Using Satellite Multiple Sensor Products to Monitor Vegetation Properties:

Vegetation-atmosphere Interaction

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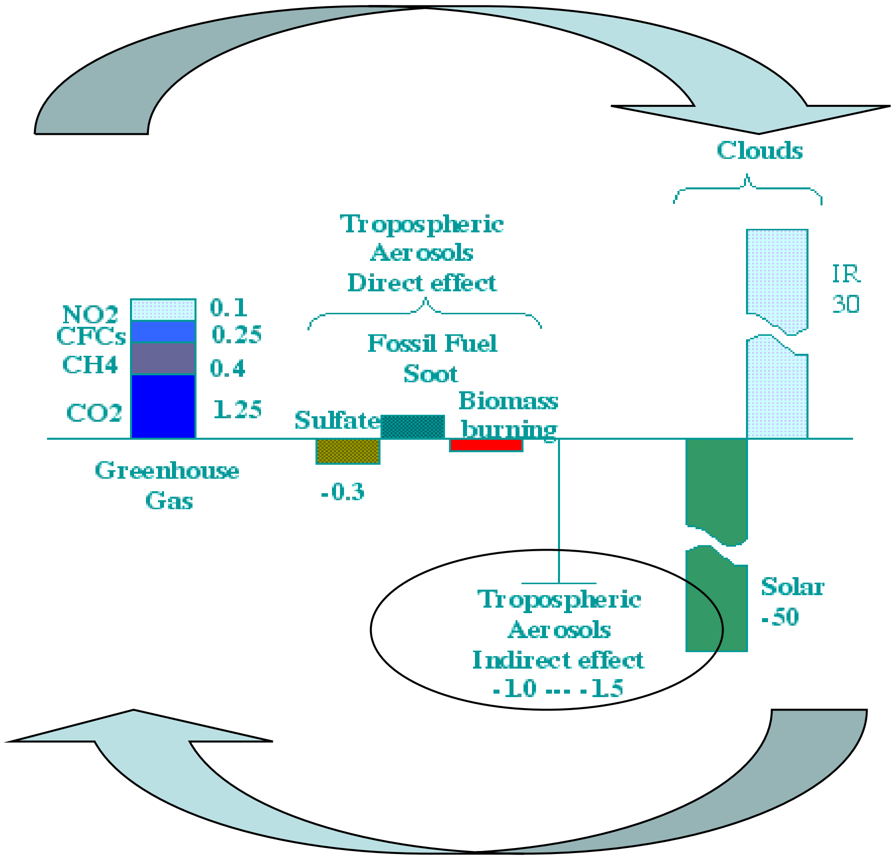
Vegetation-atmosphere interaction

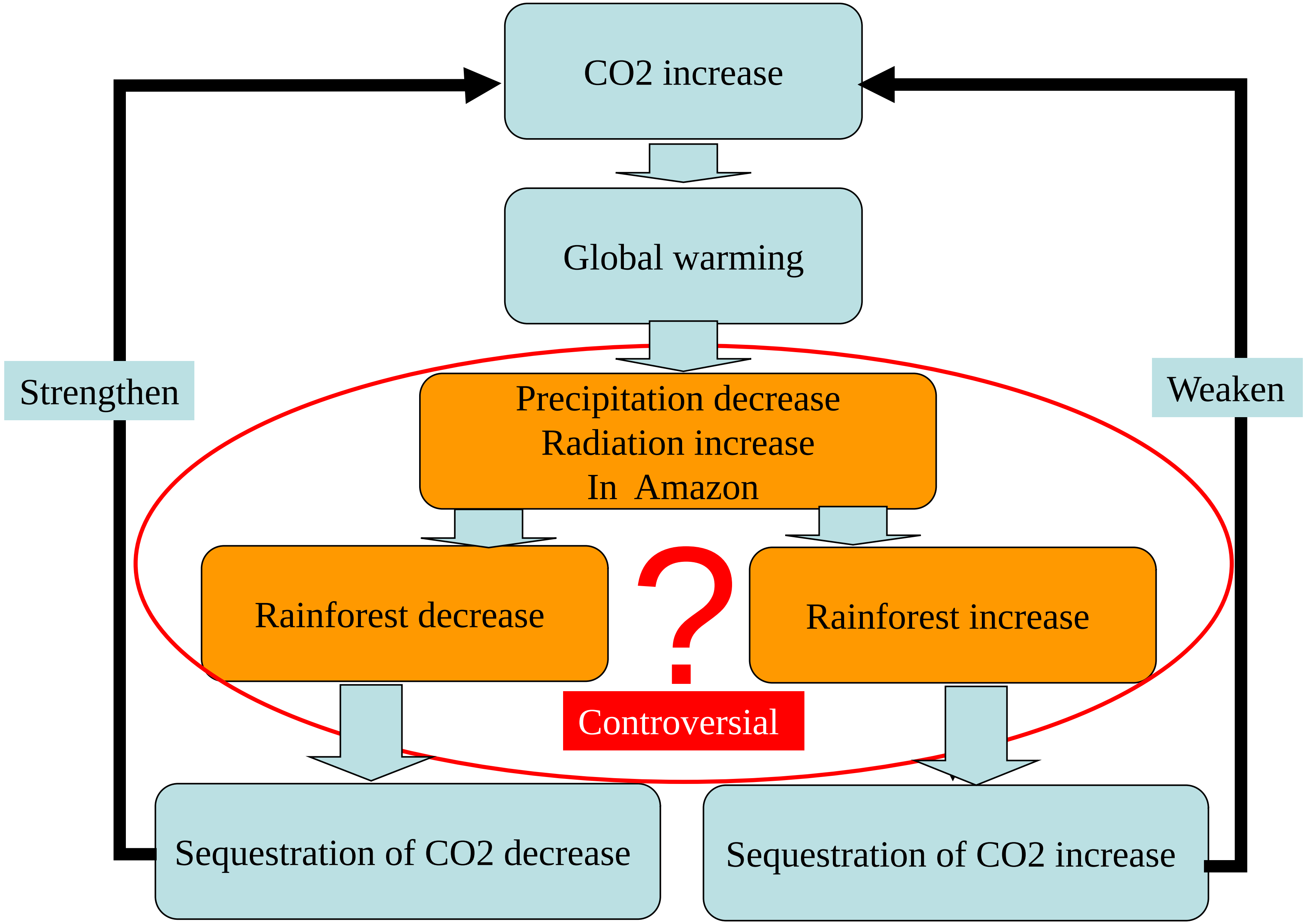
"Lack of definition of climate forcing and inability to quantify the response of the climate system to this forcing are two obstacles for understanding and predicting of climate changes…" (IPCC)



Issues

- The greatest uncertainty in predictability of future climate arises from aerosols and clouds
- Understanding aerosols and its interaction with clouds is not only important for climate but also for weather forecasting
- Coupling of carbon, water, and energy cycles: ecosystem-atmosphere interaction.

Amazon forests and global CO2:

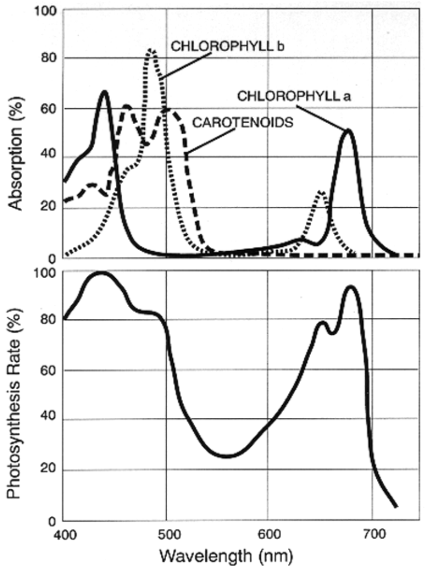


Satellite optical vegetation index (e.g. NDVI, EVI)

- ✓ High spatial resolution
- ✓ Daytime and influenced by aerosols and clouds
- ✓ Saturation (LAI<3)
- ✓ Sensitive to chlorophyll not to vegetation water content

$$NDVI = \frac{r_{0.86} - r_{0.67}}{r_{0.86} + r_{0.67}}$$

- ➢ Most global NDVI products are only available at 8 or 16 days interval. It can not be used to study vegetation-atmosphere interactions in synoptic or finer time scales.



