Clouds, Rainforest and Terrestrial Hydrological Cycle in the Tropics

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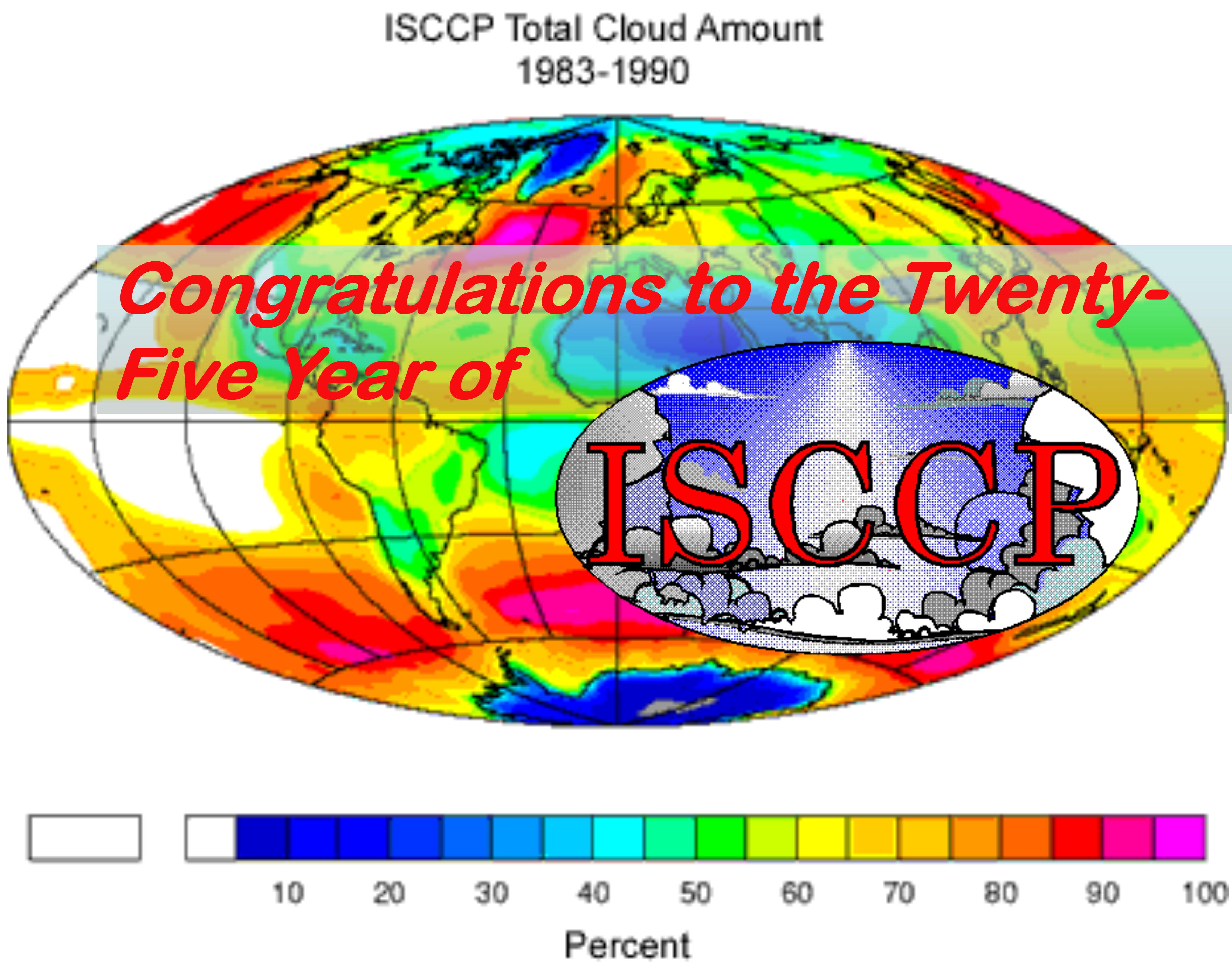
NAS GISS, New York City

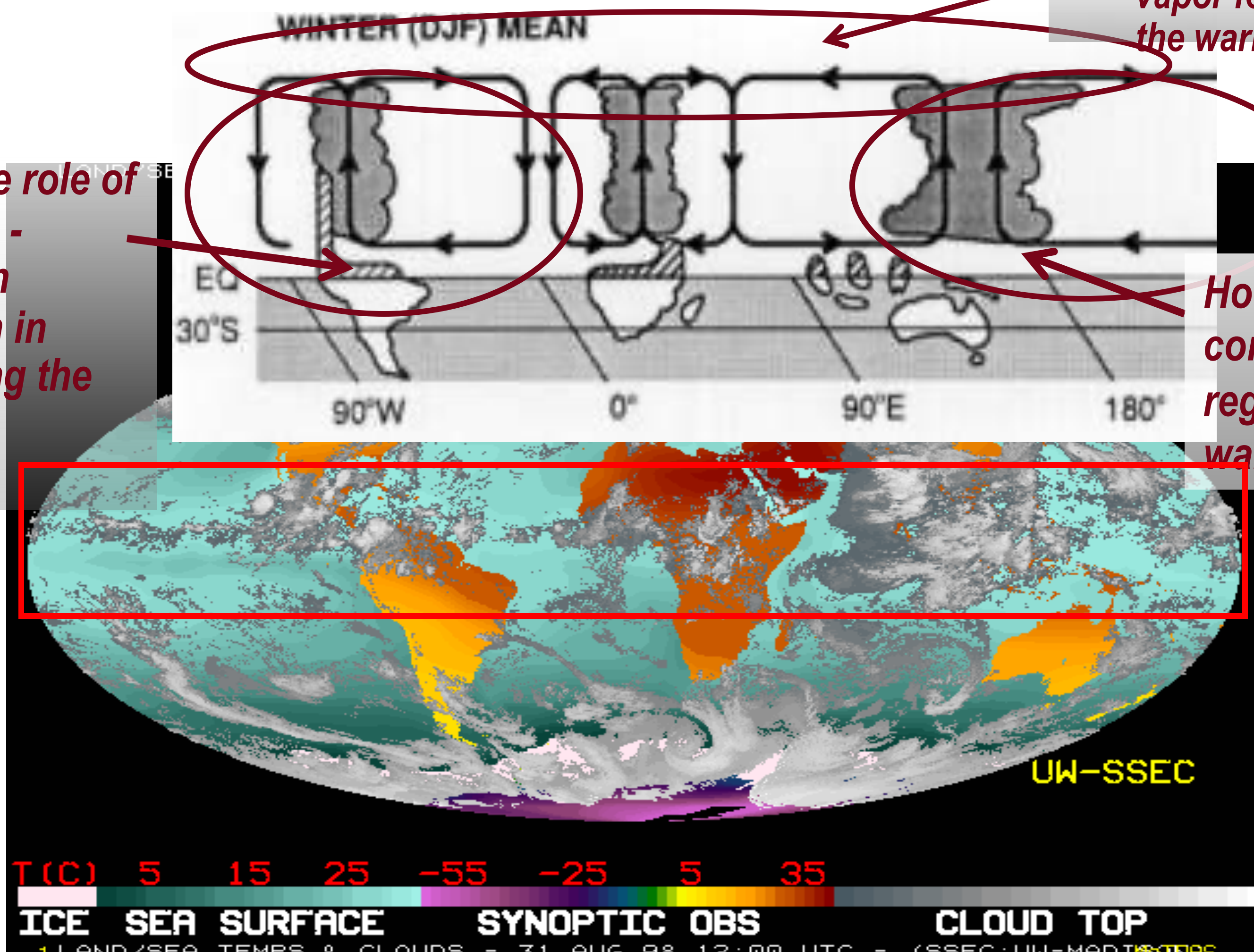

ISCCP Total Cloud Amount
1983-1990
Congratulations to the Twenty-Five Year of
ISCCP
10
20
30
40
50
60
70
80
90
100
Percent

The Overarching Question:

What is the role of the tropical atmospheric hydrological cycle in determining the stability of the Earth climate system?

How strongly would water vapor feedback amplify the warming?

What is the role of vegetation - convection interaction in determining the fate of the Amazon?



How does convection regulate the warmest SST?

Most of terrestrial biomass is concentrated in the tropical forest areas:

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Global EVI

Tropical rainforest productivity appears to increase in the past few decades:

- Growth and mortality rates of the tropical rainforest increased since 1980s, esp. in the less disturbed areas. (Philips et al. 2004; Lowis et al. 2004; Laurance et al. 2005.)

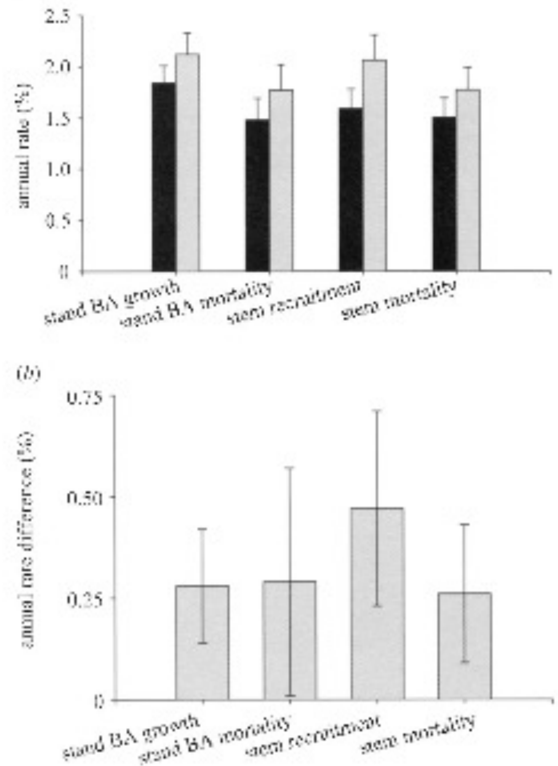


Figure 3. (*a*) Annualized rates of stand-level BA growth, stand-level BA mortality, stem recruitment and stem mortality from two consecutive census intervals (black bars, interval 1; grey bars, interval 2); (*b*) stand-level BA growth, stand-level BA mortality, stem recruitment and stem mortality over census interval one subtracted from that over interval two (rate difference), each from 50 plots with 95% CIs. The average mid-year of the first and second censuses was 1989 and 1996, respectively.

Figure 2. The location of the study plots. Codes RIO, JAR, CAX and YAN have one plot each, EDL, JAC and SUC have two plots, TAP, BNT and JAS, have three plots, ALP and CUZ have four plots, MNU and TAM have six plots and BDF has 11 plots.

Proposed causes:

- CO_2 fertilization (Laurance et al. 2005; Gedney et al. 2006)
- Change in cloudiness (Nemarn et al 2003)
- Increase in aerosols
  - Increase nutrient (Artaxio et al. 2002)
  - Increase diffused light (Guo et al. 2003)

The increase of productivity is strongest in the tropics:

- *Nemarn et al. (2003): Increase in temperature in high-latitudes, and decrease in clouds in tropics maybe responsible for increase global terrestrial NPP;*

Increase NPP in tropics, esp. Amazon accounted for 42% of the global increase of bio-productivity.

