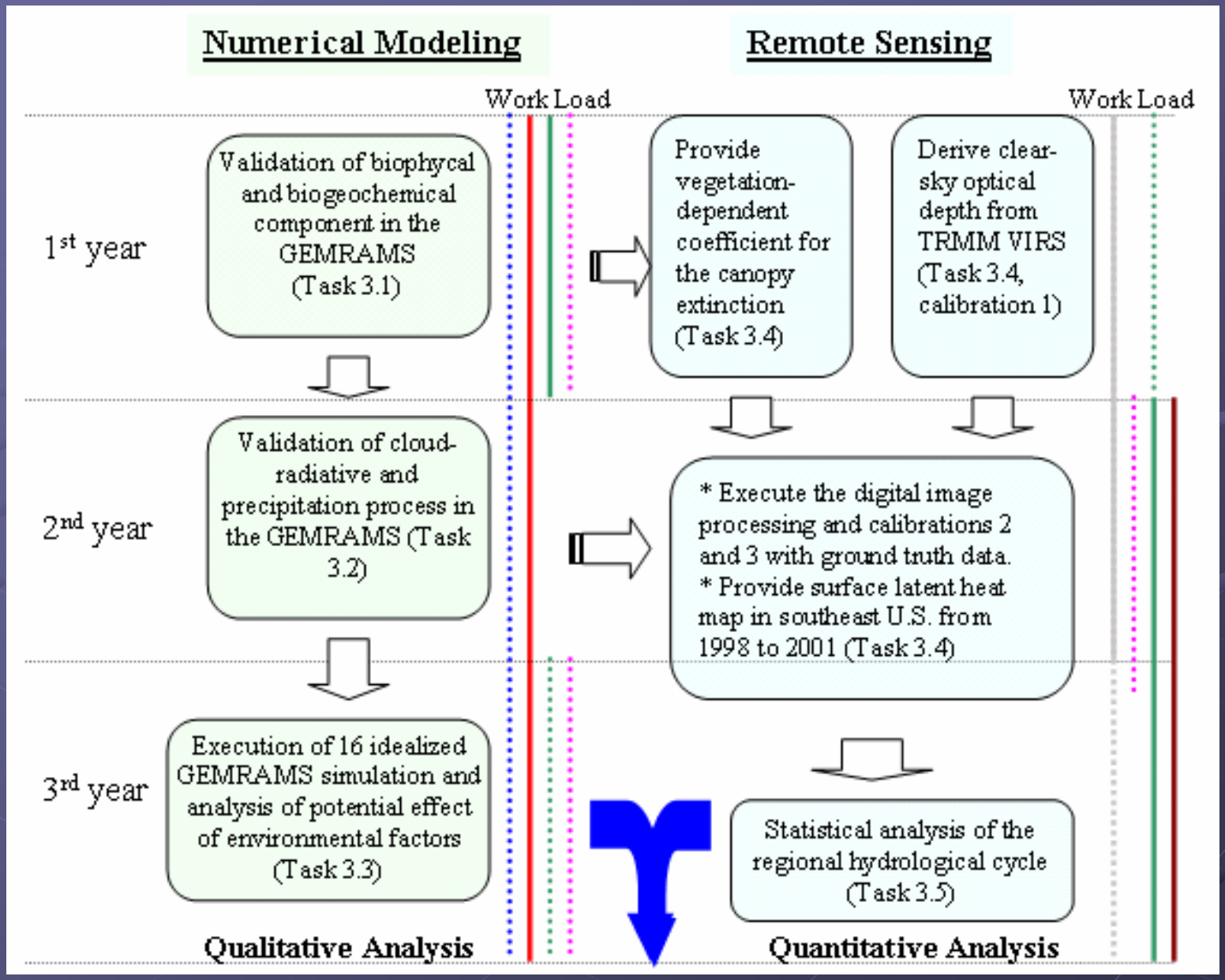
-GEMTM and RAMS based

-Several interactive processes

-Surface and satellite data ingestion

-Process based assessment possible




Numerical Modeling
Remote Sensing
Work Load
Work Load
1st year
Validation of biophycal and biogeochemical component in the GEMRAMS (Task 3.1)
Provide vegetation-dependent coefficient for the canopy extinction (Task 3.4)
Derive clear-sky optical depth from TRMM VIRS (Task 3.4, calibration 1)
2nd year
Validation of cloud-radiative and precipitation process in the GEMRAMS (Task 3.2)
* 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)
3rd year
Execution of 16 idealized GEMRAMS simulation and analysis of potential effect of environmental factors (Task 3.3)
Statistical analysis of the regional hydrological cycle (Task 3.5)
Qualitative Analysis
Quantitative Analysis

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

- How are regional biogeochemical and water cycles responding to the variation of radiative forcing?

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

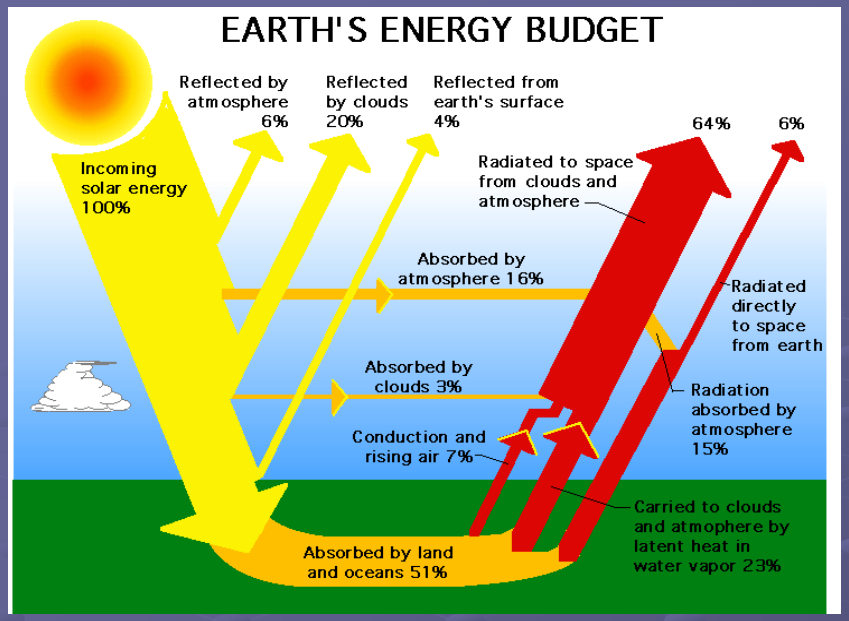
Task 1 Calibration and Evaluation of Biogeochemical Process in the GEMRAMS Model

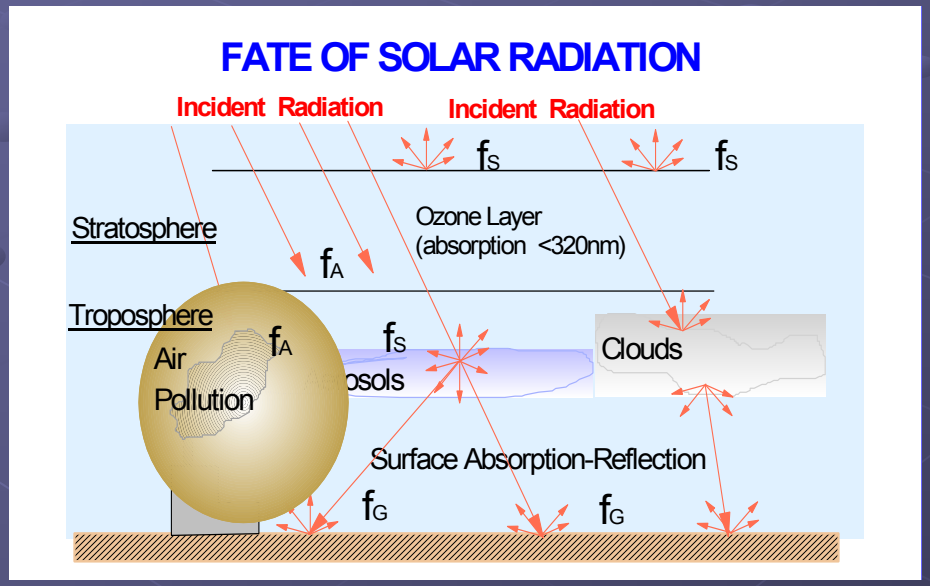
- Calibration Efforts are detailed in a poster (Matsui et al.)

- Optimization approach and tests with different datasets
- Modular GEMRAMS code to ingest variable data sources and formats
- Calibration using observations and optimization models
- Testing and evaluation

Focus of this presentation….

- How are regional biogeochemical and water cycles responding to the variation of radiative forcing and LULC?





- CLOUDS AND AEROSOLS AFFECT THE RADIATIVE FEEDBACK OF THE ENVIRONMENT

-Majority of the studies have focused on the 'temperature effects' =>whether clouds and aerosols cause cooling or warming effect in the regional climate.

-In this study we propose that:

Clouds and Aerosols, in particular, also have a significant biogeochemical feedback on the regional landscapes; this feedback will change as a function of LULC; and should be considered in carbon and water cycle studies

Diffuse Radiative Feedback over Different Landscapes

Clouds and Aerosols (haze, smoke…) can change the radiative forcing.
Total solar radiation = (Diffuse + Direct) solar radiation

For increased Cloud Cover or Increased Aerosol Loading,
Diffuse Component Increases => changes the DDR (Diffuse to Direct Radiation Ratio)

We hypothesize that:
Increase in DDR will impact the Terrestrial
Water and Carbon Cycle through Transpiration and Photosynthesis changes

(Transpiration is the most efficient means of water loss from land surface; Photosynthesis is the dominant mechanism for terrestrial carbon cycle)

Outstanding Questions…

- Is the effect of increasing photosynthesis and transpiration rate observed at leaf and canopy scale, also valid at field and regional scale?
- Will increased DDR and aerosol loading affect water vapor and CO2 fluxes (at field scale)?
- Are the effects of aerosols significant so as to be included in biogeochemical and land surface process studies at field and regional scale
- Study expected to represent an additional (biogeochemical) means of quantifying the impacts of LCLUCs

Approach:

- Synthesize field measurement for CO2 and water vapor fluxes over different landscapes under different environmental conditions and aerosol loading.