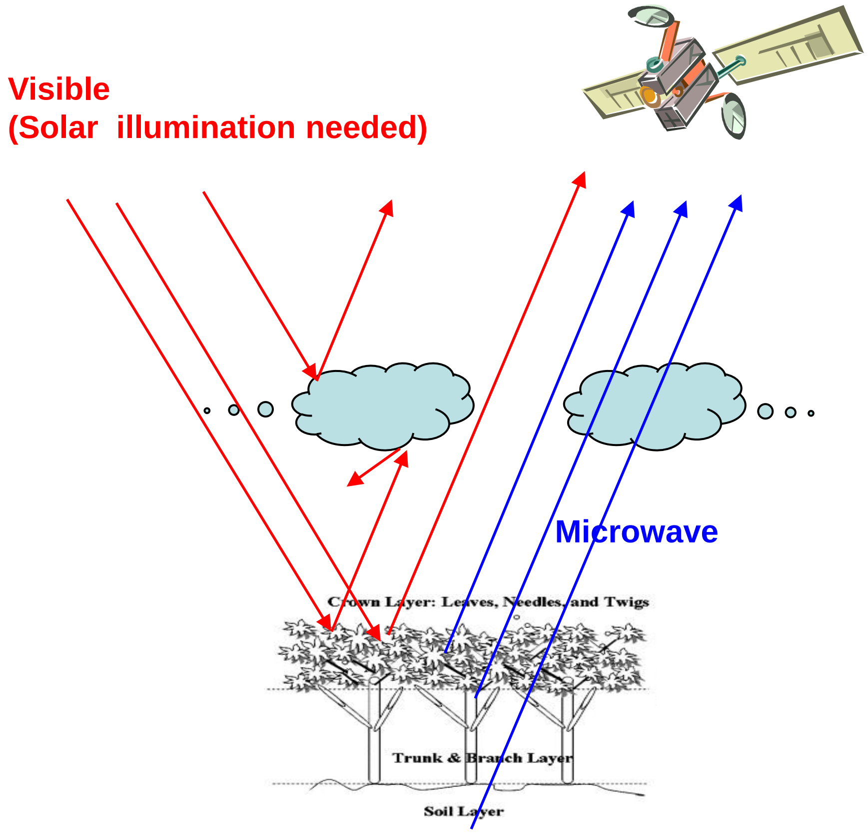
Microwave Land Surface Emissivity (MLSE) and Microwave Vegetation Index

MLSE

- ✓ Available in day and night time
- ✓ Less influence by atmospheric loading (capable to penetrate clouds)
- ✓ Sensitive to vegetation water content and vegetation structure
- ✓ Coarse spatial resolution (AMSR-E, TMI: 10s of km)

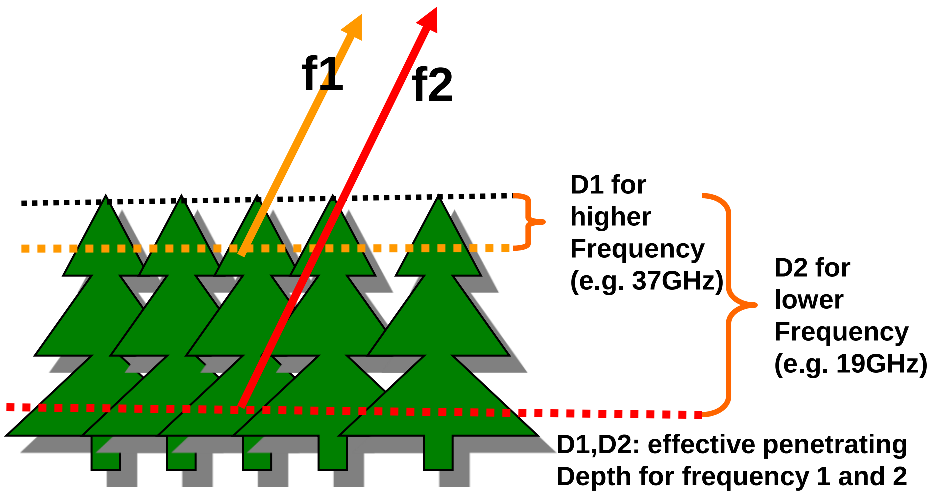
Microwave vegetation indexes:

- ✓ MPDT: Microwave Polarization Difference Temperature (Choudhury and Tucker, 1987; Becker and Choudhury, 1988; Calvet et al 1994)
- ✓ Vegetation Water Content (Njoku, Eni. 2007)
- ✓ MVI: Microwave vegetation index (Shi et al 2008)
  - Mostly sensitive to sparse/short vegetation
  - No atmospheric correction, particularly for clouds

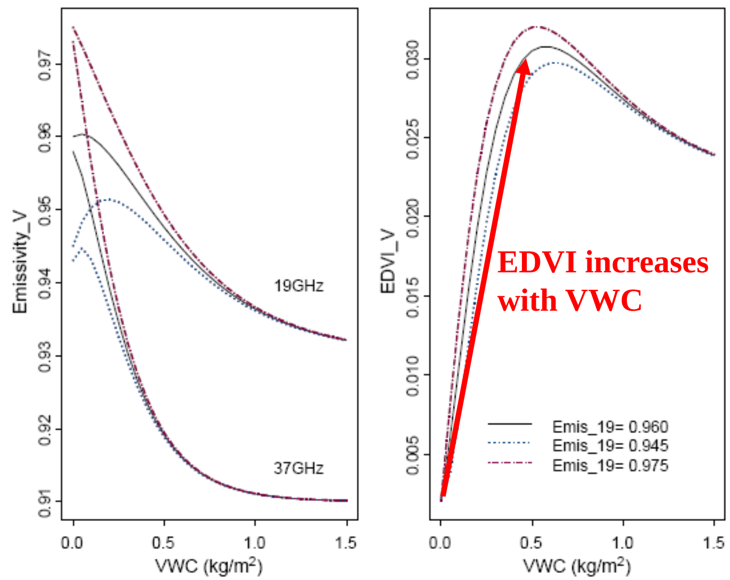


Microwave Land Surface Emissivity (MLSE)
and Microwave Emissivity Difference Vegetation Index (EDVI)

MLSEs at two different frequencies



MLSEs and EDVI:
A two-layer model simulation
(soil-trunk layer + crown layer)