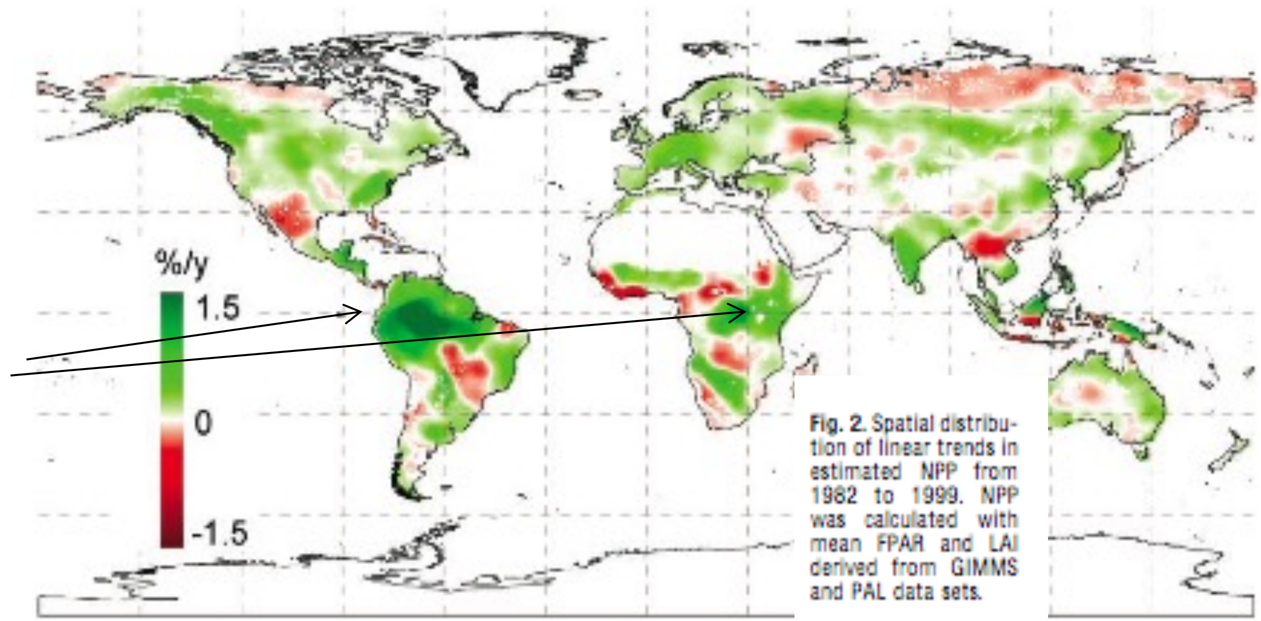


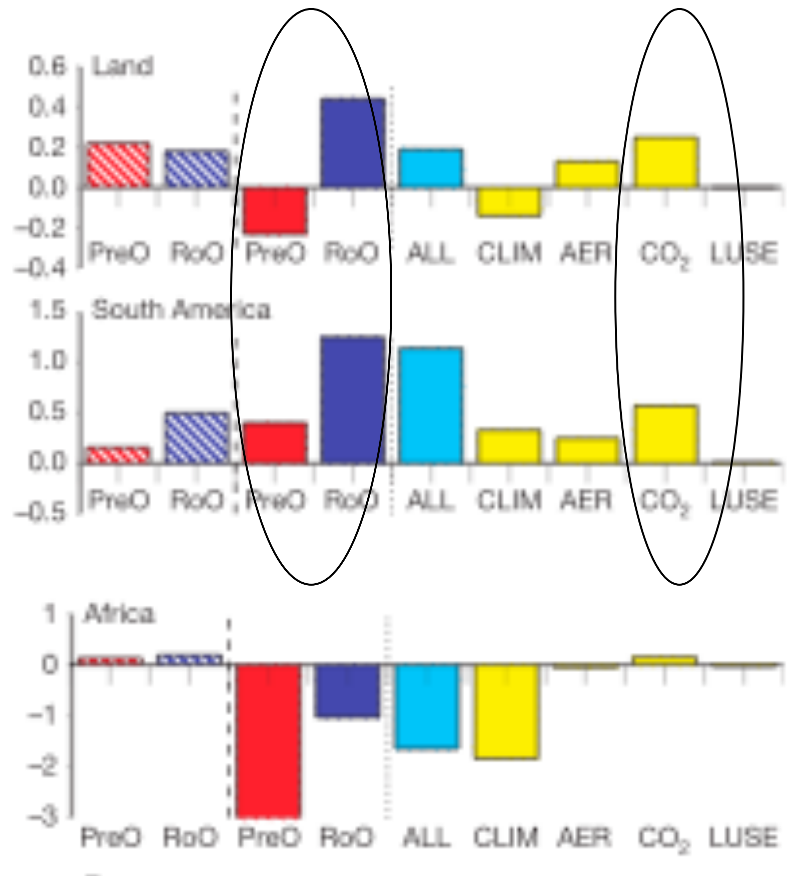
Fig. 2. Spatial distribution of linear trends in estimated NPP from 1982 to 1999. NPP was calculated with mean FPAR and LAI derived from GIMMS and PAL data sets.

Nemarn et al. 2003

Hydrological cycle over tropical land also appear to change:

Gedney et al. 2006:

- ***Runoff has been increasing, despite decrease of rainfall over land, esp. during post-1960 period.***
- ***Response of vegetation to increase of CO_2 can reduce ET, thus cause increase of runoff.***



Outline:

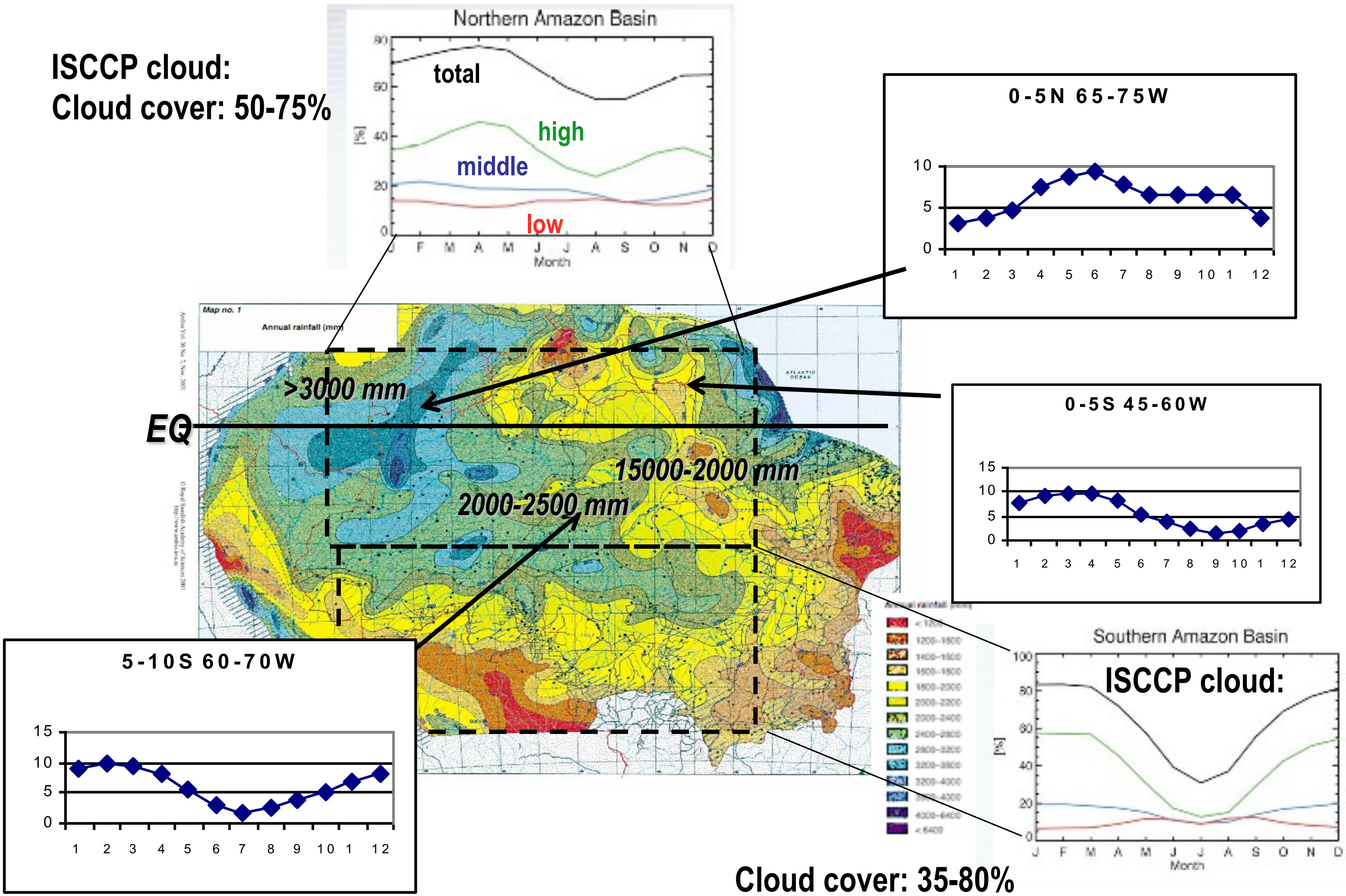
- *Is increase of productivity of the Amazon rainforest a cause or a result of the change in hydrological cycle?*
  - *Link between the forest productivity and hydrological cycle*
  - *Change of cloudiness and potential causes*
  - *Potential role of aerosol-cloud interaction in determining the change of hydrological cycle*
  - *Issues and challenges*

Summary:

- Over tropical rainfall forests, change in clouds largely control the climate variability of the photosynthesis, thus CO_2 flux and ET, on seasonal, interannual, perhaps also on decadal scales.
-
- The response of the rainforest to changes of cloud/radiation tend to stabilize the original climate anomaly. However, smoke aerosol emitted by burning forests could interact with clouds, and may amplify the original climate anomalies;

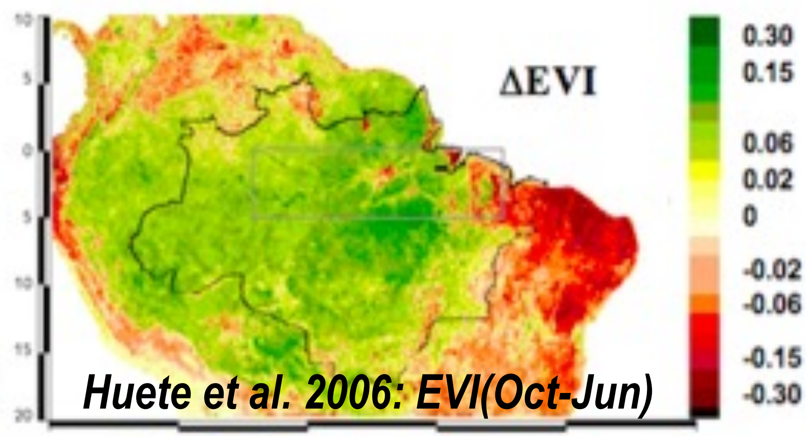
- A well calibrated multi-decades clouds data with adequate diurnal resolution (e.g., the ISCCP data) are critical to understand the interaction between terrestrial biosphere and hydrological cycle in a changing climate.

Cloud and rainfall climatology over the Amazon:

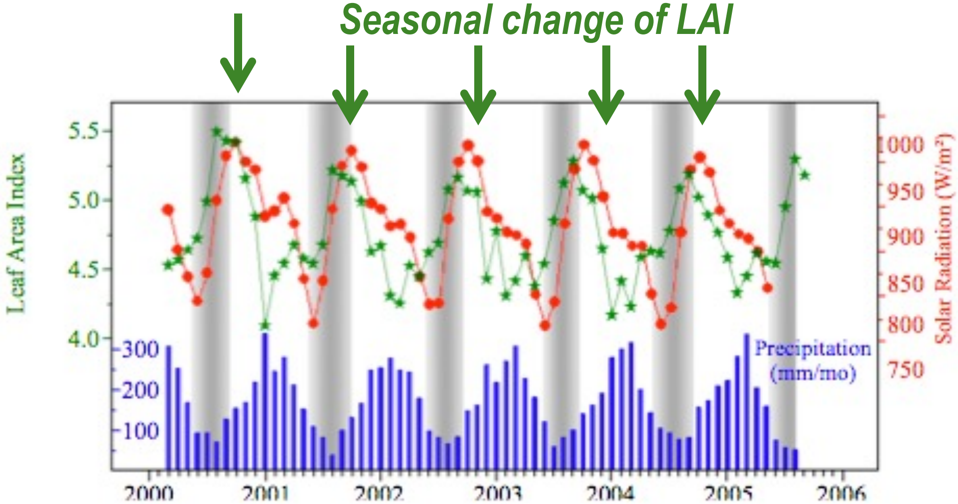


Seasonal cycle of the forest productivity and ET is correlated to that of the surface radiation:

- ***LAI and ET increase at the end of the dry season is correlated with the growth and greening of the forest canopy responding to the increase of solar radiation.***



Huete et al. 2006: EVI(Oct-Jun)



Myneni et al. 2007, PNAS

Flux tower ET

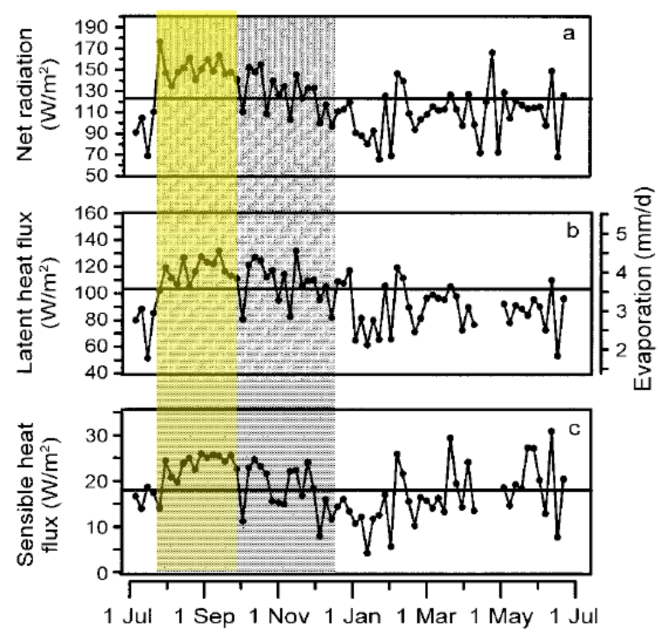
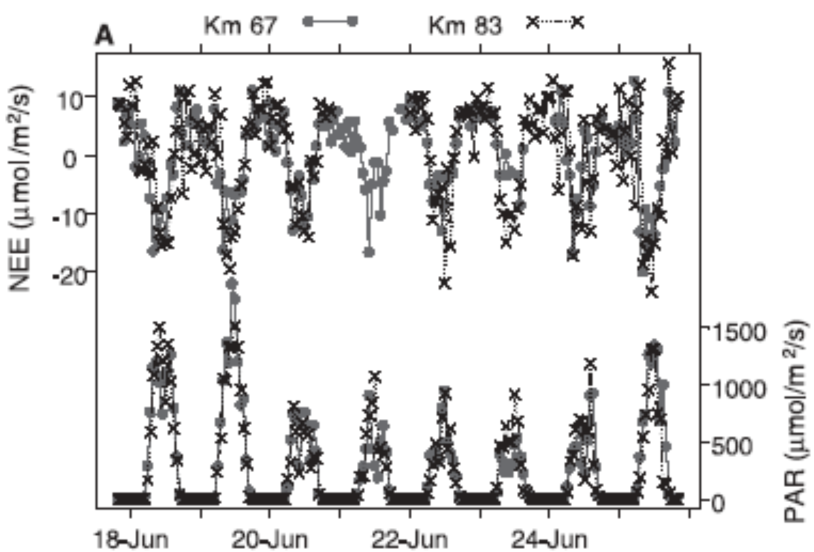