Data :

Need simultaneous observations of CO2 flux, water vapor flux, radiation (including DDR), and aerosol loading.

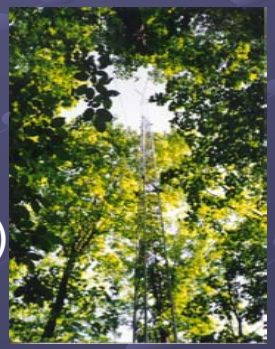
- CO2 and water vapor flux and landscape biophysical information – Ameriflux
- Radiation (including DDR) information from Ameriflux or NOAA Surface Radiation (SURFRAD) sites
- Aerosol loading information from NASA Aerosol Robotic Network (AERONET) and MODIS and IMPROVE AOD (comparison paper by Matsui et al. 2004; published Nov 2004 – Geophys. Res. Lett.)

Study sites

- Six sites available across the globe that have information on the required variables for our study (aerosol optical depth: AOD,diffuse radiation,CO_2 flux,and latent heat flux)

Shidler, OK (grassland 98,99)

Willow Creek, WI
Lost Creek, WI
(mixed forest,00,01)

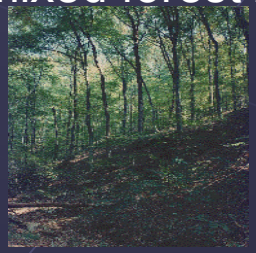


Bondville, IL (agriculture, C3 / C4, 98-02)

Ponca, OK (wheat 98,99)

Barrow, AK (grassland 99)

Walker Branch, TN (mixed forest 2000)



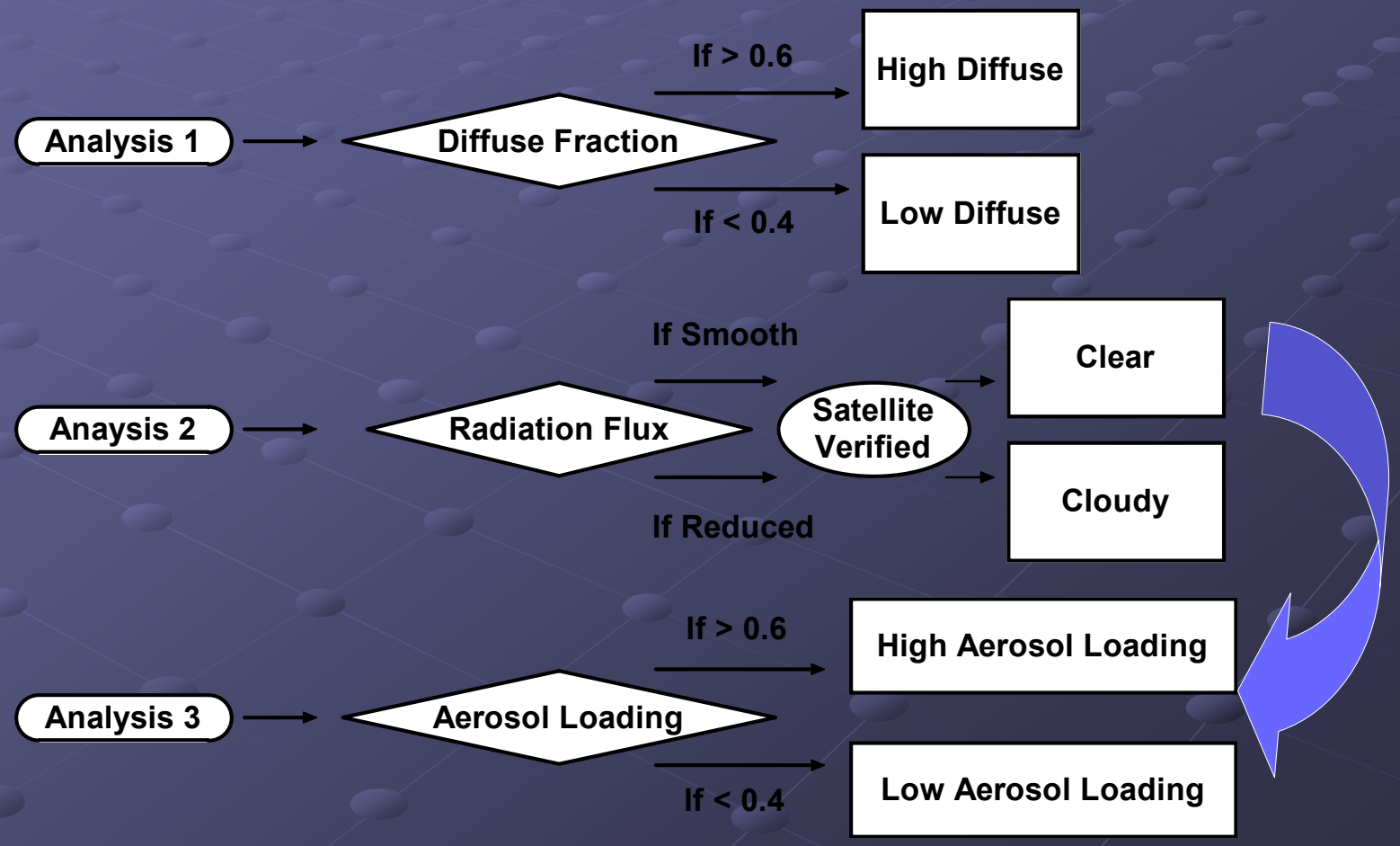
Hypothesis to be tested from the observational analysis :

- Increase in the aerosol loading could increase CO2 and latent heat flux at field scales
  - This would indicate a more vigorous terrestrial carbon cycle because of aerosol interactions
  - This would also indicate potential for changes in the terrestrial water cycle because of aerosol loading

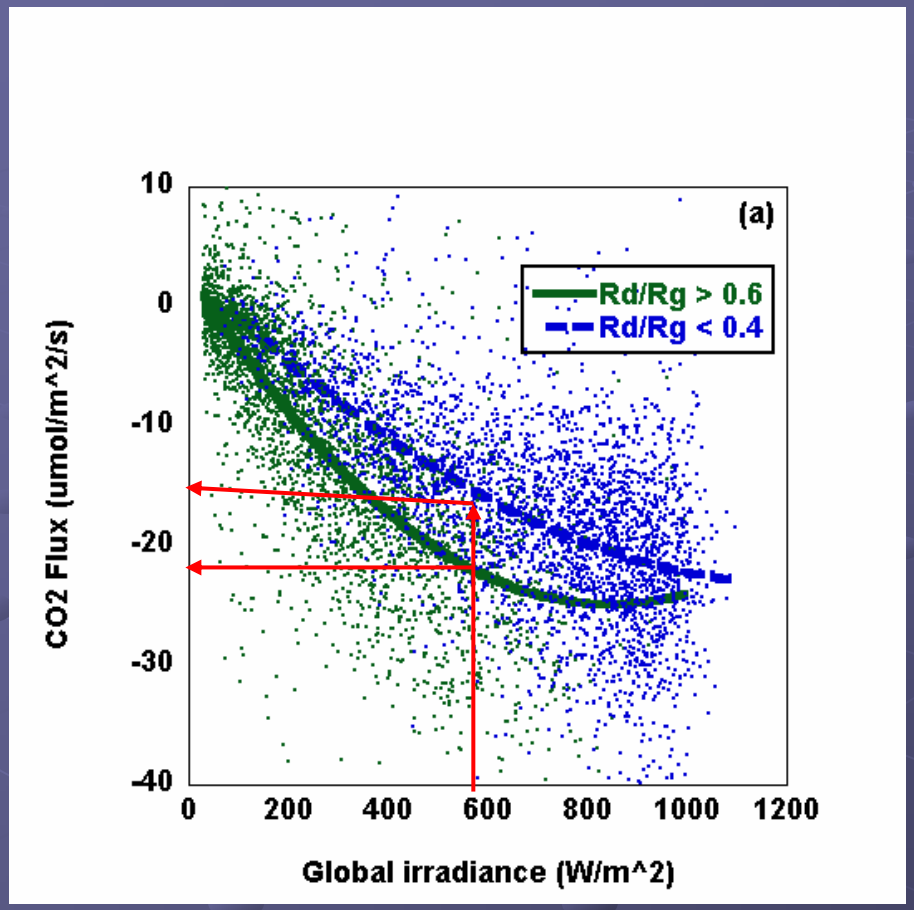
Data Analysis Flow Chart

Sub-objectives of our first part of the study are:

1. Do DDR changes affect field scale measurements?
2. What is the effect of clouds on DDR and field scale CO2 flux? , and
3. What is the effect of aerosols on field scale CO2 Flux?