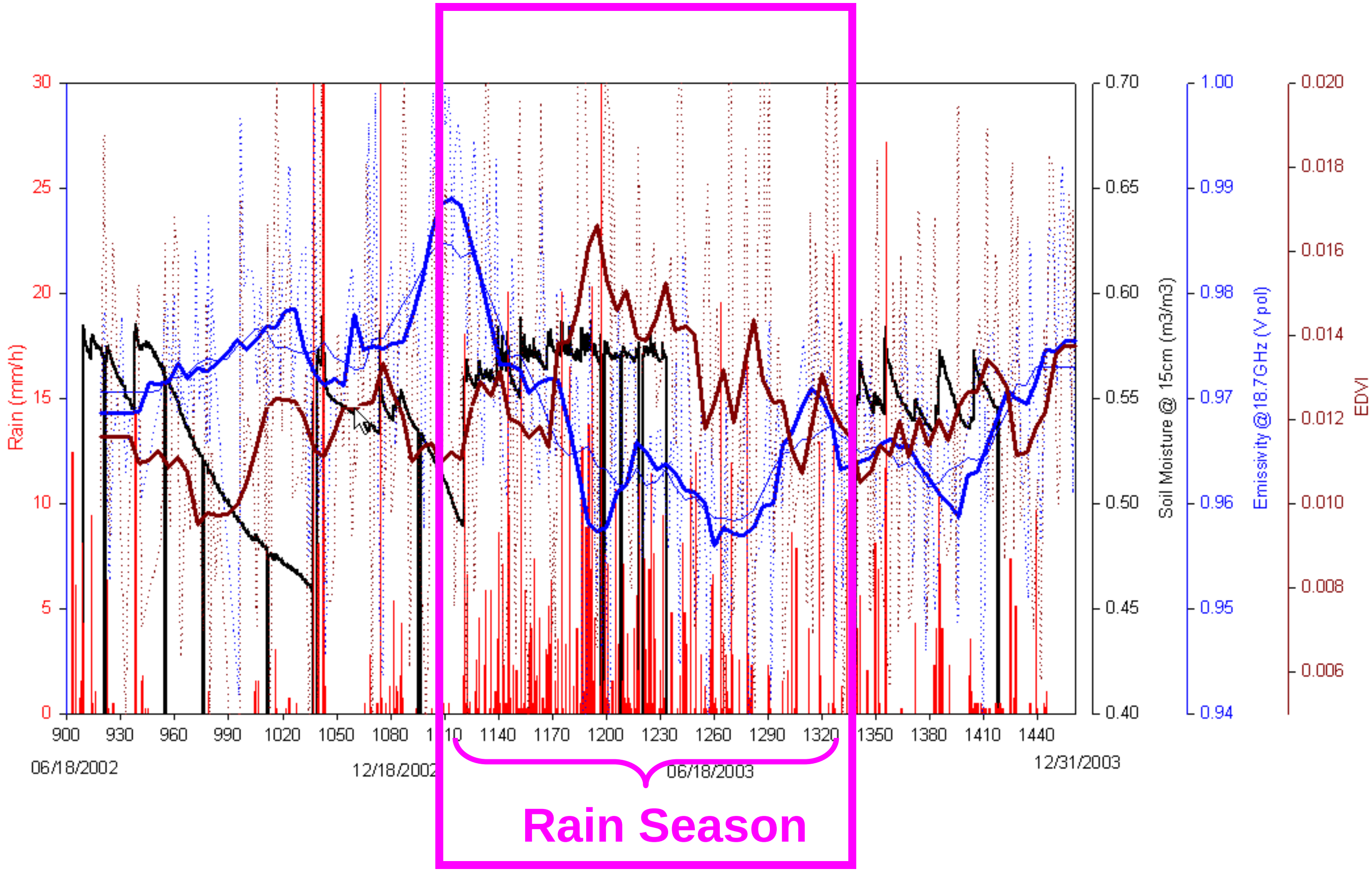
Emissivity Difference Vegetation Index (EDVI)
Proposed by Min and Lin (2006a and 2006b)

$$\mathrm{EDVI}=\frac{\mathrm{MLSE}_P^{f1}-\mathrm{MLSE}_P^{f2}}{\mathrm{MLSE}_P^{f1}+\mathrm{MLSE}_P^{f2}}$$

Synergetic retrievals by combining visible, infrared, and microwave

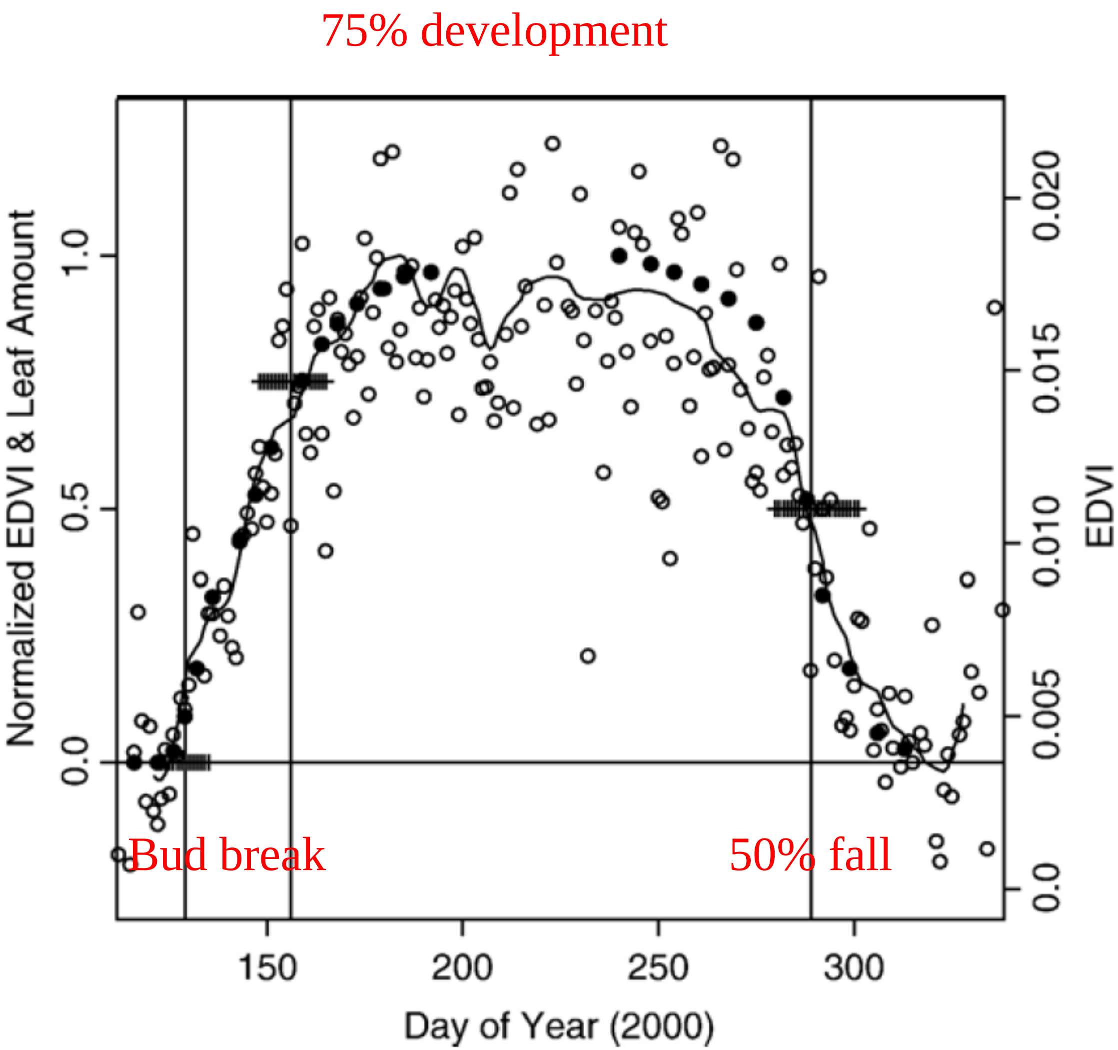
- High temporal resolution (day & night)
- Less sensitive to atmospheric loading (under all weather conditions)
- Sensitive to vegetation water content (directly linked to Evapotranspiration)
- A large dynamic range of vegetation water content from sparse to dense vegetation

MLSE, EDVI, SM, and precipitation



- ✓ Satellite observed emissivity is determined by both soil moisture and the vegetation moisture, when soil moisture is not saturated.
- ✓ When the soil is saturated, as in the rain season, the emissivity is largely determined by the vegetation water content.
- ✓ EDVI is a good indicator of the vegetation water content.