FIG. 7. (a) Net radiation (lines connecting 5-d means), (b) latent heat flux (on the left axis) and evaporation (on the right axis), and (c) sensible heat flux. T[...] represent the annual means. The dry seas[...]

de Rocha et al. 2002

Change of radiation also largely control the interannual variation of NEE in the Amazon:

- ***For most of interannual drought:***
- ***SR_{sfc} ↑→ NEE & ET ↑→ mitigate surface dryness***



Saleska et al. 2005: In situ LBA data

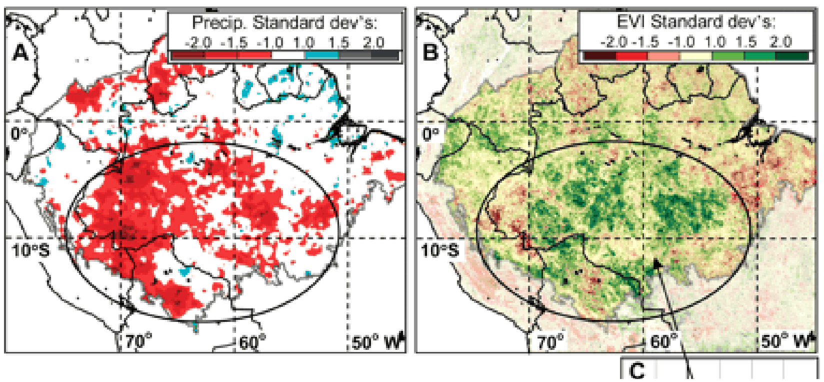


Fig. 1. Spatial pattern of July to September 2005 standardized anomalies (3) in (A) precipitation (derived from Tropical Rainfall Measuring Mission satellite observations during 1998–2006) and in (B) forest canopy "greenness" (the EVI derived from MODIS satellite observations during 2000–2006). ***Saleska et al. 2007***

Use of ISCCP and EVI to derive ET over the Amazon rainforest:

Negrón Juárez et al. 2008

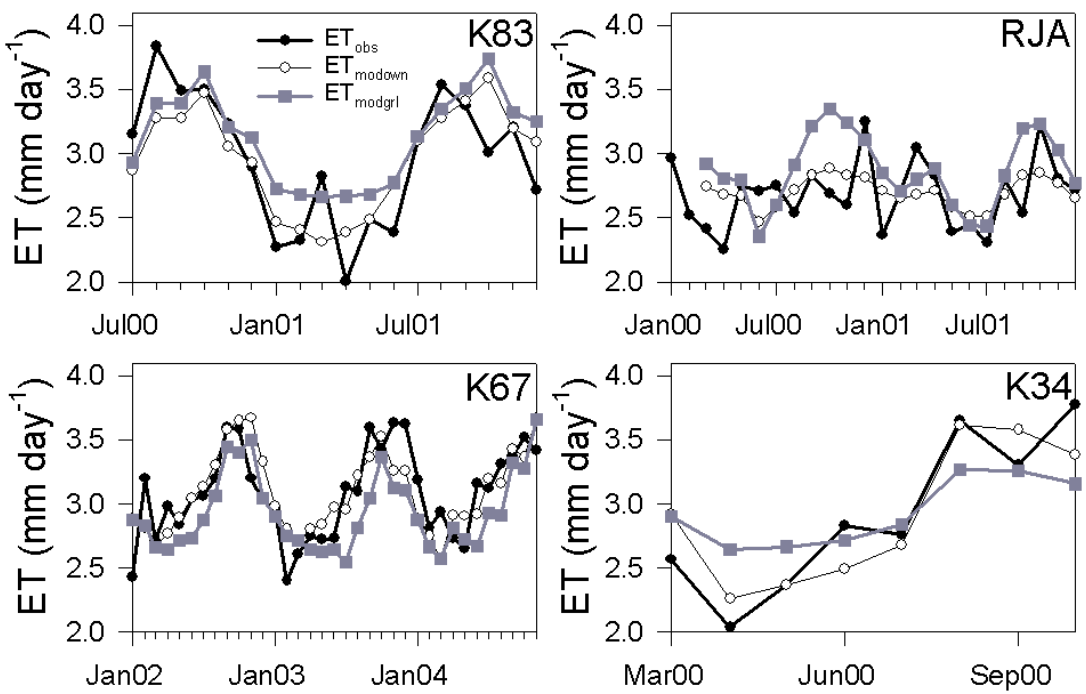
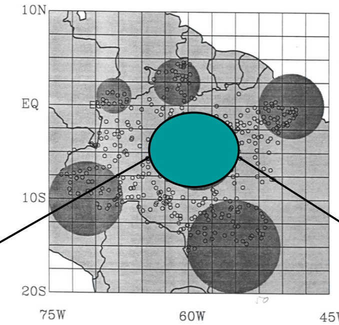
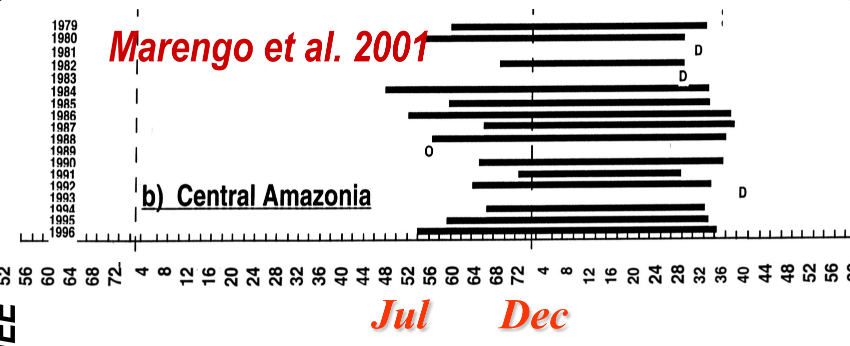


Figure 5. Comparison between observed, ETobs (solid black line), and calculated values of evapotranspiration using a calibrated model for each site, ETsite (gray line and open circles), and a general model based on K83 and RJA sites, ETgrl (gray line and full squares) for sites K83, RJA, K67, and K34.

Importance of wet season onset:

- *Change in wet season onset date has the greatest impact on NEE (bio-productivity) and biomass burning through rapid increase of cloudiness and rainfall.*





AERONET, Schafer et al. 2007

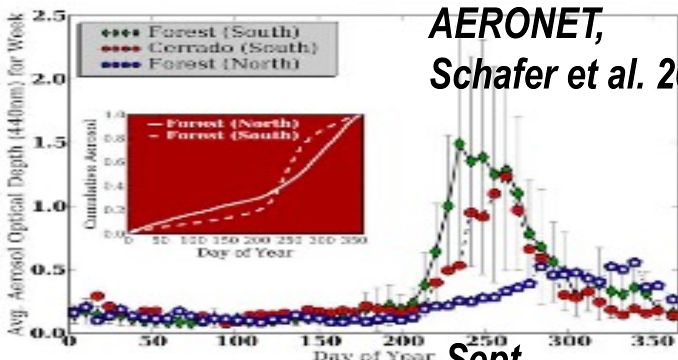
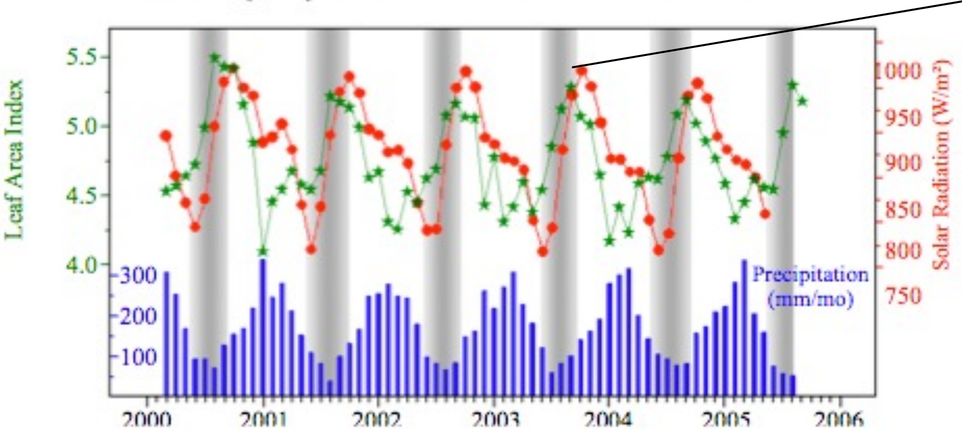
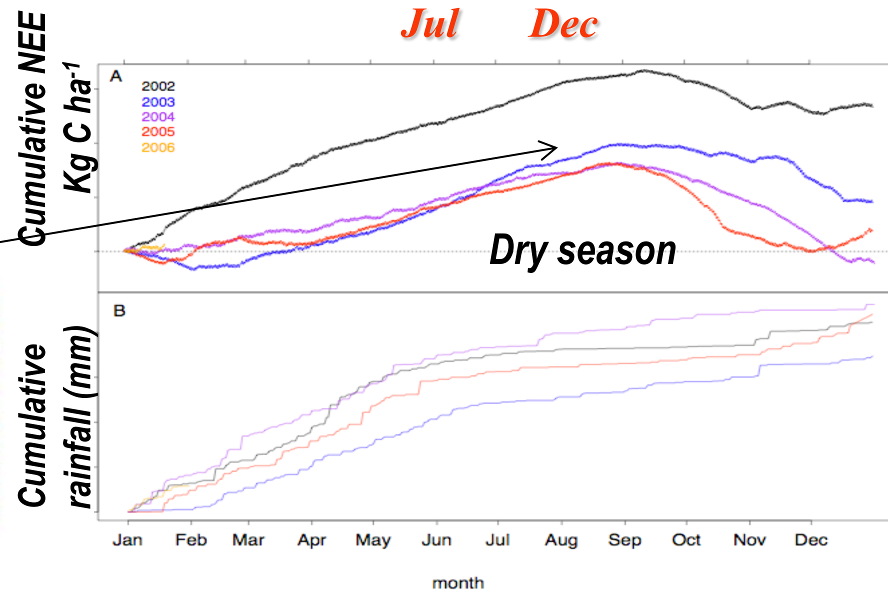


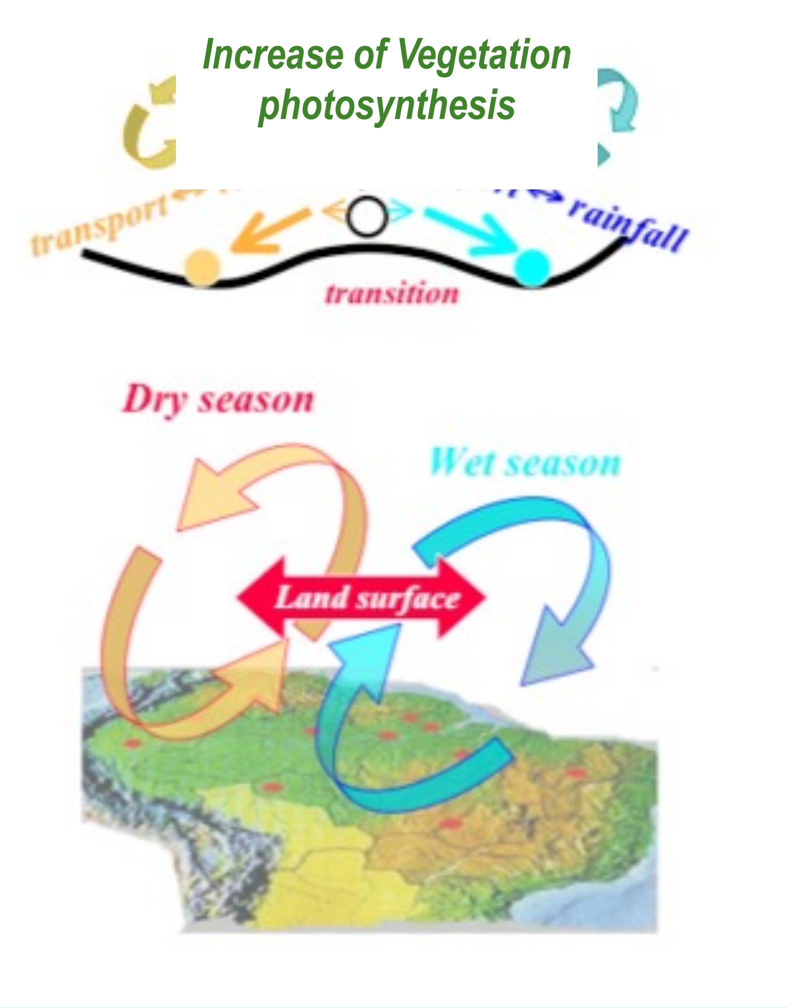
Figure 2. Weekly averages of aerosol optical depth (440 nm) for regionally grouped sites and cumulative aerosol contribution (inset).