Does DDR Change Cause Changes in the CO2 Flux at Field Scale?



negative values indicate CO2 sink (into the vegetation)

Walker Branch Forest Site

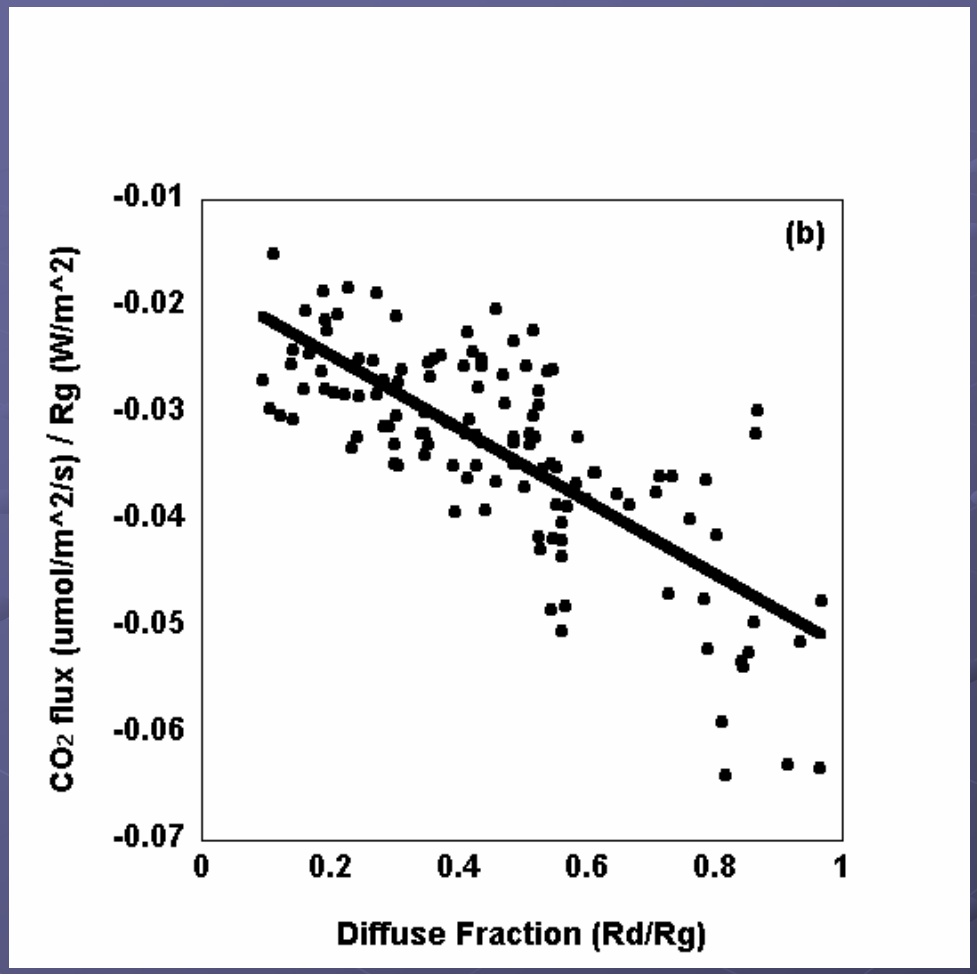
-CO2 flux into the vegetation (due to photosynthesis) increases with increasing radiation

-For a given radiation, CO2 flux is larger for higher DDR

Rg-total radiation

Rd-diffuse radiation

Effect of DDR on field scale CO2 Flux



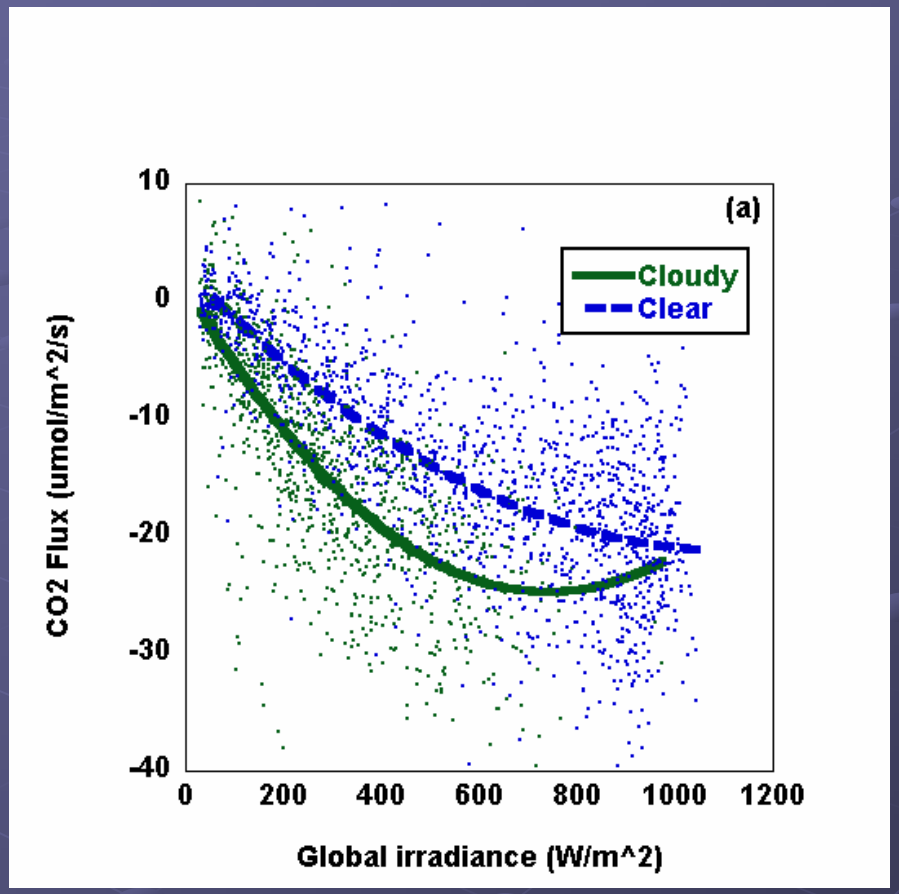
Changes in CO2 flux Normalized for changes in global Radiation versus Diffuse Fraction

Does DDR Change Cause Changes in the CO2 Flux at Field Scale?

Yes!

Increase in DDR appears to increase the observed CO2 flux in the field measurements.

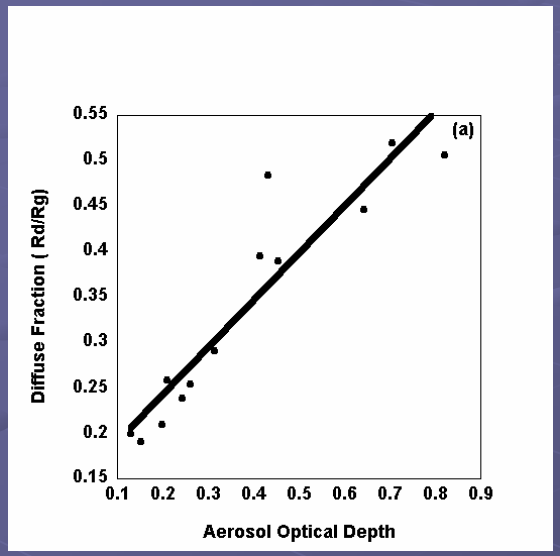
Do clouds affect CO2 flux at Field Scale?

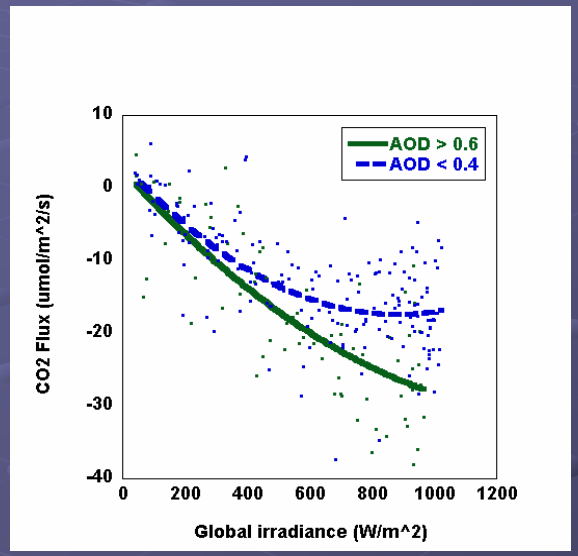


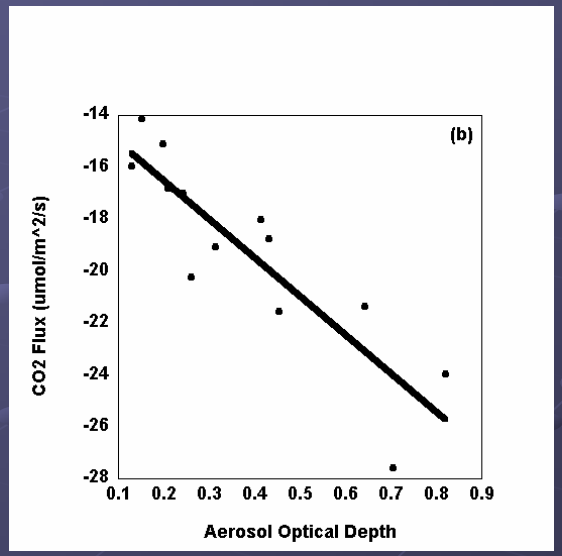
- Yes, clouds appear to affect field scale CO2 fluxes significantly.

-CO2 flux into the vegetation (due to photosynthesis) is larger for cloudy conditions

Do Aerosols affect field scale CO2 Flux?