EDVI and in-situ measured leaf amount

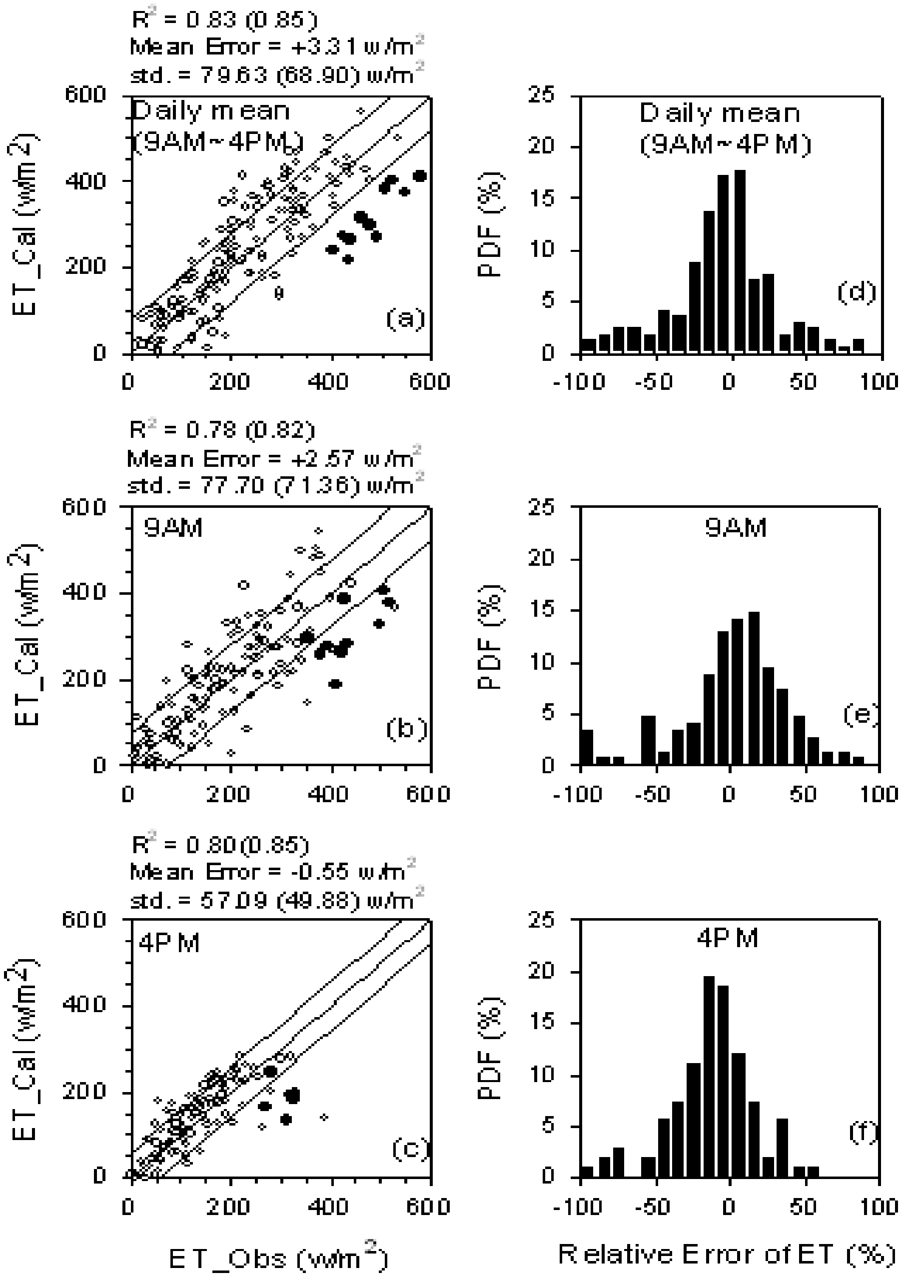


Normalized EDVI: $EDVI_P^N$

$$EDVI_P^N = \frac{EDVI_P - EDVI_P^{Onset}}{EDVI_P^{Max} - EDVI_P^{Onset}};$$

Temporal variation of $EDVI^N$ (open circles and solid curve) agrees very well with observed leaf amount at the surface site of Harvard Forest (Min and Lin 2006a)

EDVI and Evapotranspiration (ET)



A new physical and quantitative algorithm to estimate evapotranspiration (ET) from the first principle of surface energy balance model by using EDVI.

- Long term seasonal trend of EDVI is linked to variance of canopy resistance
- Short term changes of EDVI is used to parameterize the responds of vegetation resistance to the quick changes of environmental factors including water vapor deficit, water potential and others.

✓All weather conditions

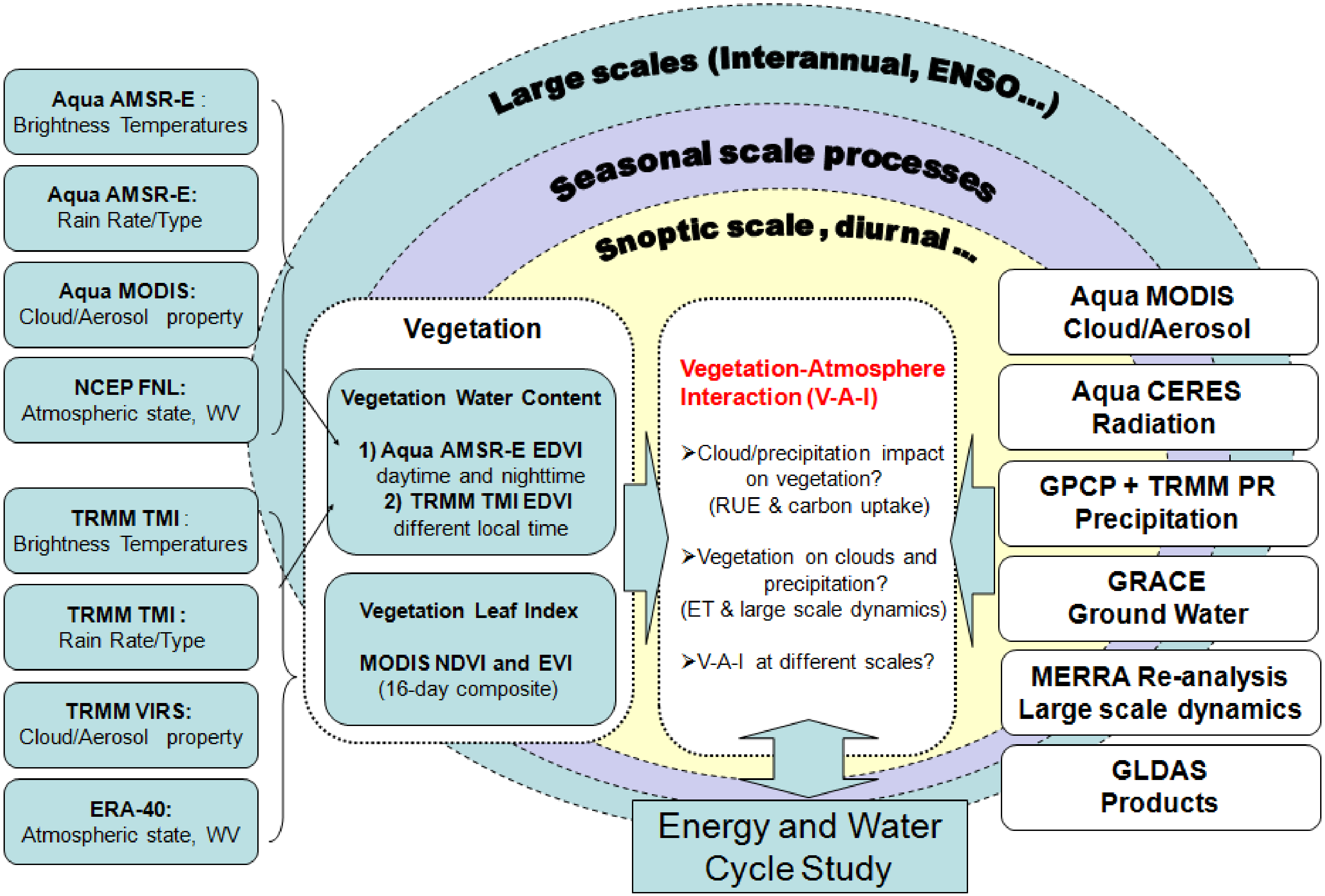
✓Diurnal variations of ET is detectable

✓High correlation coefficient (R^2=0.83)

✓Overall uncertainty is 30% (bias 3.3 w/m2 and Std 79 w/m2), which is within the uncertainty of current ground based ET measurements.