Hutyra et al. 2007: Tapagos National Forest

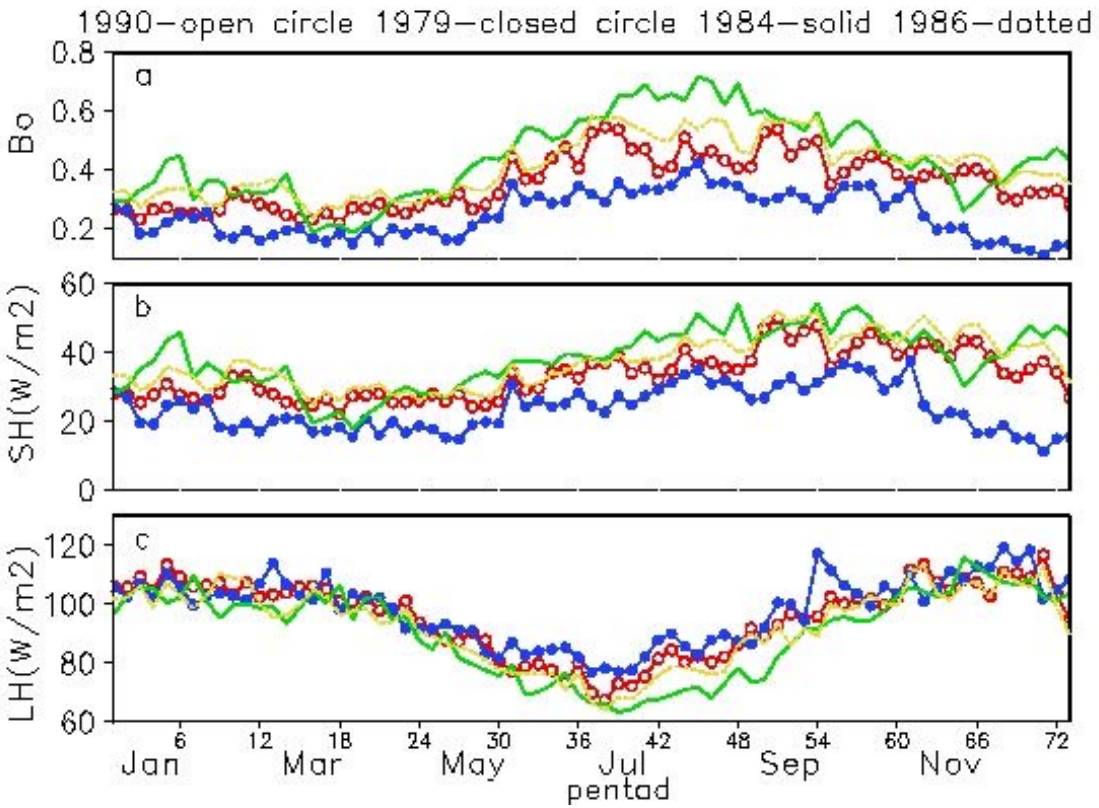
Role of the rainforest in wet season onset:



- *Seasonal growth of rainforest increases surface latent flux at the end of dry season, which in turn initiates the transition from dry to wet season.*

Li & Fu 2004

- *Interannual changes of wet season onset is highly sensitive to changes in surface latent and sensible fluxes in the dry season;*
- *Earlier termination of wet season can delay subsequent wet season onset.*



1979-early

1990-norm

1984-late

1986-late

Bo=SH/LH

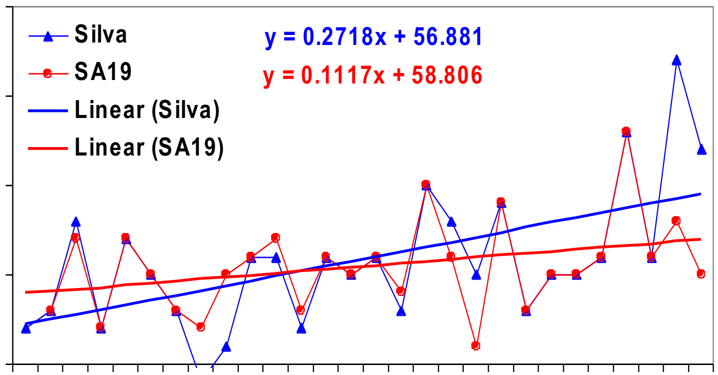
Early onset: lower Bowen ratio in dry season
Later onset: higher Bowen ratio

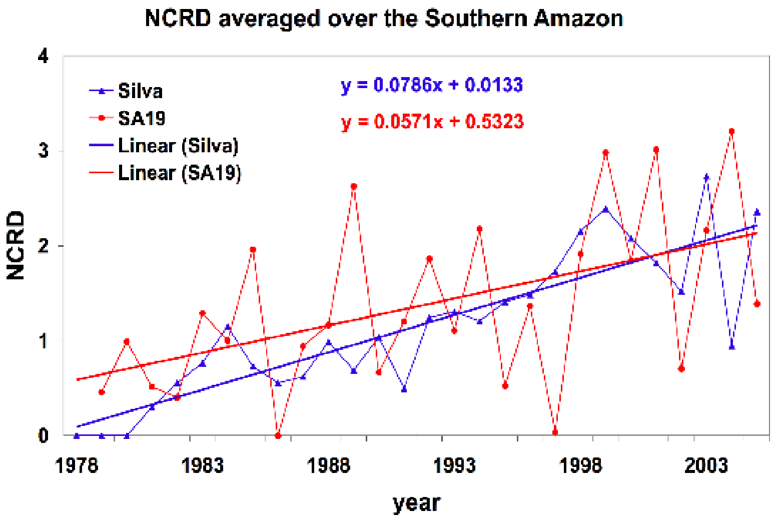
Fu & Li 2004

- ***Vegetation and hydrological cycle are strongly coupled, esp. through its influence on wet season onset.***

- ***How has hydrological cycle changed over the Amazon in the past few decades?***

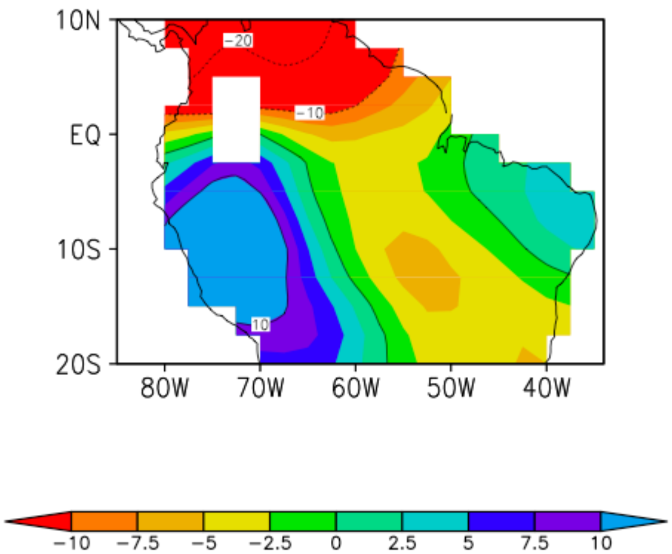
Observed changes in rainfall:





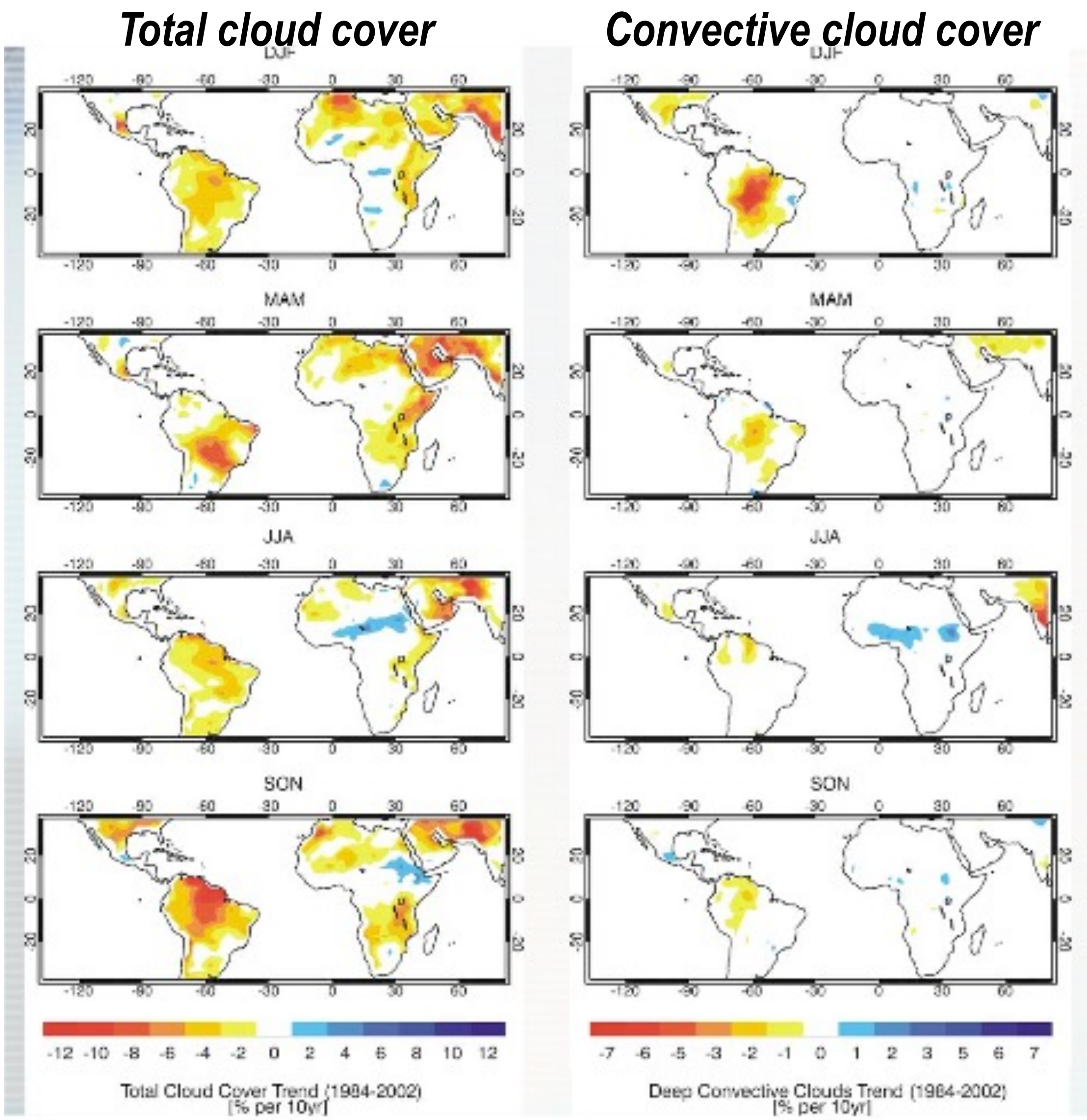
Fu et al. 2008, Dai 2004

- **Long-term raingauges data suggest a delay of wet season onset and an increase in drought severity over the S. Amazon (5˚-15˚S, 50˚-70˚W) during the period of 1979-2005 (Mann-Kendall test, 95% confidence).**
- **Days with heavier rain during wet season has also increased (Machado 2004). This could potential increase runoff.**