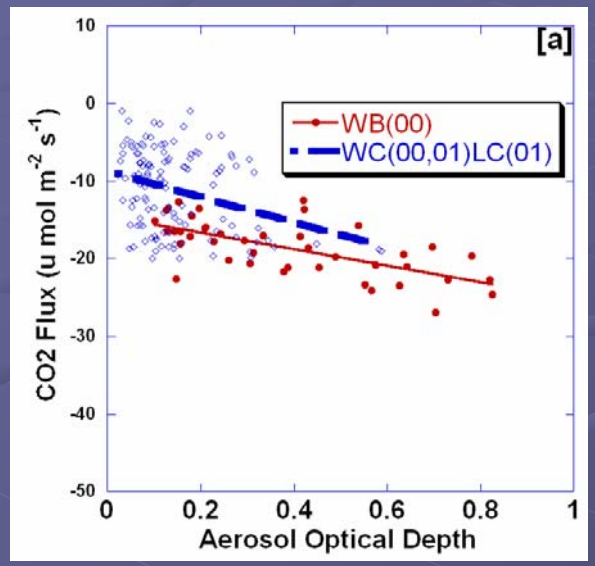


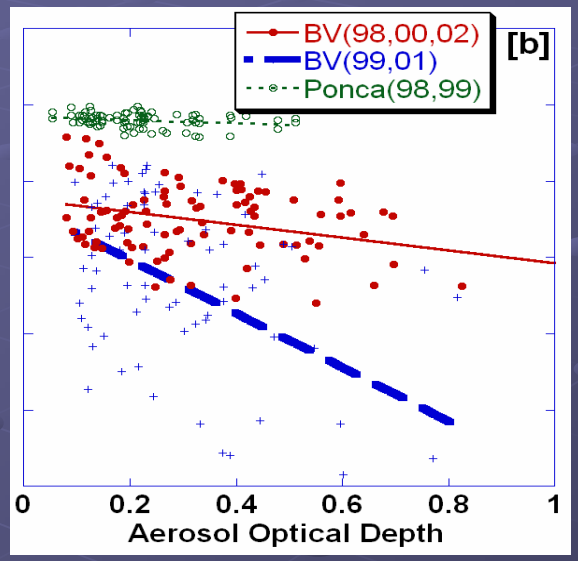


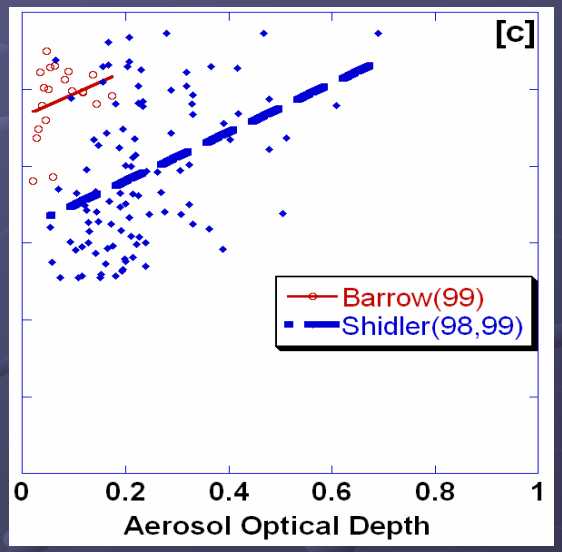


- Increase in AOD (no cloud conditions) causes increase in DDR (diffuse fraction)
- CO2 flux into the vegetation (due to photosynthesis) is larger for higher AOD conditions
- Aerosol loading appears to cause field scale changes in the CO2 flux

Are these results true for different landscapes?



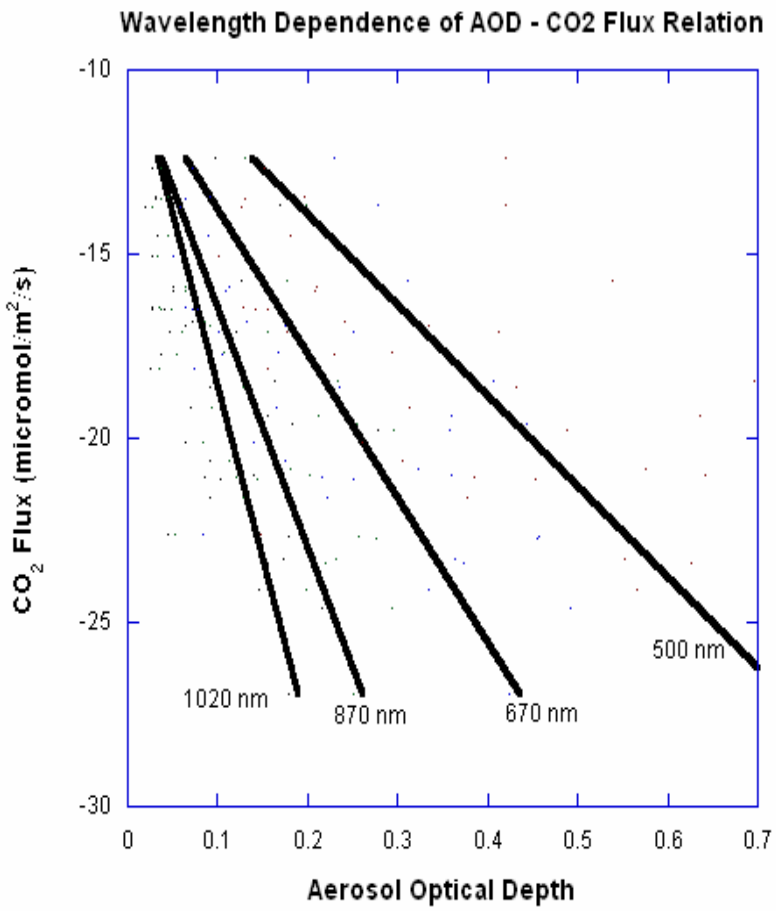


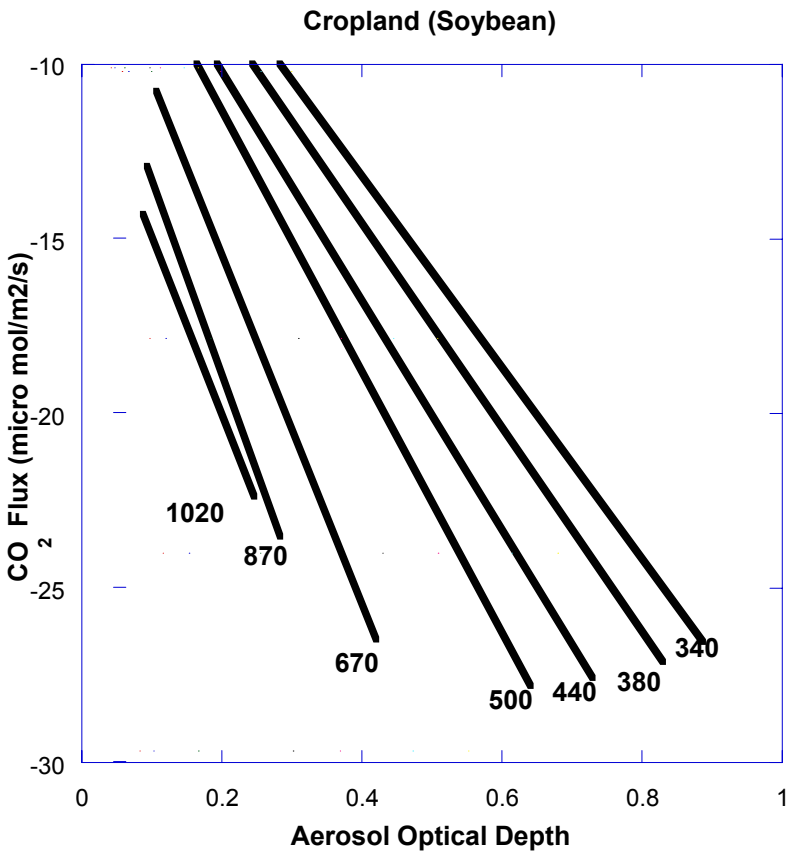


Forests Croplands Grasslands

For Forests and Croplands, aerosol loading has a positive effect on CO_2 flux, where there shows a CO_2 flux source at Grassland sites.

Effects of AOD Wavelength on the CO2 – aerosol sensitivity





Summary for Carbon cycle data analysis:

- Increasing aerosols could increase CO2 flux at forest and crop sites; decrease CO2 flux over grassland sites
  - There were some differences in the response for photosynthesis pathway (C3 or C4).
    - -In general C4 plants appear to be more sensitive.

- AOD-carbon sensitivity could be wavelength- dependent for forest sites, while it is relatively less for croplands.

Do Aerosols affect water vapor flux?

Photosynthesis and transpiration are inter-related.

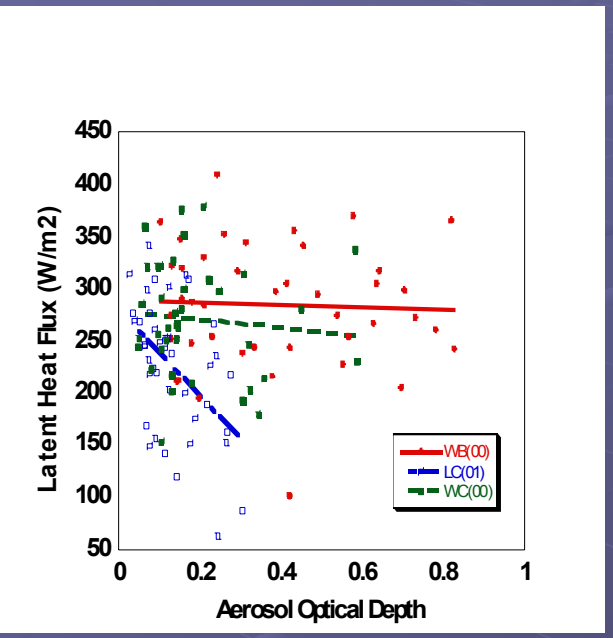
If aerosols increase photosynthesis rates, what will be the impact on Transpiration?