(Li, Min and Lin, 2009)

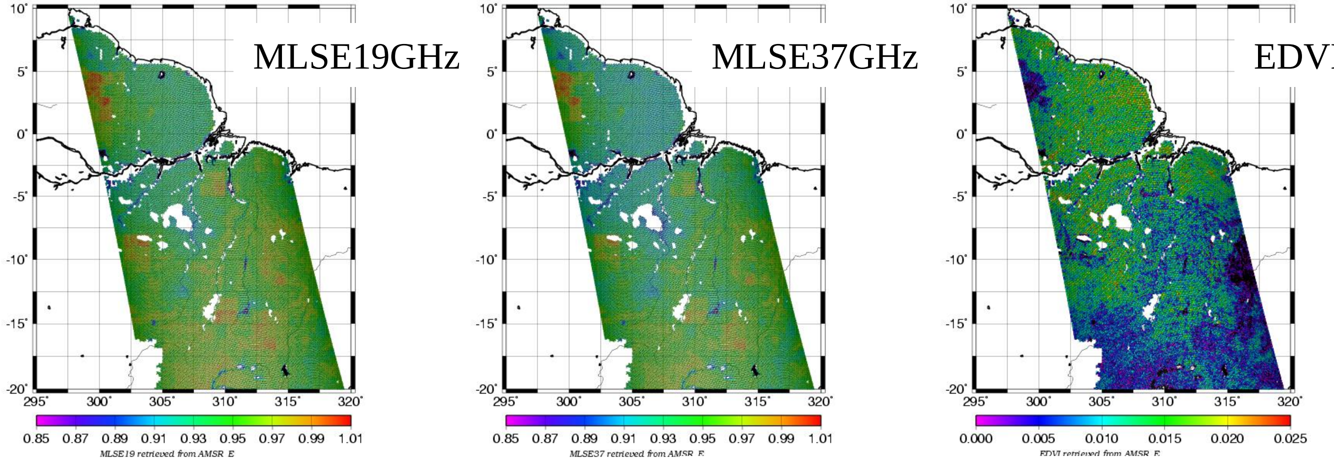
From Harvard forest (site observation)
to Amazonian rainforest (large regional observation)

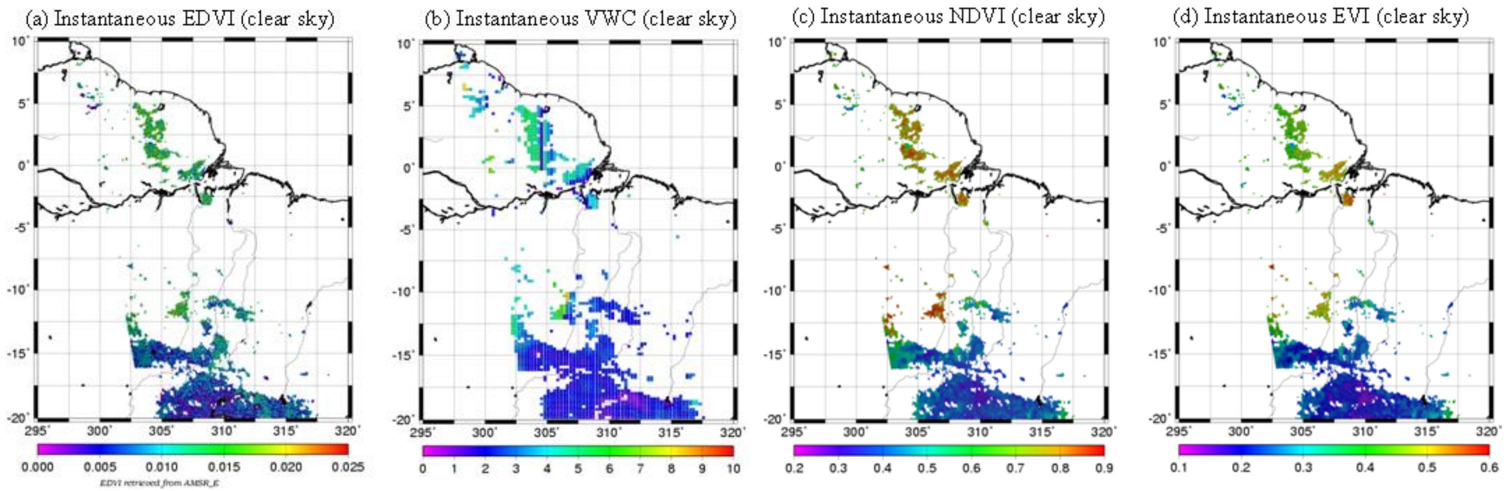


The synergetic and unique EDVI products

→ To answer several critical scientific questions in the Vegetation-Atmosphere-Interaction (V-A-I) at multiple scales.

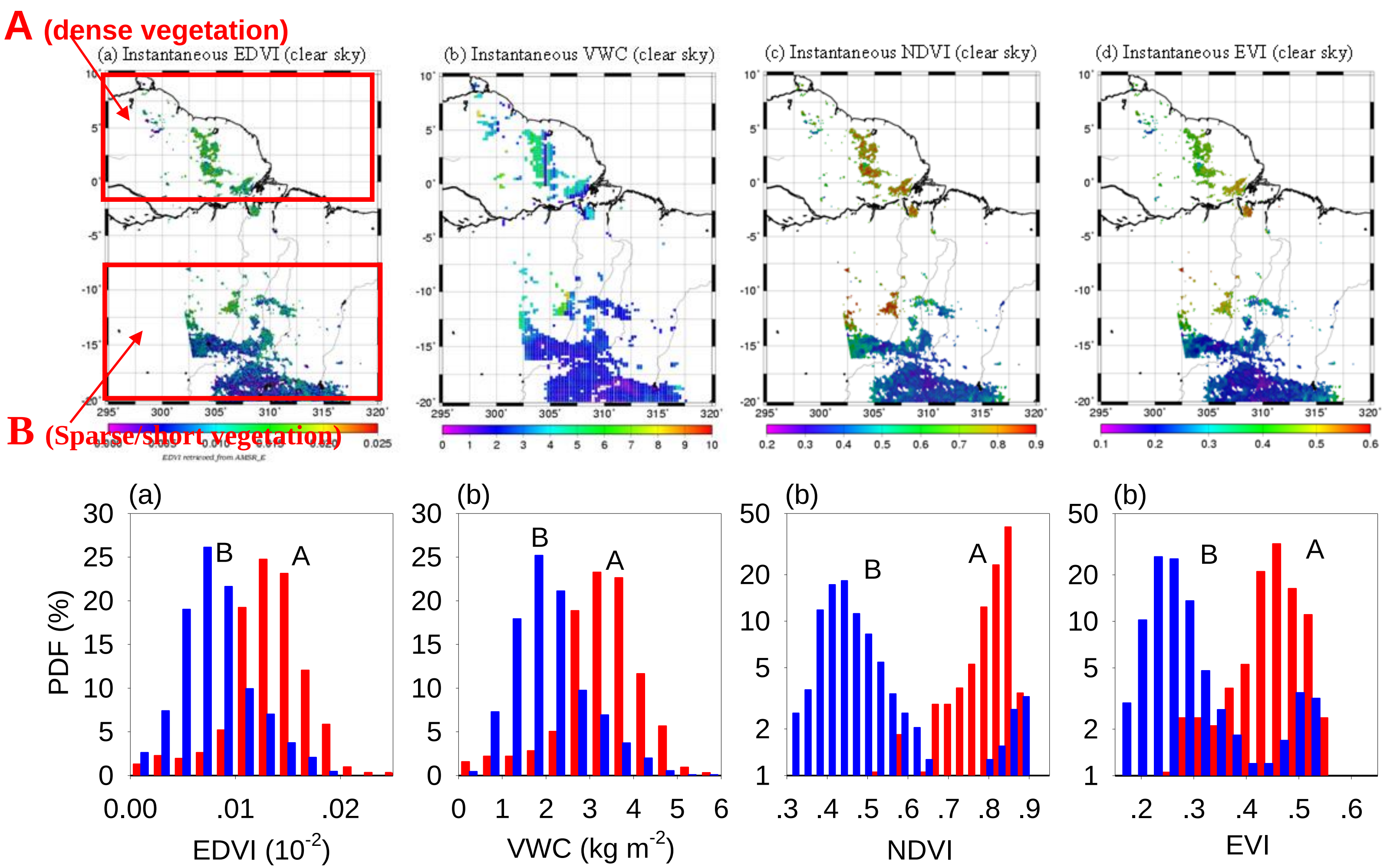
From Harvard forest
to Amazonian rainforest: A case study





- ✓ Case study on Aug 30, 2004 (dry season)
- ✓ the NDVI available pixels (i.e. clear-sky): less than 14%.
- ✓ The EDVI available pixels: ~99%