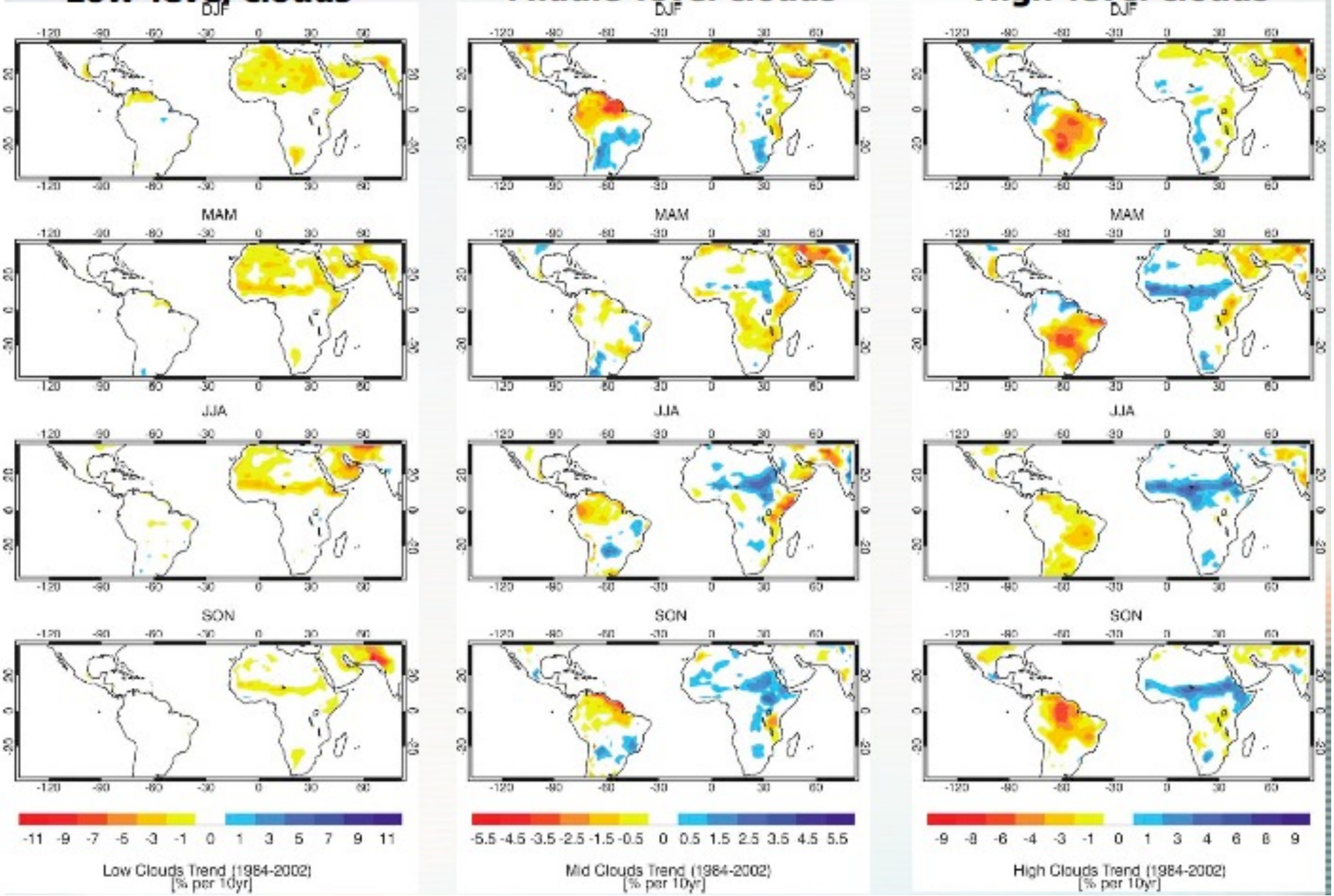


Daily rainfall data of Liebmann and Allured (2005) for 1979-2005.

Total convective cloud fractional cover apear to decrease:

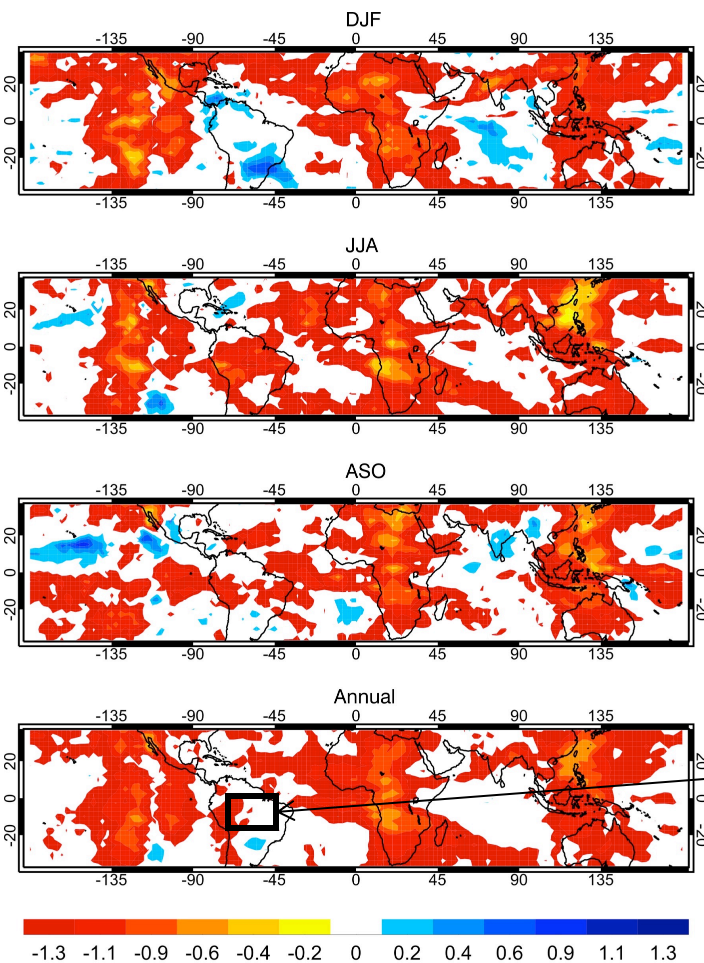


Low-level clouds **Middle-level clouds** **High-level clouds**

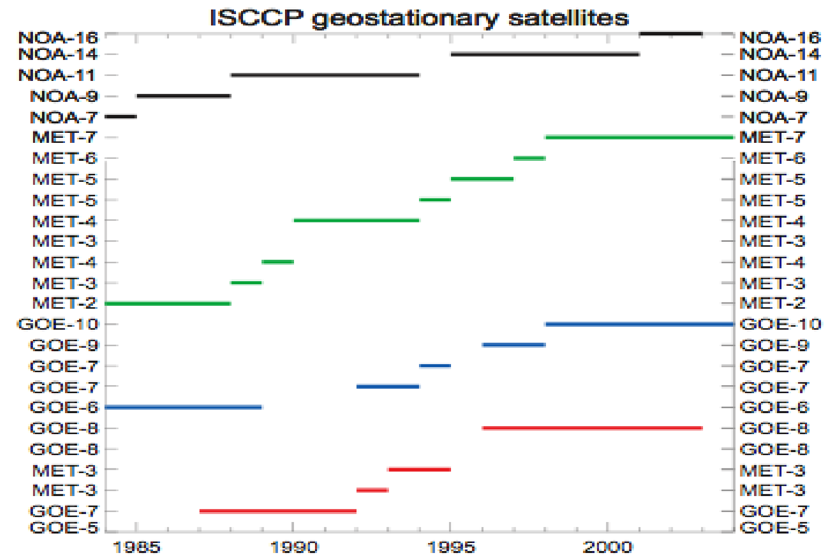


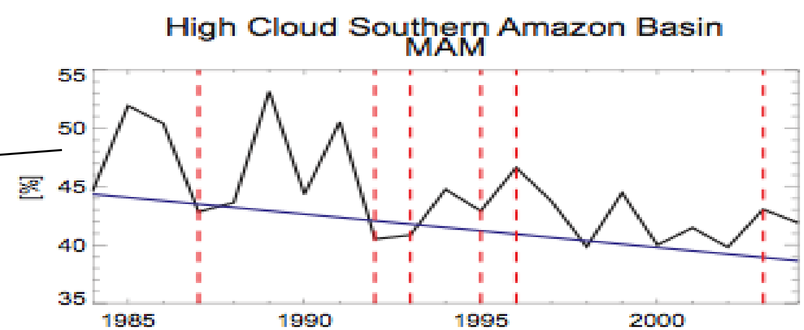
Is the trend a result of inter-satellite bias?

- Unlikely.



Total Cloud Cover Trend (1984-2004)
[% per year]





What might cause decrease of cloudiness?

Results derived from several independent data suggest that

- ***Atmospheric stability has increased and the LFC has been elevated for the period of 1980-2005.***
- ***Moisture transport has also been weakened***
- ***Cold front incursions have decreased during SON.***

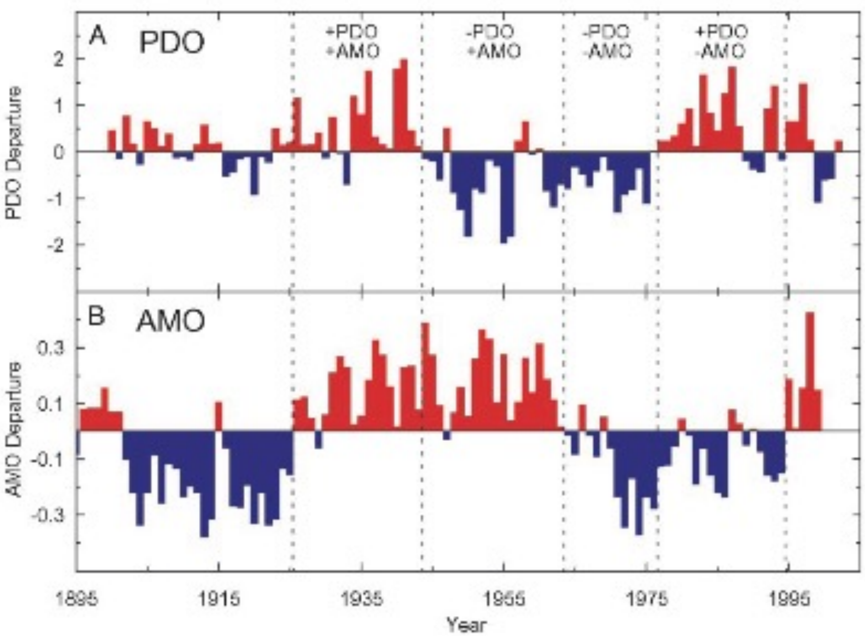
These changes are consistent with a decrease of convective and high clouds showing by ISCCP data.

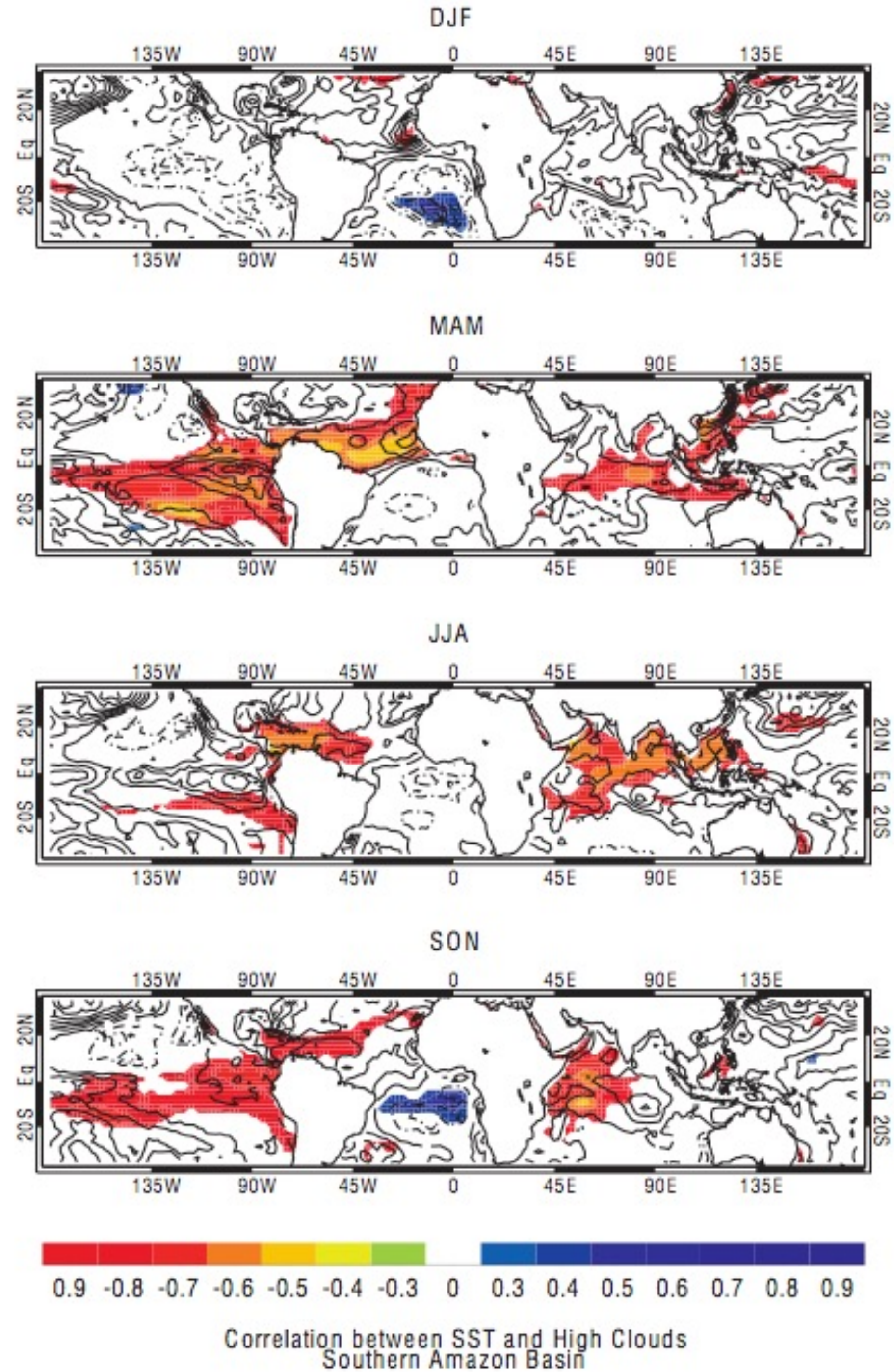
Table I: The trends of air relative humidity and temperature below 850 hPa (~1.5 km above the sea-level), the Convective Available Potential Energy (CAPE), and the Level of Free Convection (LFC) for the period of 1980-2005. The trends of the vertically integrated moisture transport from surface to 600 hPa, and cold front incursion index for the period of 1979-2005. Zero values indicate that the trends fail to reach 95% significance based on the Mann-Kendall test.