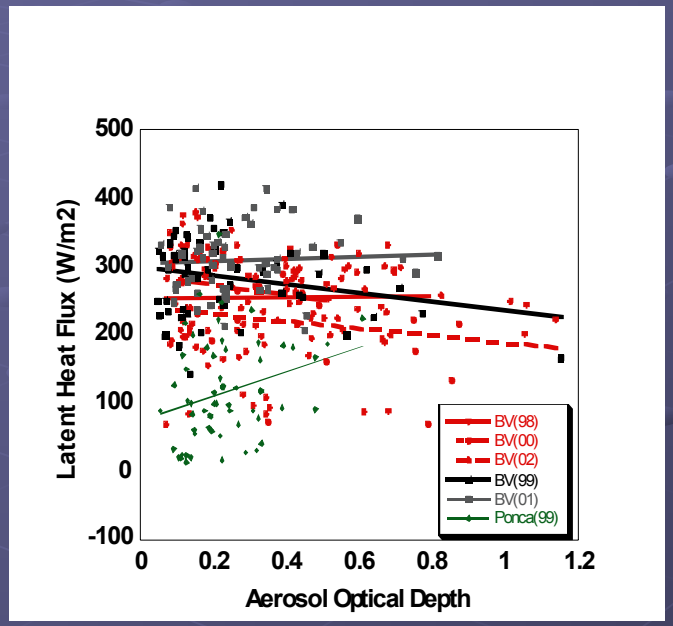
Increased transpiration flux could indicate increased vigor of the water cycle.

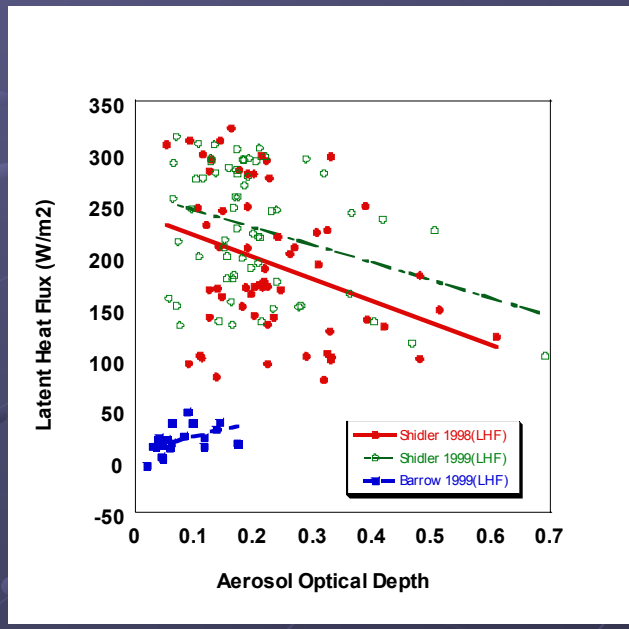
Hypothesis to be tested from the observational analysis:

- Increase in aerosol loading will significantly affect the transpiration rate and hence the water vapor flux (Latent Heat Flux)

Effect of AOD on water vapor flux (LHF) over different landscapes.



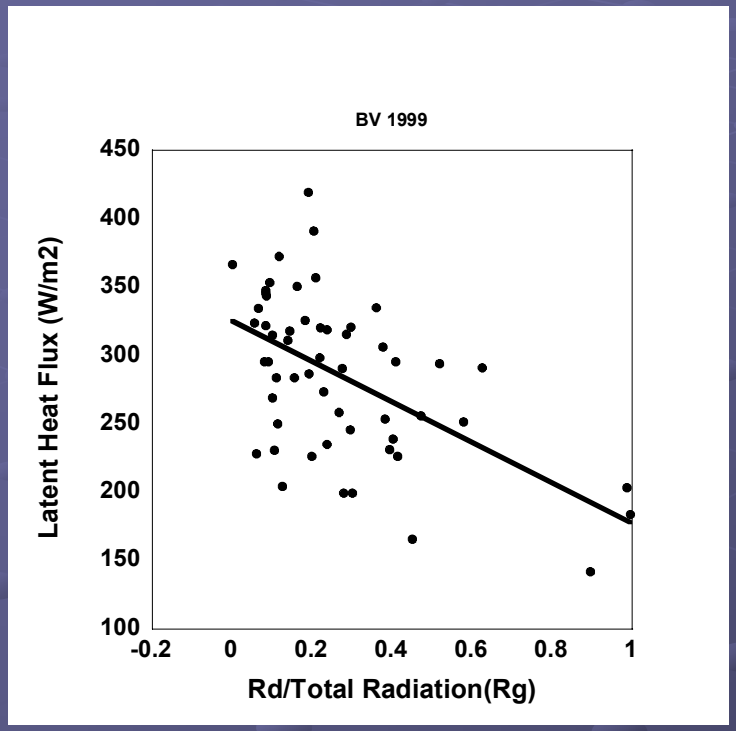




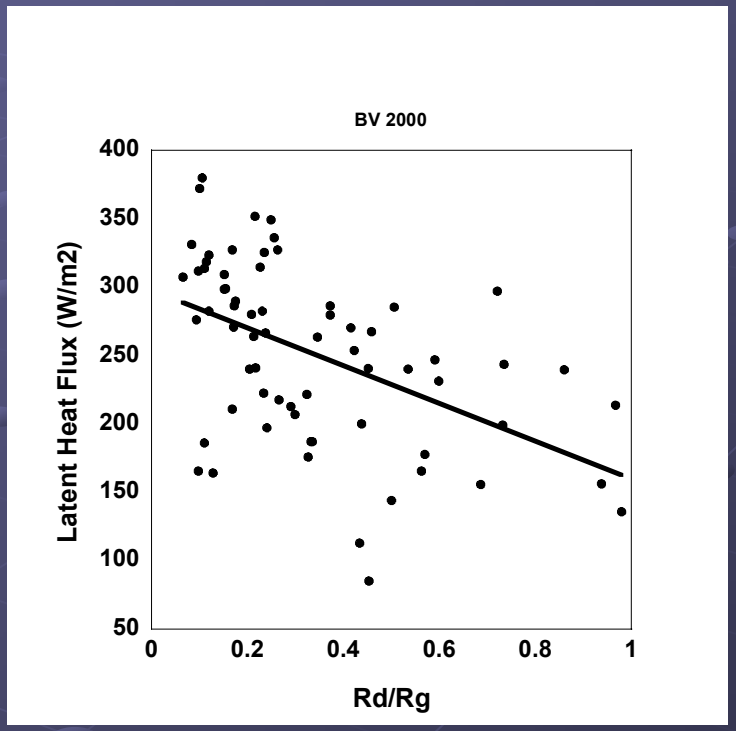
Forest site **Cropland** **Grassland**

Unlike CO2 fluxes, latent heat flux appears to generally (not always) decrease with increasing Aerosol Optical Depths for most of the sites

LHF-Diffuse Radiation relation
(Normalized for Global Radiation Changes)



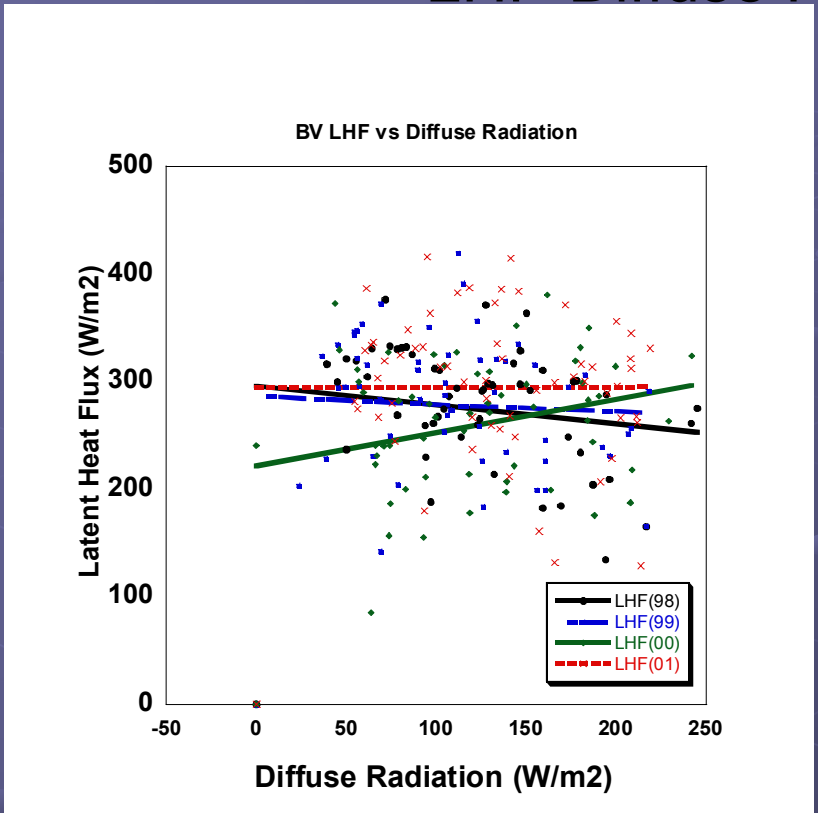
Corn



Soybean

Latent Heat Flux decreases with increasing Diffuse Radiation Ratio

Why is there no consistent relation between AOD and LHF? LHF-Diffuse Radiation relation



The scatter in the data shows… Diffuse Radiation change alone, is not the driver for latent heat flux changes!

(Note that, transpiration may still correlate with diffuse radiation as plant studies have shown!!)

LHF = transpiration + physical evaporation,

Therefore, diffuse radiation effect will depend on whether the landscape is transpiration dominated or evaporation dominated (and is discussed ahead).