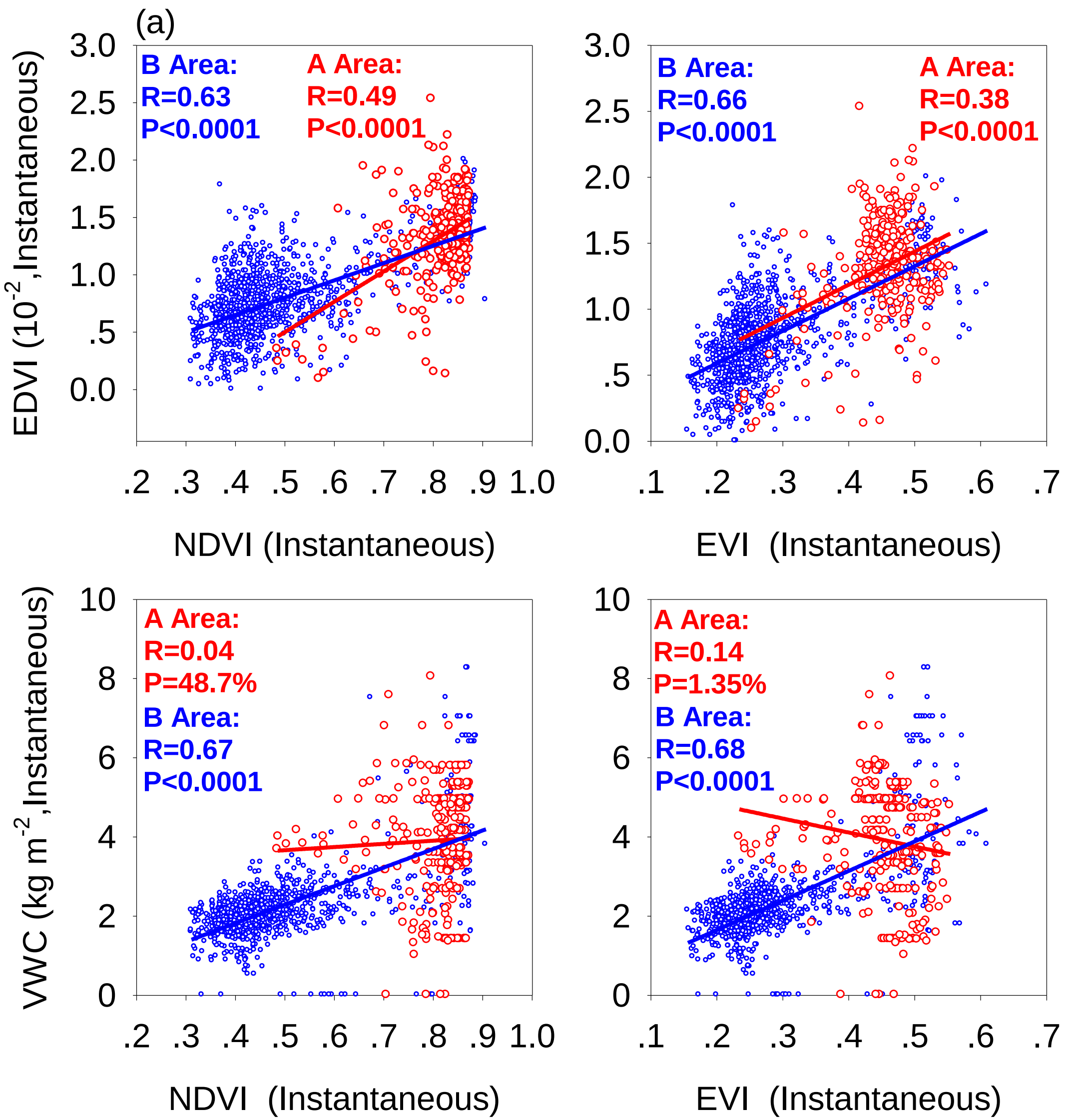
From Harvard forest to Amazonian rainforest: A case study



✓EDVI and VWC show similar vegetation distribution patterns without any sign of saturation.

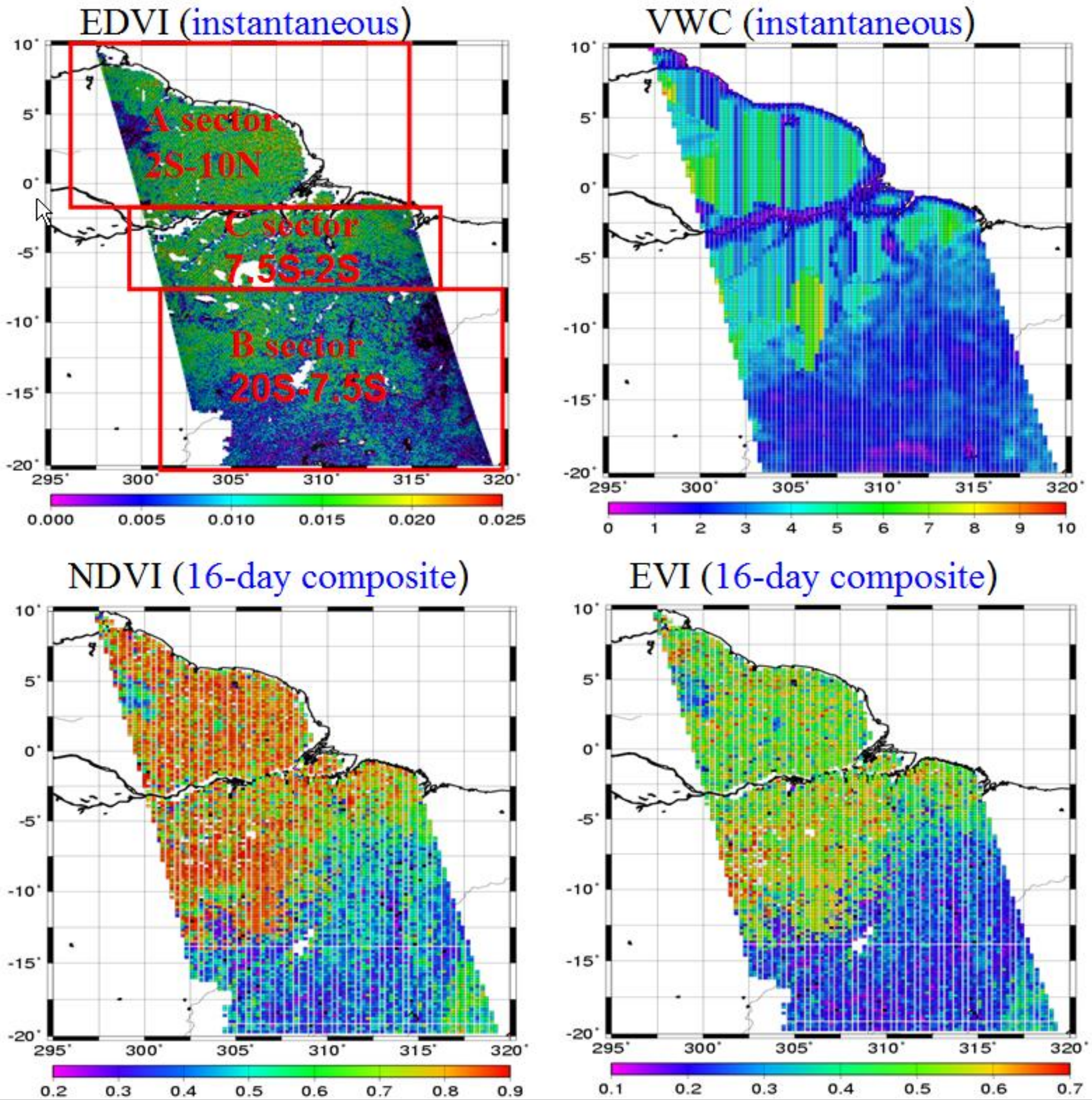
✓NDVI is clearly saturated with distribution skewed to a high value of 0.9. Having similar characteristics to NDVI, EVI exhibits much less problem of saturation than NDVI.