	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Surface-850 hPa:				
Air relative humidity (%/decade)	0	0	-6.7	-7.5
Temperature (ūC/decade)	0	0	0	0
Thermodynamic Instability:				
CAPE (J/kg/K/decade)	-80.0	-45.6	-60.5	-45.0
LFC (mb/decade)	-25.7	-5.1	-13.3	-12.7
Deep Convective Cloud Coverage:				
DCC (%/decade)	-4.0	-1.5	-0.1	-0.4
Atmospheric Transport (NCEP):				
Moisture convergence (mm/day/decade)	0.0	-0.7	-0.8	-0.8
Cold front incursions (ERA) (events/decade)	0	0	0	-0.6

Possible external forcing for the changes over the Amazon?

- Warming of E. tropical Pacific and N. tropical Atlantic in MAM and SON may force the reduction of high clouds and rainfall, esp. during MAM and SON;



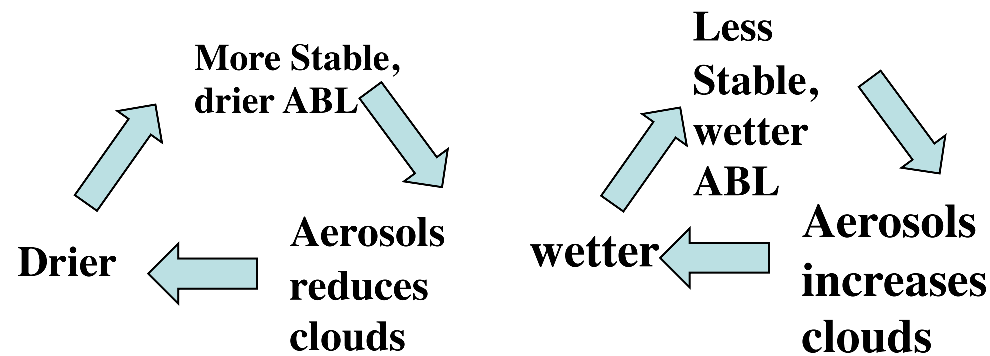


What might cause change of the terrestrial hydrological cycle?

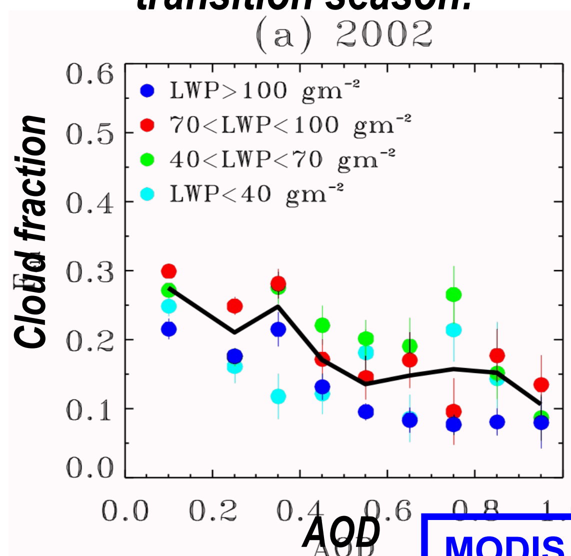
- ***External climate forcing (e.g. dSST) could qualitatively explain the observed changes in atmospheric thermodynamic structure, dynamic process and the hydrological cycle (longer dry period, more intense wet season rainfall and more runoff) and increase of bio-productivity.***
- ***Observed increase in bio-productivity may stabilize the externally forced change in hydrological cycle through radiation control of ET as long as soil moisture pool can provide needed water.***

Potential role of aerosol-cloud interaction:

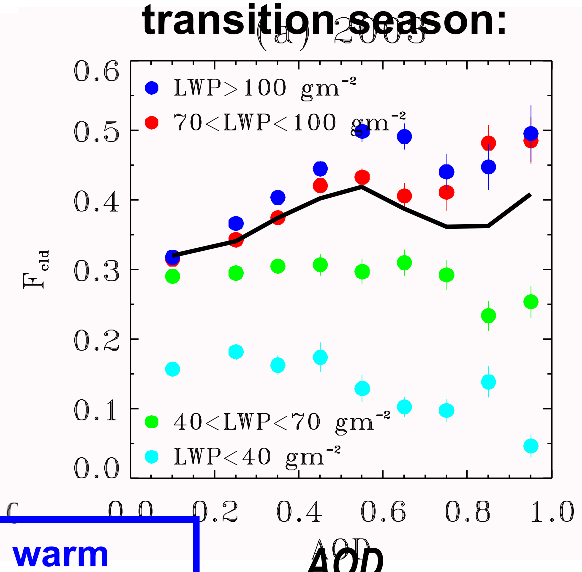
- *Hypothesis: Cloud change with aerosol may re-enforce the original dry/wet anomalies.*
- *Multi-decades cloud & aerosols data that resolve diurnal cycle are needed to evaluate such type hypothesis.*



During a drier transition season:



During an wetter transition season:



Yu et al. 2007

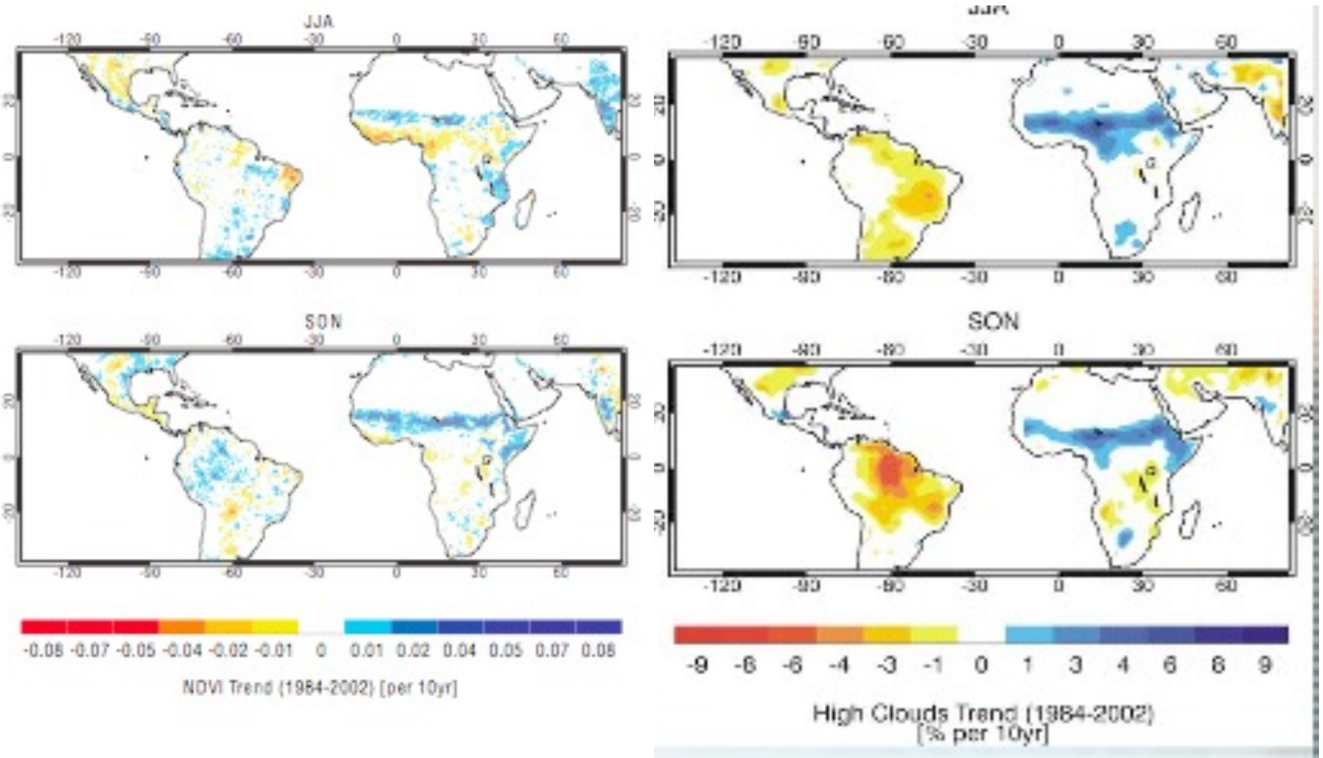
MODIS warm cloud & AOD

Issues and Challenges:

Cloud contamination in long-term NDVI:

- *In Amazon: An increase of NDVI with decrease of clouds appears to be a plausible result, especially in SON. However, the decrease of NDVI could be an artifact of cloud reduction;*

- *Can we remove the cloud contamination in long-term NDVI use existing cloud data?*

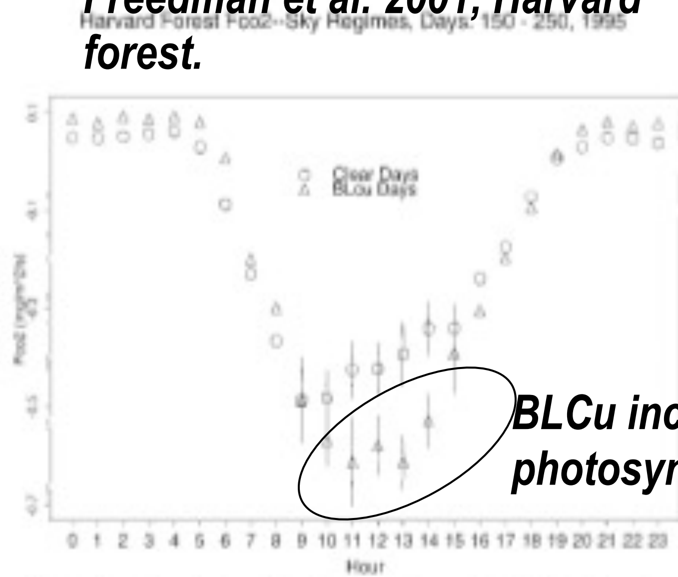


Impact of clouds and aerosols on bio-productivity through changing diffused radiation at the surface:

- ***Gu et al. 2002, 2003: aerosols increases diffuse light, thus enhance noontime photosynthesis.***

- ***A long-term global data of diffused light at the surface is needed to determine the impact of clouds/aerosols on bioproductivity.***

Freedman et al. 2001, Harvard forest.



BLCu increases photosynthesis

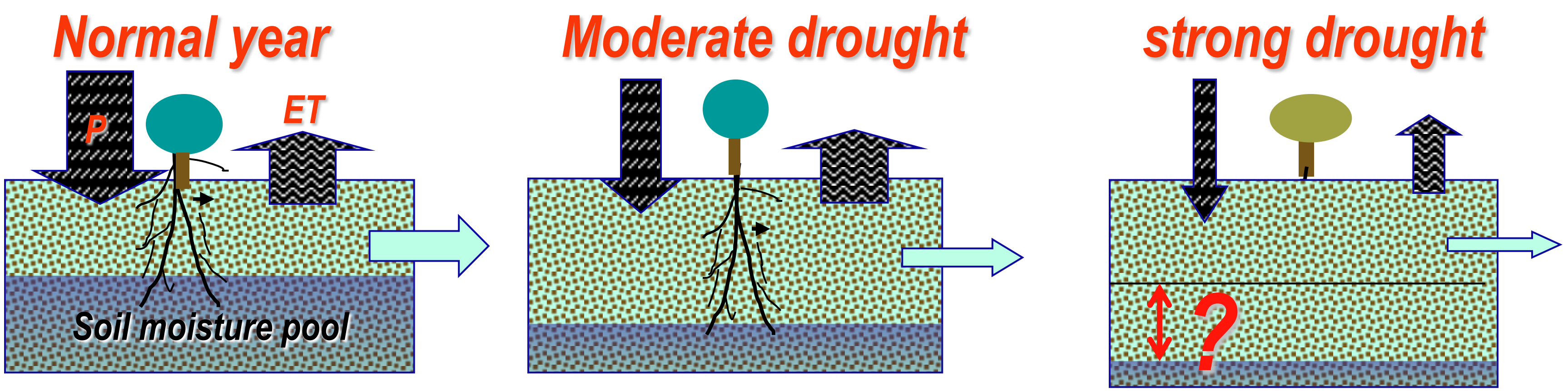
FIG. 13. Diurnal plot of hourly F_{CO_2} (mg m^{-2} s^{-1}) for clear (open circles) and BLcu (open triangles) days at HF, days 150–260, 1995. Vertical lines for hours 0900–1500 LT represent one standard error from the mean.