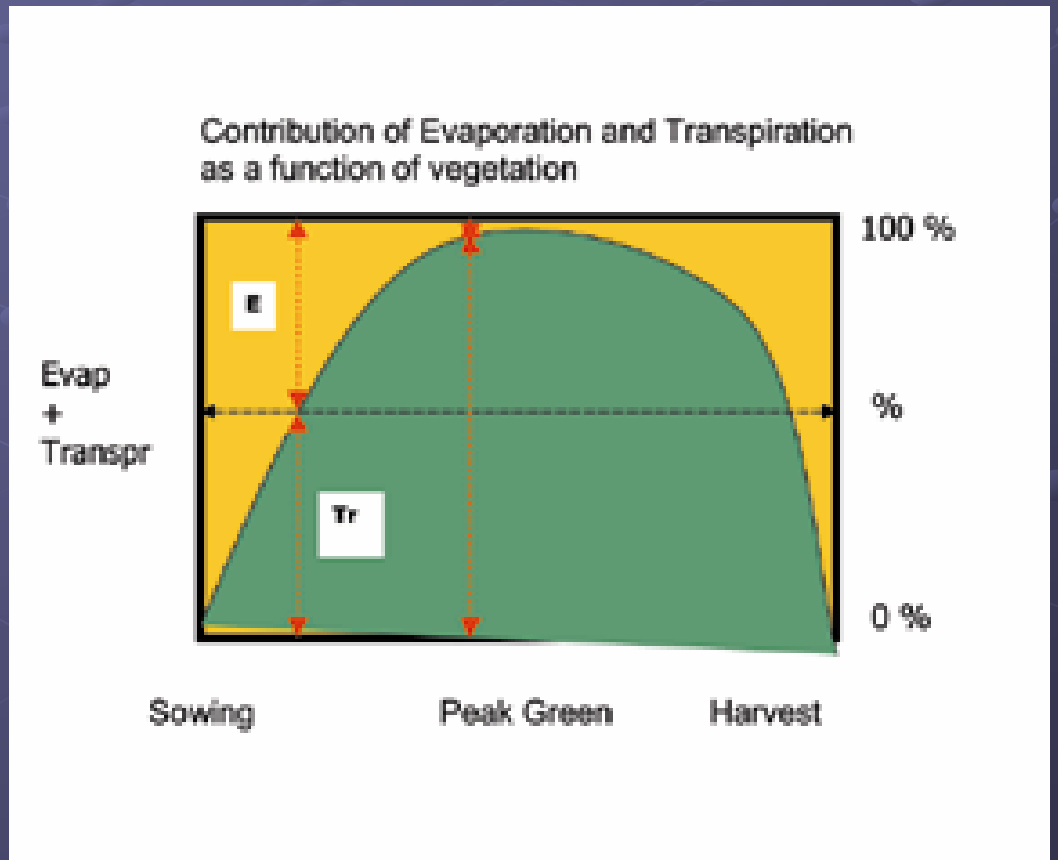
Why is there no consistent relation between AOD and LHF? LHF-Diffuse Radiation relation

[LAI = leaf area index = total leaf area / surface area]

Latent heat flux = evaporation + transpiration

Evaporation is a function of temperature (due to direct radiation);

Transpiration is directly dependent on plant photosynthesis and indirect radiation.



Leaf Area Changes over the Life of the Plant

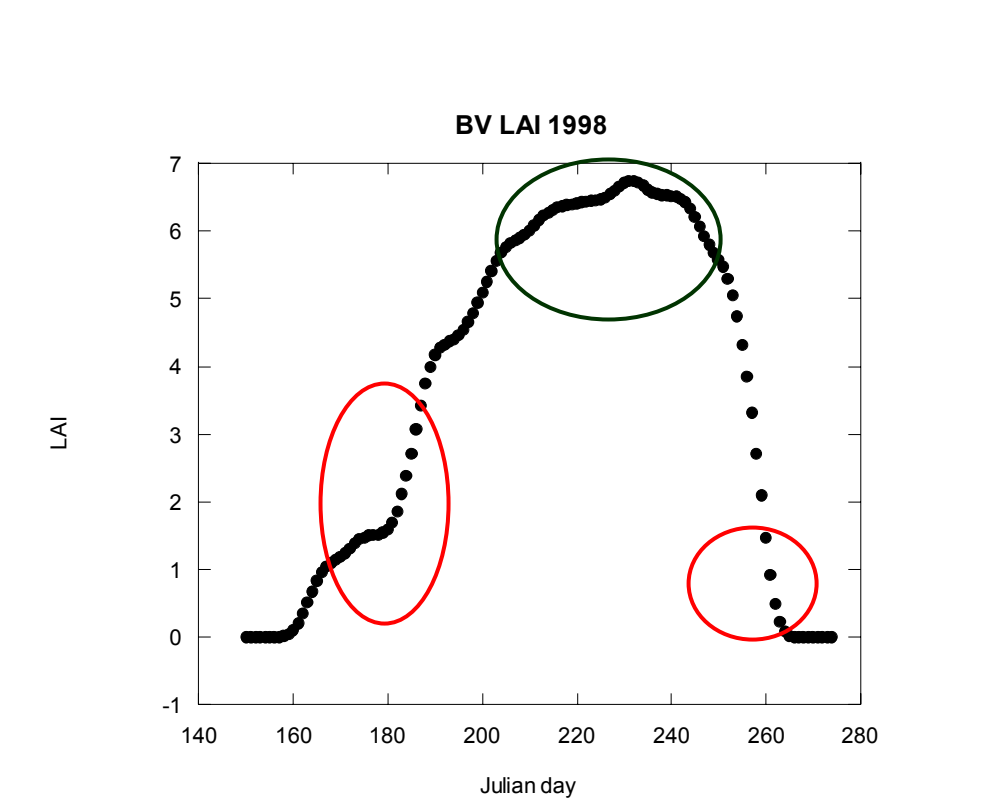
Determination of high and low Leaf Area Index:

High LAI –

Leaf Area Index > 3

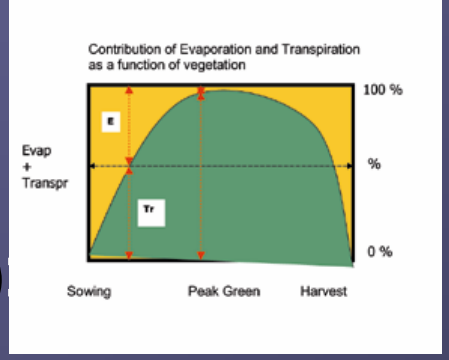
Low LAI –

Leaf Area Index < 2.5



LAI change over Bondville AmeriFlux site

Working Hypothesis



- At high vegetation LAI (leaf area index)

  LHF is mainly due to transpiration;

with increasing aerosols,diffuse radiation increases

this would cause increase the transpiration and thereby increase LHF

- At low vegetation LAI:

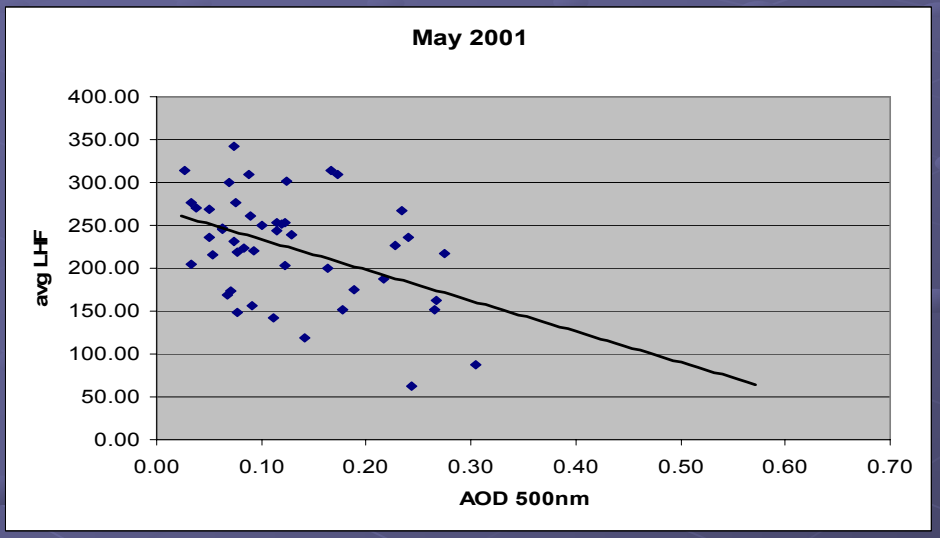
  LHF is mainly due to evaporation;

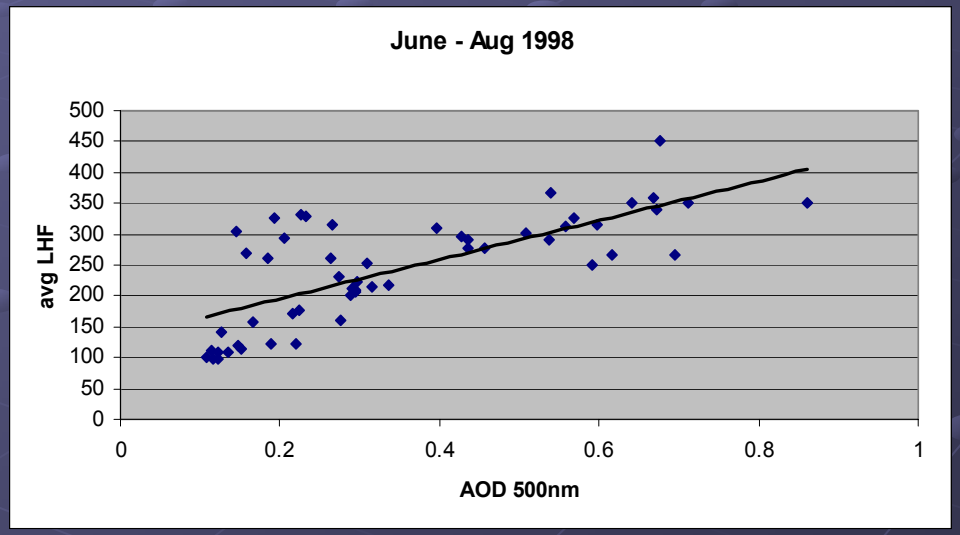
with increasing aerosols,diffuse radiation increases,

this would reduce the evaporation and therefore LHF decreases.