From Harvard forest
to Amazonian rainforest: A case study for clear-sky



- ✓ Good correlations between EDVI and NDVI & EVI in both dense vegetation (area A) and sparse and short vegetation (area B).
- ✓ Slightly better statistics of VWC with NDVI and EVI than that of EDVI in the sparse and short vegetation region (area B)
- ✓ Almost no correlations between VWC and NDVI (and EVI) in the dense vegetation region (area A).

From Harvard forest to Amazonian rainforest: A case study for all-weather

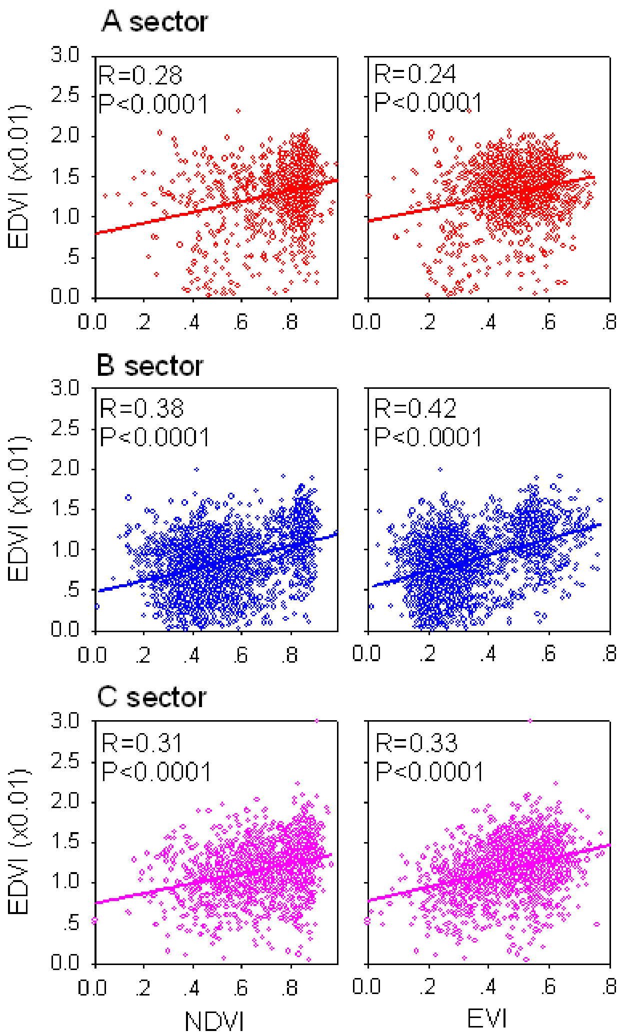


- EDVI and VWC: Instantaneous
- NDVI and EVI: 16-day composite

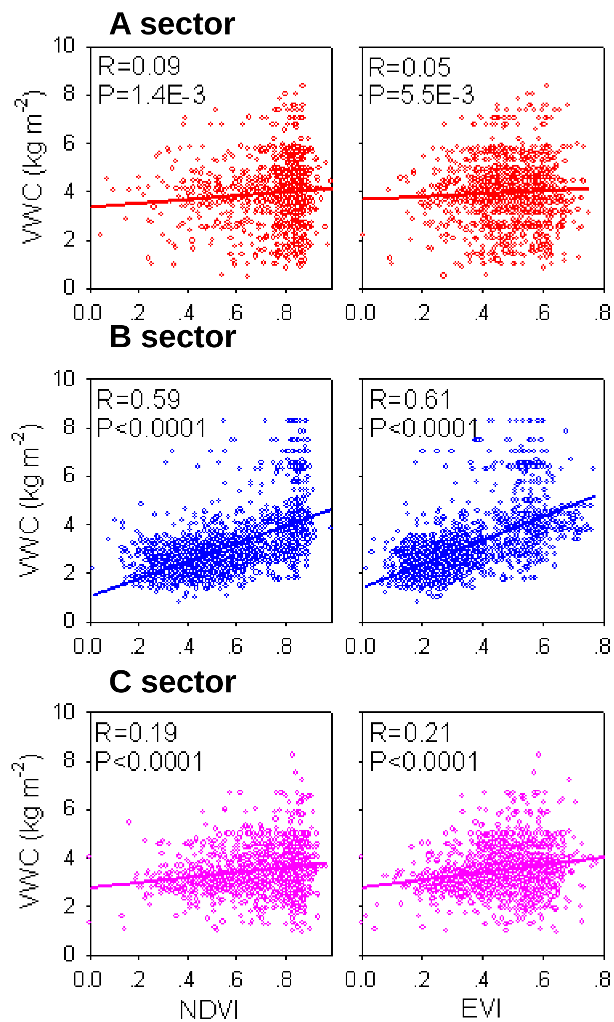
The spatial distribution of instantaneous EDVIs for cloudy pixels corresponds well with the 16-day composites of NDVI and EVI, illustrating EDVI can capture vegetation variation under all-weather conditions.