Summary:

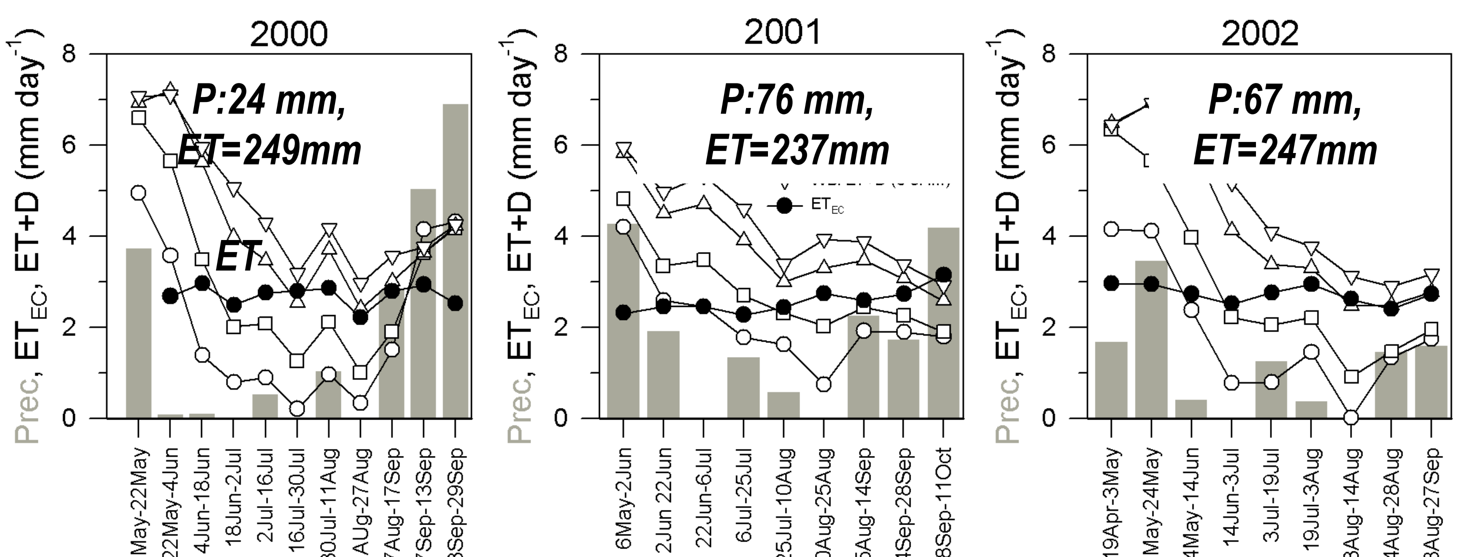
- Over tropical rainfall forests, change in clouds largely control the climate variability of the photosynthesis, thus CO_2 flux and ET, on seasonal, interannual, perhaps also on decadal scales.
-
- The response of the rainforest to changes of cloud/radiation tend to stabilize the original climate anomaly. However, smoke aerosol emitted by burning forests could interact with clouds, and may amplify the original climate anomalies;
- A well calibrated multi-decades clouds data with adequate diurnal resolution (e.g., the ISCCP data) are critical to understand the interaction between terrestrial biosphere and hydrological cycle in a changing climate.

Why radiation control?

- *Forest is not water limited because root uptake from deep soil moisture pool provides sufficient water to support photosynthesis.*



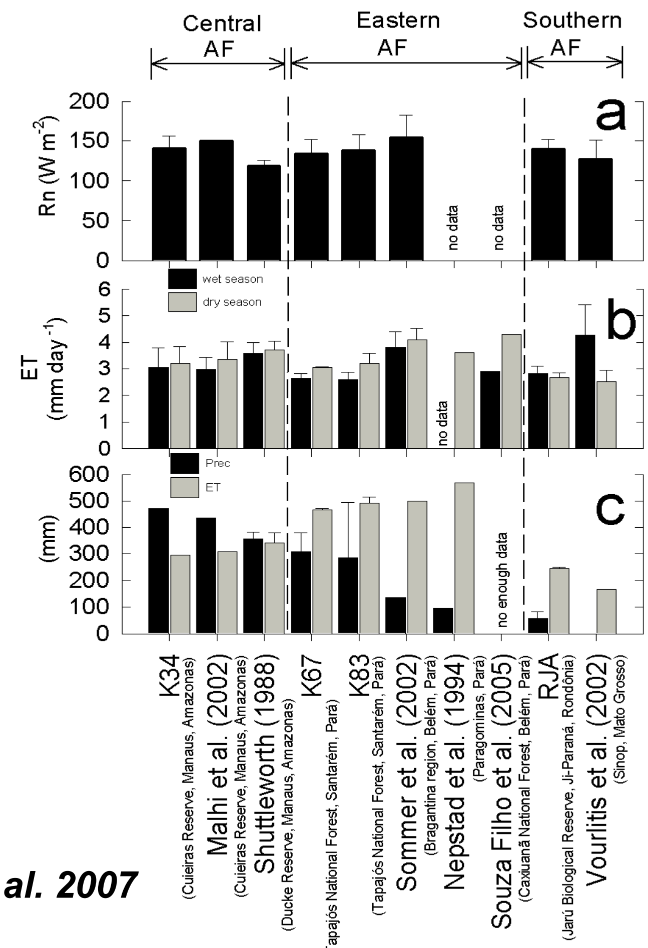
LBA: Jarú (10S, 62W) S. Amazon

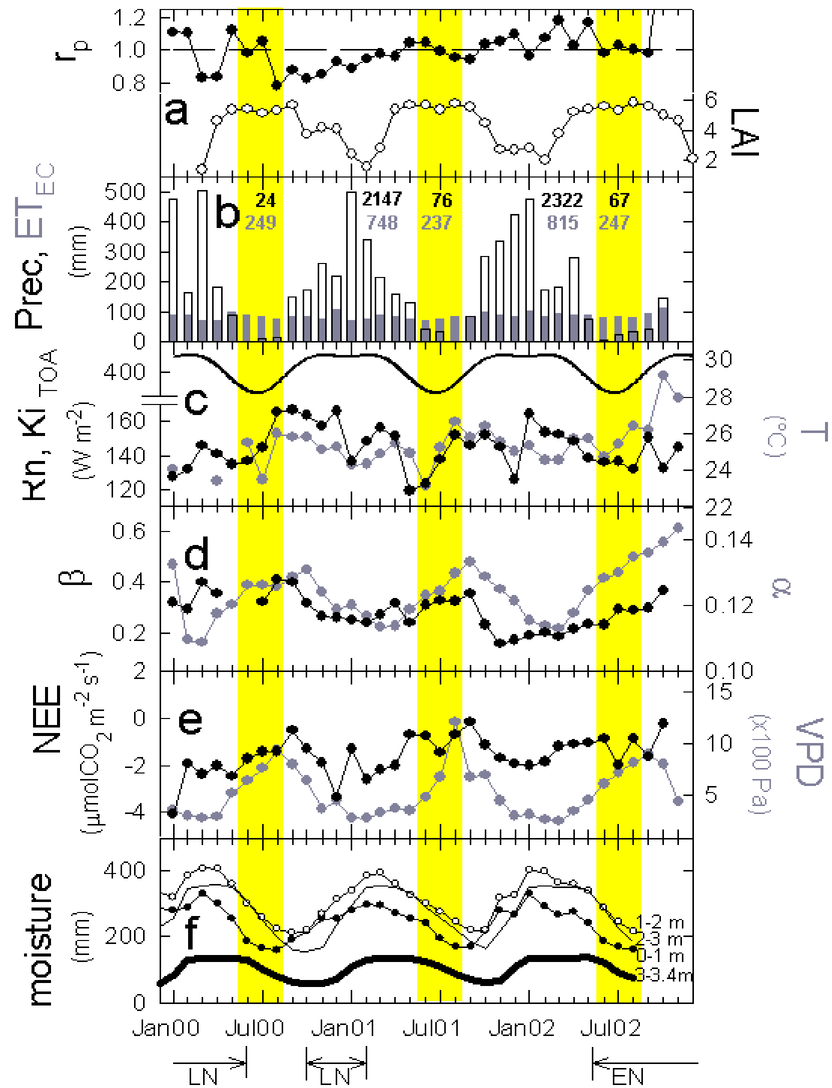


Negrón Juarez et al. 2007

Why?

- ***Forest is not water limited because root uptake from deep soil moisture pool provides sufficient water to support photosynthesis.***
- ***Radiation controls seasonal and spatial patterns of the forest productivity and ET.***





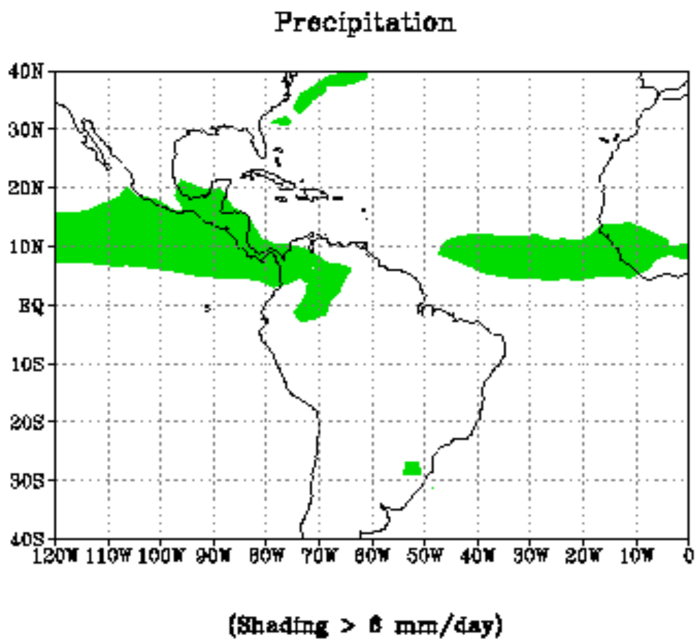
LBA: Jarú (10S, 62W) S. Amazon

RJA: Prec: mm (Blk), ET_{EC}, mm, gray; r_p: ET_{EC}/ET_{PT}, black, MODIS LAI, open circles); Ki_{TOA}, W m^{-2}: average incoming solar radiation at the top of atmosphere, Rn, Wm^{-2}: average net radiation, black; T, ° C: average temperature, gray; β: average Bowen ratio, black, α: canopy albedo, gray; NEE, μmol CO_2 m^{-2} s^{-1}, average net ecosystem exchange, blk;

Negrón Juarez et al. 2007

Seasonal cycle of the rainfall and clouds:

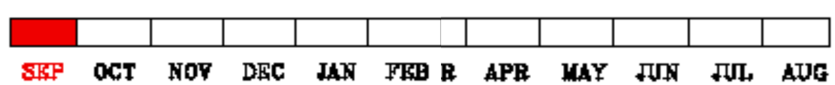
SE



On average, dry season ends in early November and begins in June.

Rapid increase of rainfall across broad latitudes occurs during austral spring (September to November).

Wet season ends by gradual northward migration of the rainy areas during austral fall (March to May).

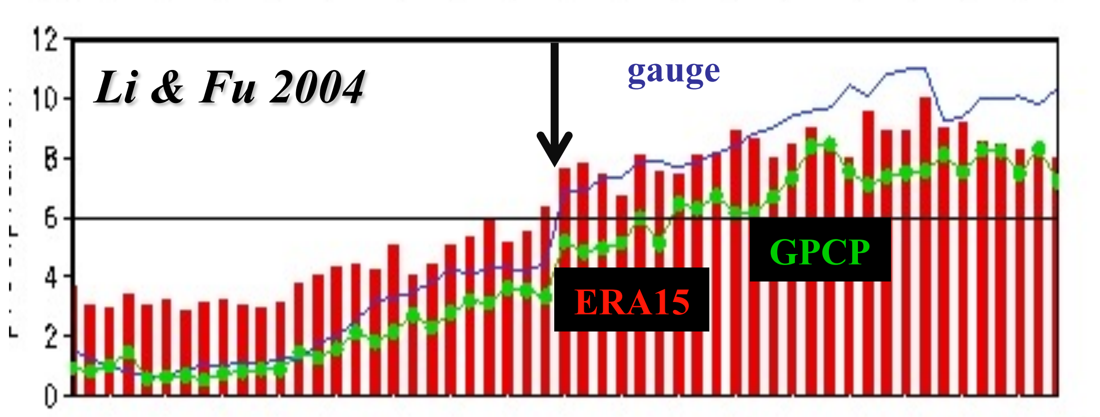


Kousky 1979; ; Marengo et al. 2000

Wet season onset:

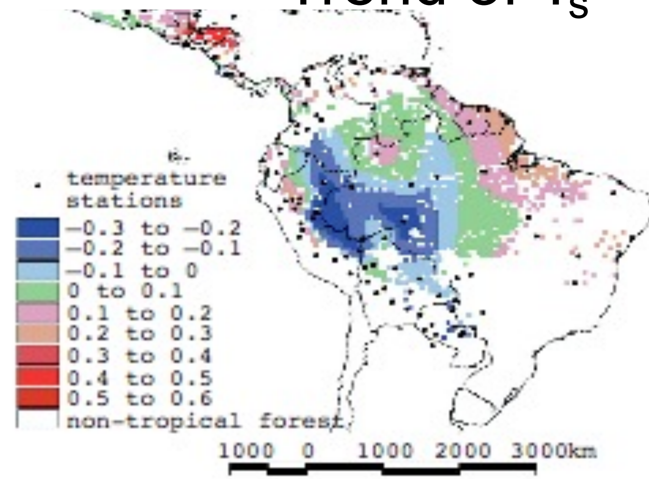
- *The jump from persistently lower rainrate to persistently higher rainrate relative to the annual mean.*

- *Define the onset date: The pentad before which rain rate is less than its climatological annual mean value during 6 out of 8 preceding pentads and after which rain rate is this rainfall threshold during 6 out of 8 subsequent pentads (Marengo et al. 2001; Liebmann & Marengo 2001)*



Can we detect any changes that could increase the photosynthetic activity?