Clustering for LAI Changes

Walker Branch (Forest site):





Low LAI case (LAI < 2.5)

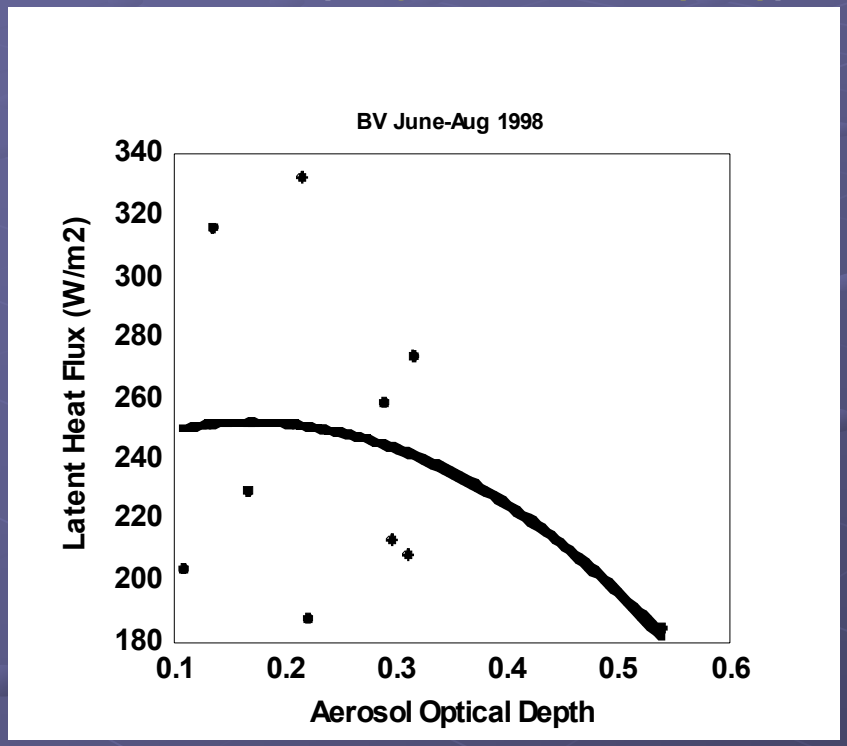
LHF decrease with aerosol loading

High LAI case (LAI >3)

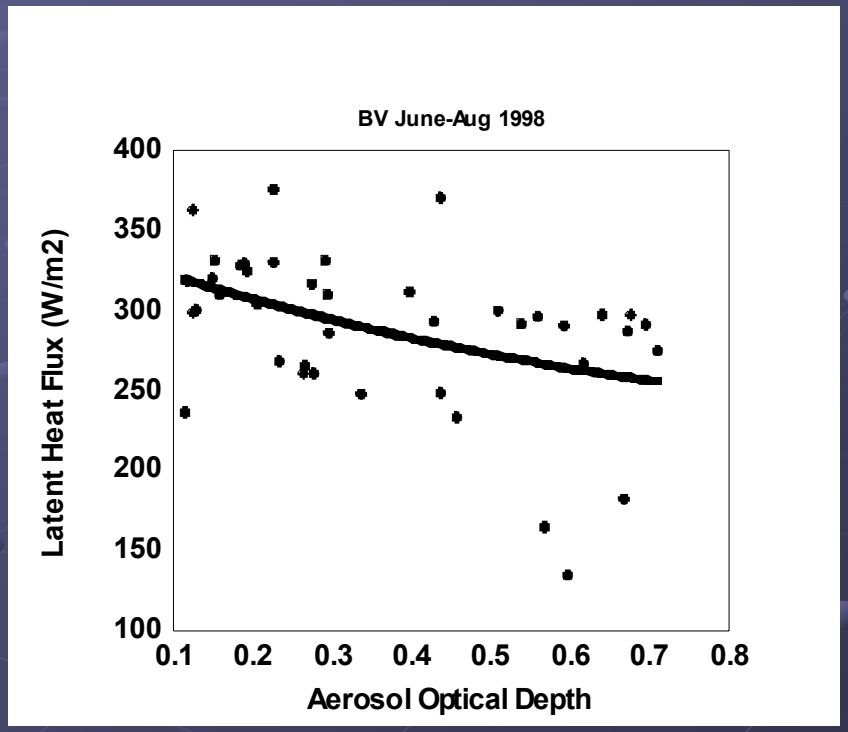
LHF increase with aerosol loading

However, analyzed results vary for different landscapes

Bondville (soy bean site(C3)):



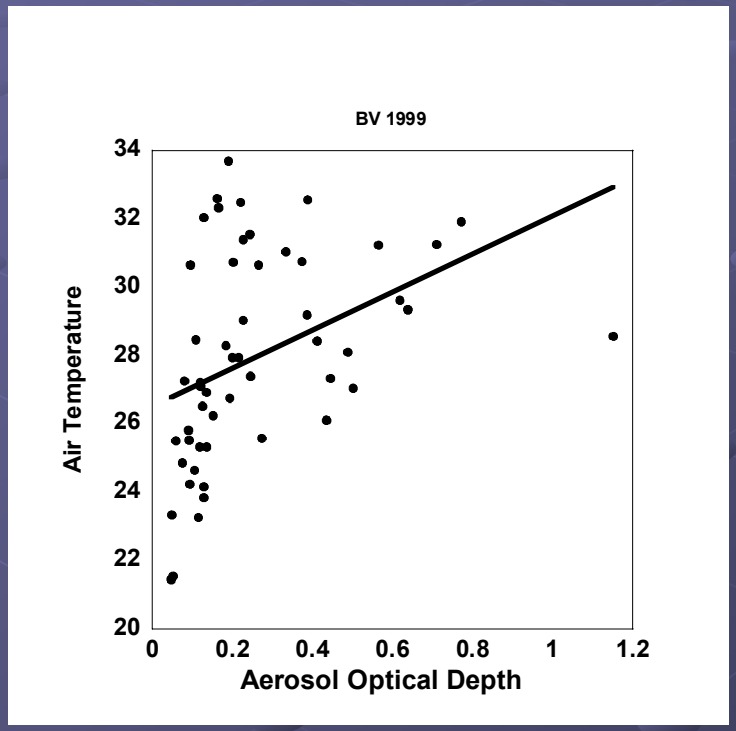
Low LAI case



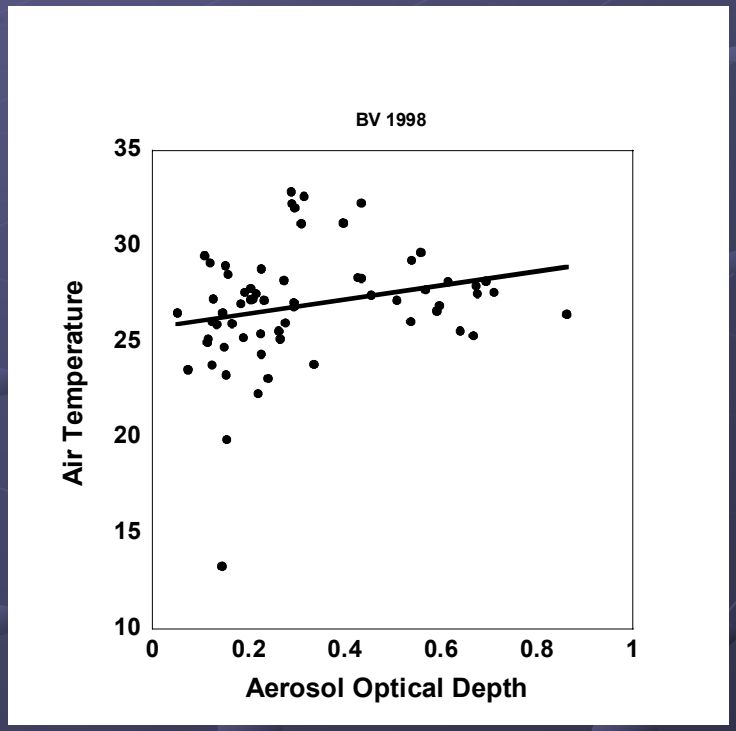
High LAI case

Effect of Temperature changes:

With AOD changes, as a result of radiation changes, air temperature can also change (warming or cooling depending on aerosol type)