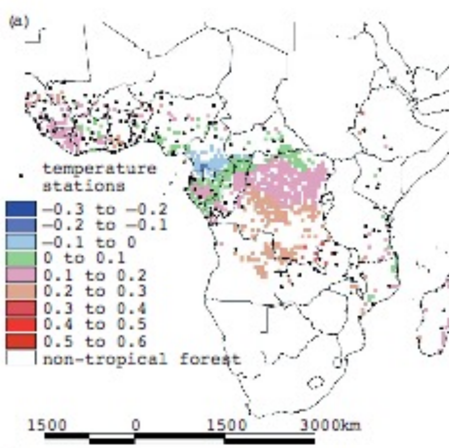
Trend of T_s

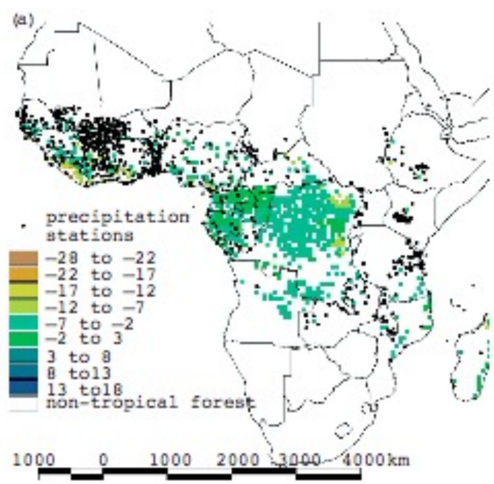


- ***Malhi & Wright 2004: A significant trend of decreasing annual rainfall can be detected over tropical Africa, but not over the Amazon for the period of 1960-1998.***
- ***Few stations in Amazon rainforest, no station inside of Congo rainforest.***

Trend of P

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.





Trend of T_s

Trend of P

What control the wet season onset over the Amazon?

surface latent flux ⇑

⇓

surface air buoyancy ⇑

⇓

convective inhibition energy (CINE) ⇓

⇓

Rainfall ⇑, elevated atmospheric heating

Chiang et al. 2001

⇓⇑

moisture convergence.

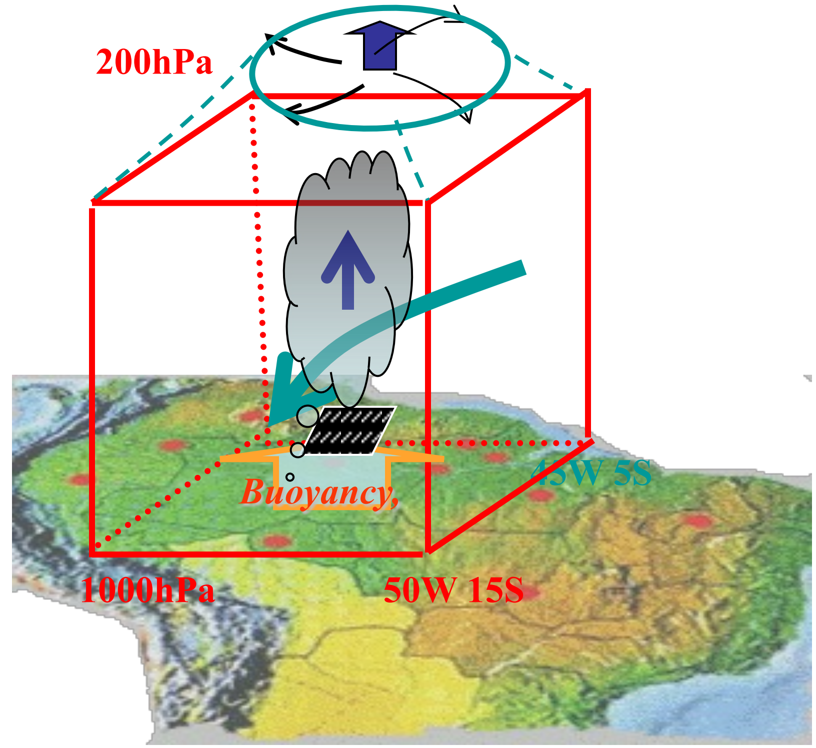
⇓

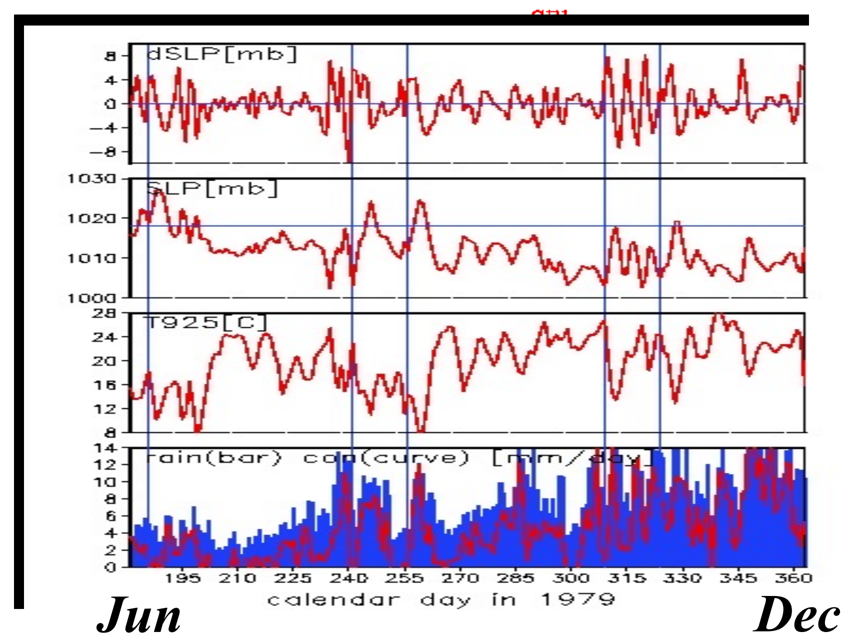
upper troposphere anticyclonic flow

⇓

wet season onset

Trigger mechanism: cold fronts incursions



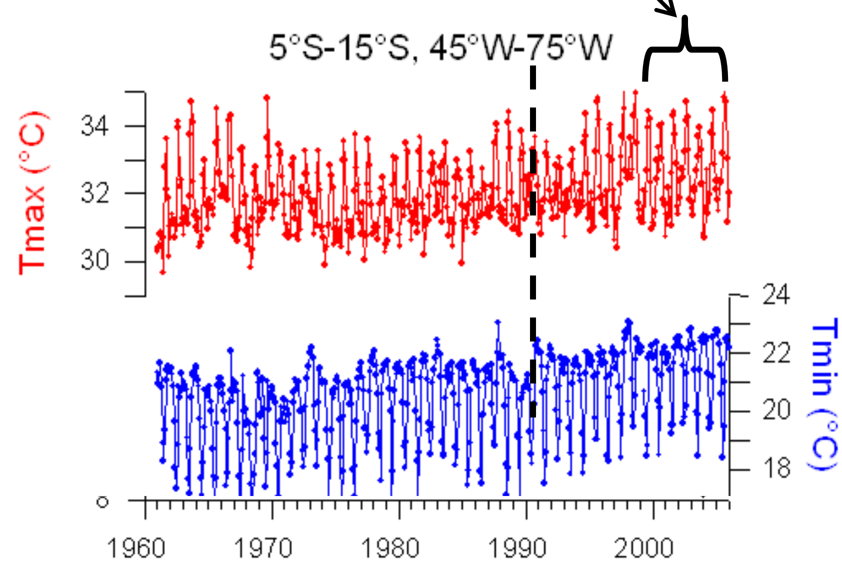


Li and Fu 2004, 2006, J. Climate

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

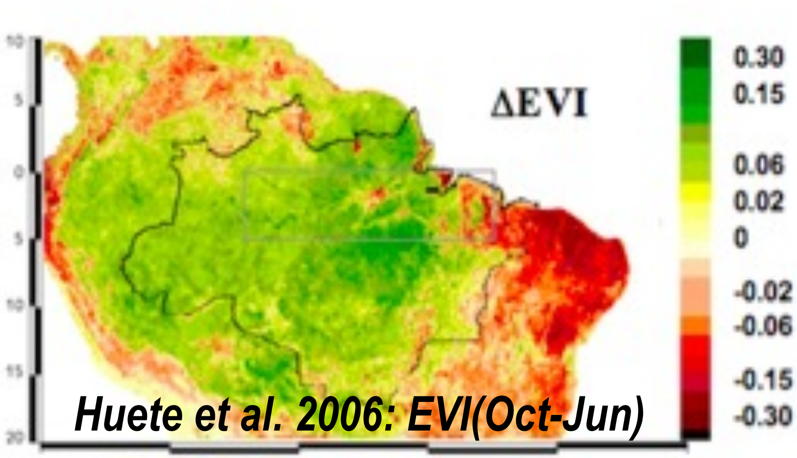
Hansen et al. 2006

- ***Strong surface warming, especially the night-time temperature, is observed over the Amazonian rainforest (≥ 1˚C/dec) in recent decade.***



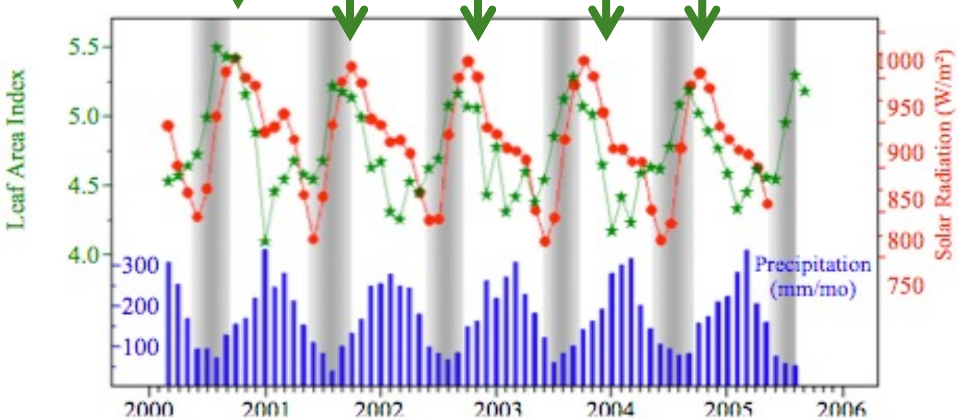
Tropical rainforest is light-limited, instead of

- ***ET increases at the end of the dry season is correlated with the growth and greening of the forest canopy responding to the increase of solar radiation.***



Huete et al. 2006: EVI(Oct-Jun)

Seasonal change of LAI



Myneni et al. 2007, PNAS

Flux tower ET

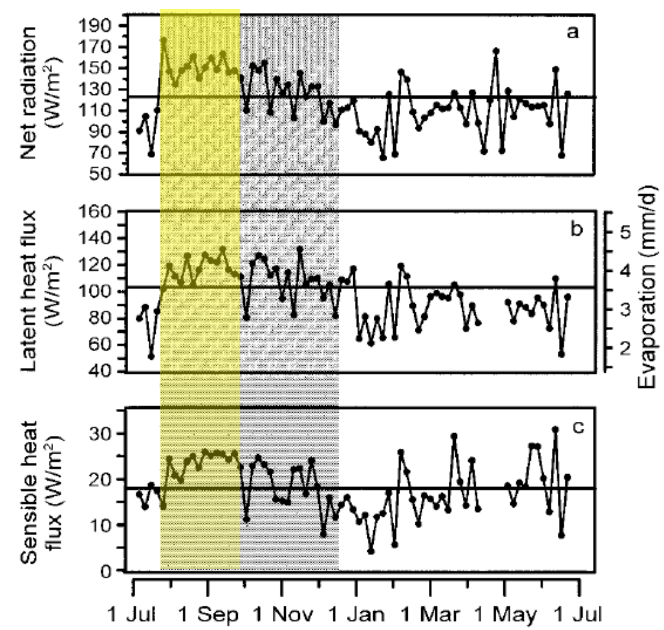


FIG. 7. (a) Net radiation (lines connecting 5-d means), (b) latent heat flux (on the left axis) and evaporation (on the right axis), and (c) sensible heat flux. T
represent the annual means. The dry seas

de Rocha et al. 2002

Issues and Challenges:

Aerosol-cloud interaction:

- ***Cloud change with aerosol appear to re-enforce the original dry/wet anomalies.***