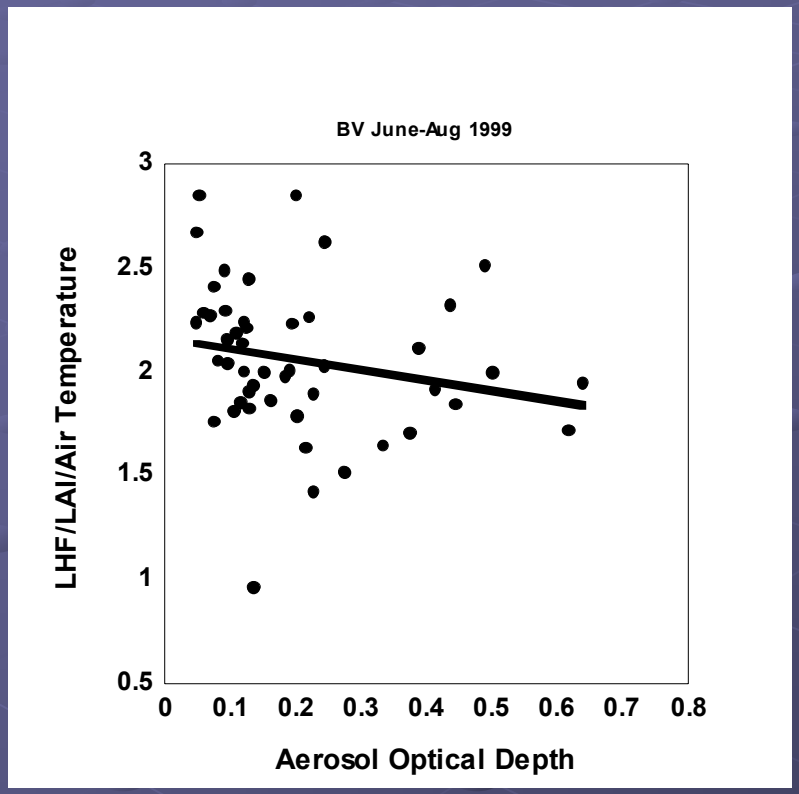


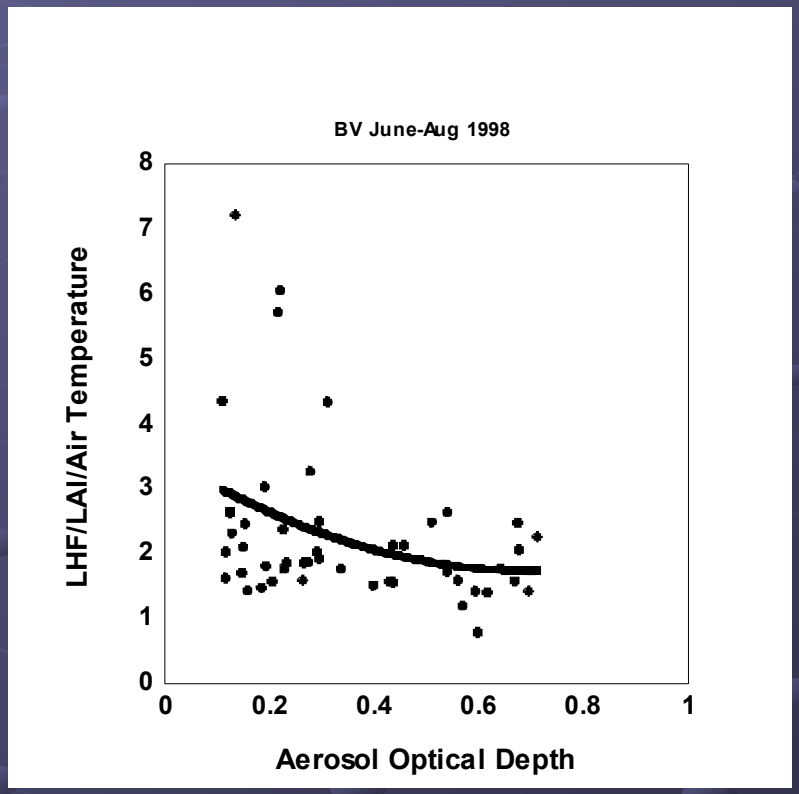
Corn



Soybean

AOD-LHF relation after accounting for both leaf area and air temperature effects:



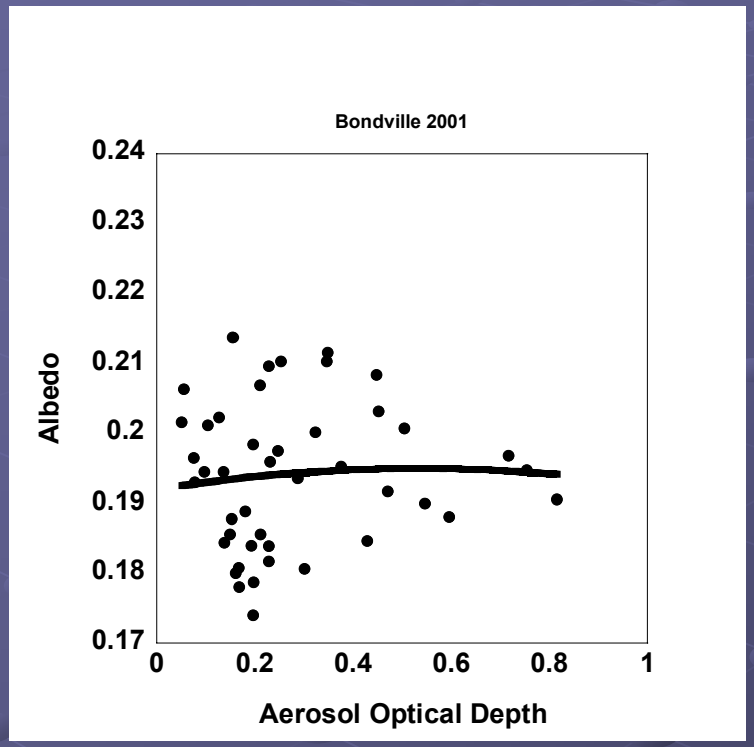


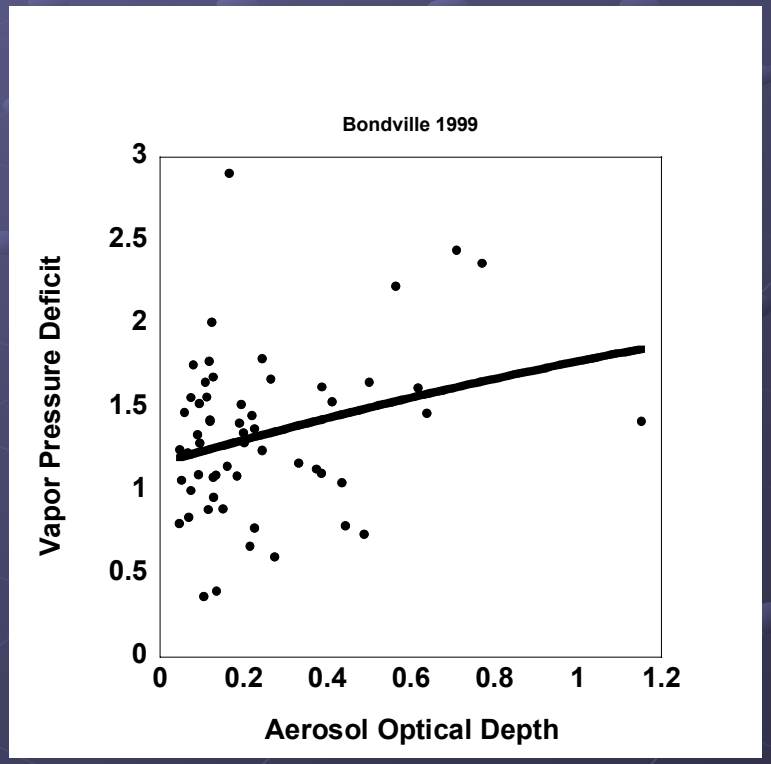
corn site

soy bean site

More consistent LHF decrease with increasing aerosol loading

AOD - LHF-vpd - Albedo nexus (soybean)



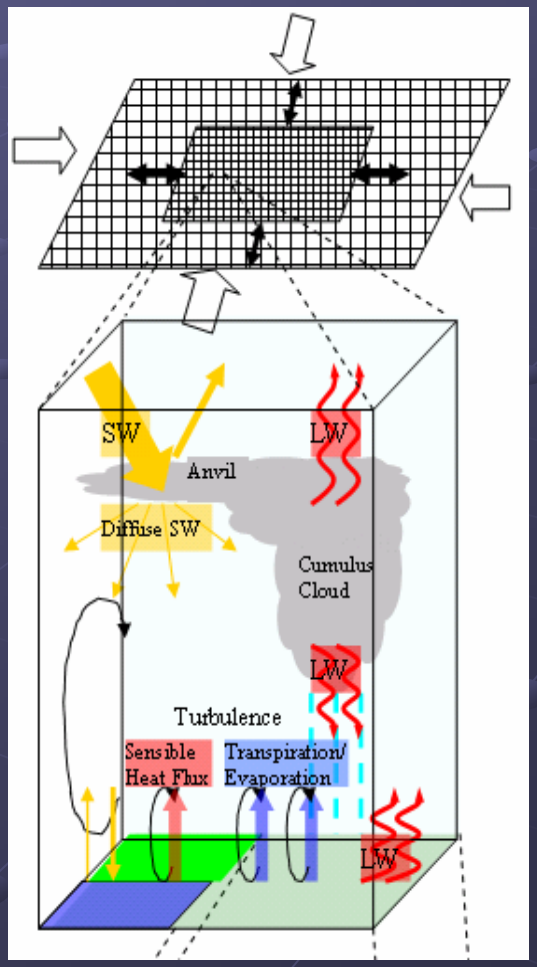


Conclusions:

- Aerosols affect land surface processes
  - Results confirmed for different canopy conditions (mixed forests, corns, soybeans, winter wheat and grasslands).
- CO_2 sink increases with increasing aerosol loading over forests and croplands (both C3 and C4)
- CO_2 source increases with increasing aerosol loading over grasslands
- Water Vapor Flux generally decreases with increasing aerosol loading
  - Exceptions were winter wheat sites,one grassland, and high LAI forest sites

Ongoing and Future work:

- Isolating the effects of different variables in understanding the aerosol feedbacks on the land surface response
  - Initial work with offline model (GEMTM)
  - Followed by coupled model (with RAMS)



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 “temperature-centric” feedback)

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

Additional references

Direct Observations of the Effect of Aerosol Loading on Net Ecosystem CO2 Exchange over different landscapes, Geophys. Res. Lett., Published October 2004 (Niyogi et al.)

Direct Observations of the Aerosols Effects on Terrestrial Carbon and Water Cycles, AGU Fall Meeting, Dec 2004 (Niyogi et al.)

NASA Press Release (UPN, Yahoo News,Washington Post, and over 50 other sites) [NASA study finds tiny particles in air may affect carbon sinks; Dec 16, 2004]
http://www1.nasa.gov/vision/earth/environment/aerosol_carbon.html

Direct Observations of the Effect of Aerosols on Water Cycles, in preparation (Early 2005 submission)

Thanks!