From Harvard forest
to Amazonian rainforest: A case study for all-weather

EDVI vs. NDVI &EVI

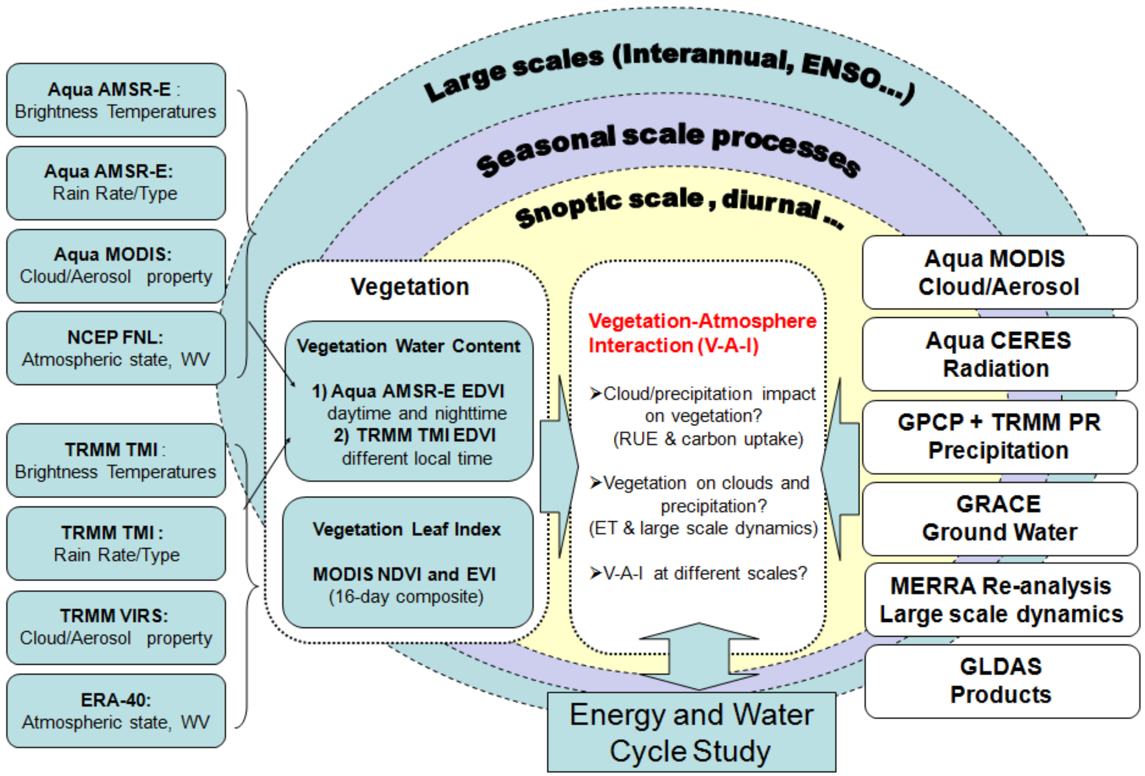


VWC vs. NDVI &EVI



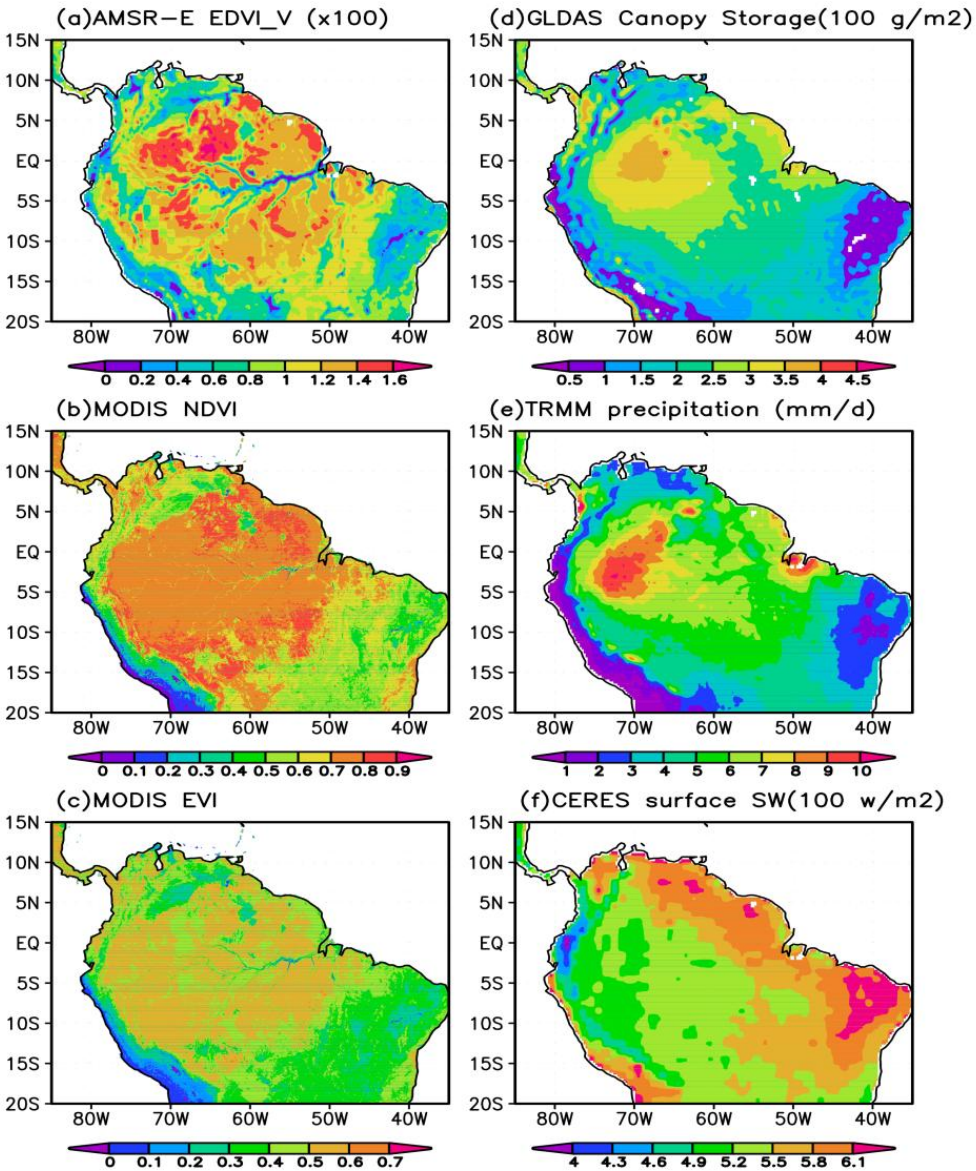
- ✓ All weather results are consistent with the finding under clear-sky conditions
- ✓ The relationships between EDVI and the composite NDVI and EVI get stronger and stronger with decreasing vegetation density (i.e. **B**>**C**>**A**) due to the saturation of NDVI and EVI for dense vegetation.
- ✓ The relationships between VWC and NDVI (and EVI) are weaker than those between EDVI and NDVI (and EVI), except for sparse vegetation area.

Scientific questions



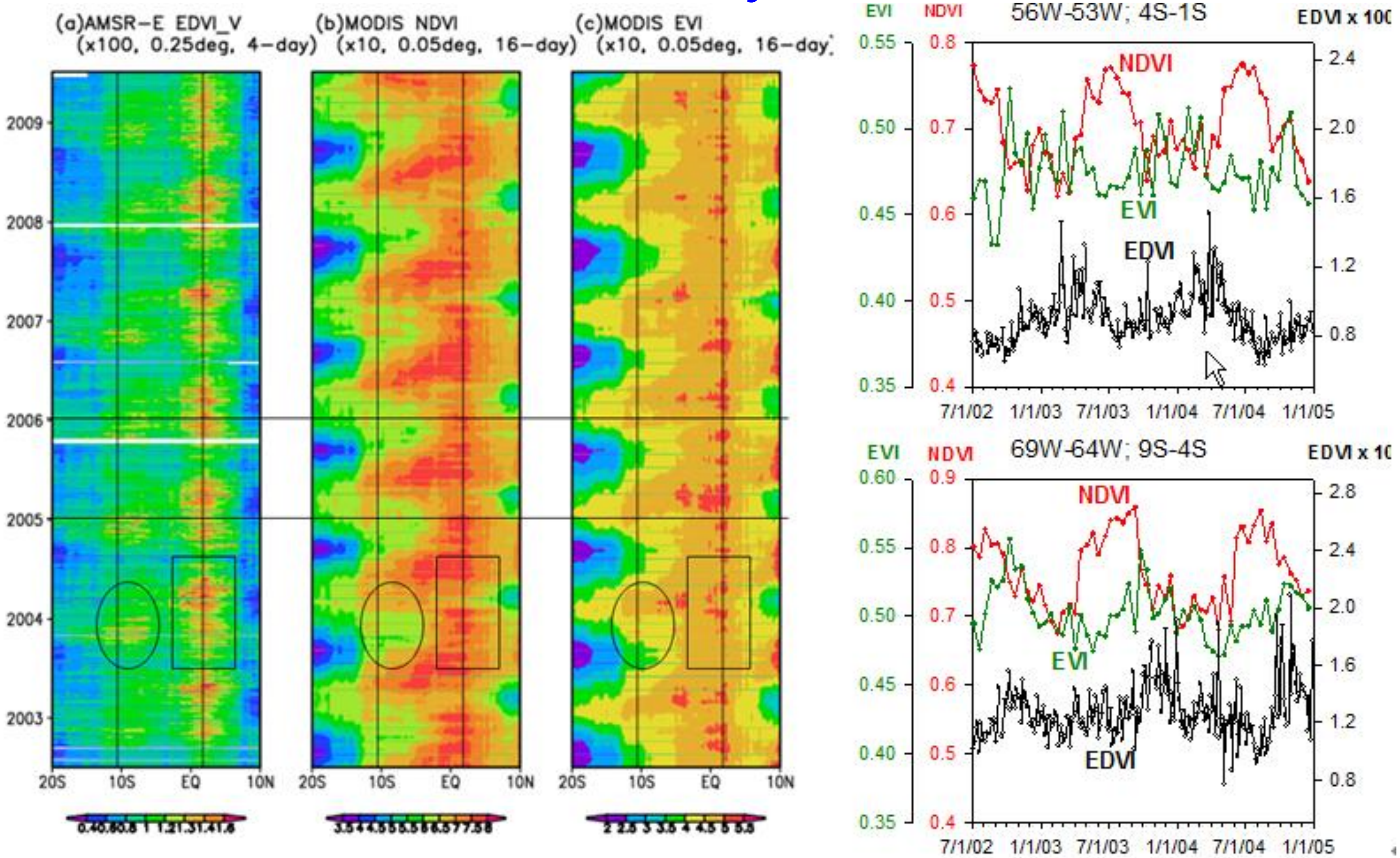
- Extent satellite ET observations from day time/clear sky to all time and all-weather conditions
- Examine the real seasonality of vegetation in Amazon at different regions with different vegetation types
- Investigate the diurnal pattern of forest vegetation.
- Understand the key parameters and processes associated with the vegetation-atmosphere interactions on water and energy cycles, including radiation, clouds, precipitation, water vapor, and large-scale dynamic factors

A multi-year EDVI dataset in Amazon
(from AQUA 2002 Jul – present: 8-years)



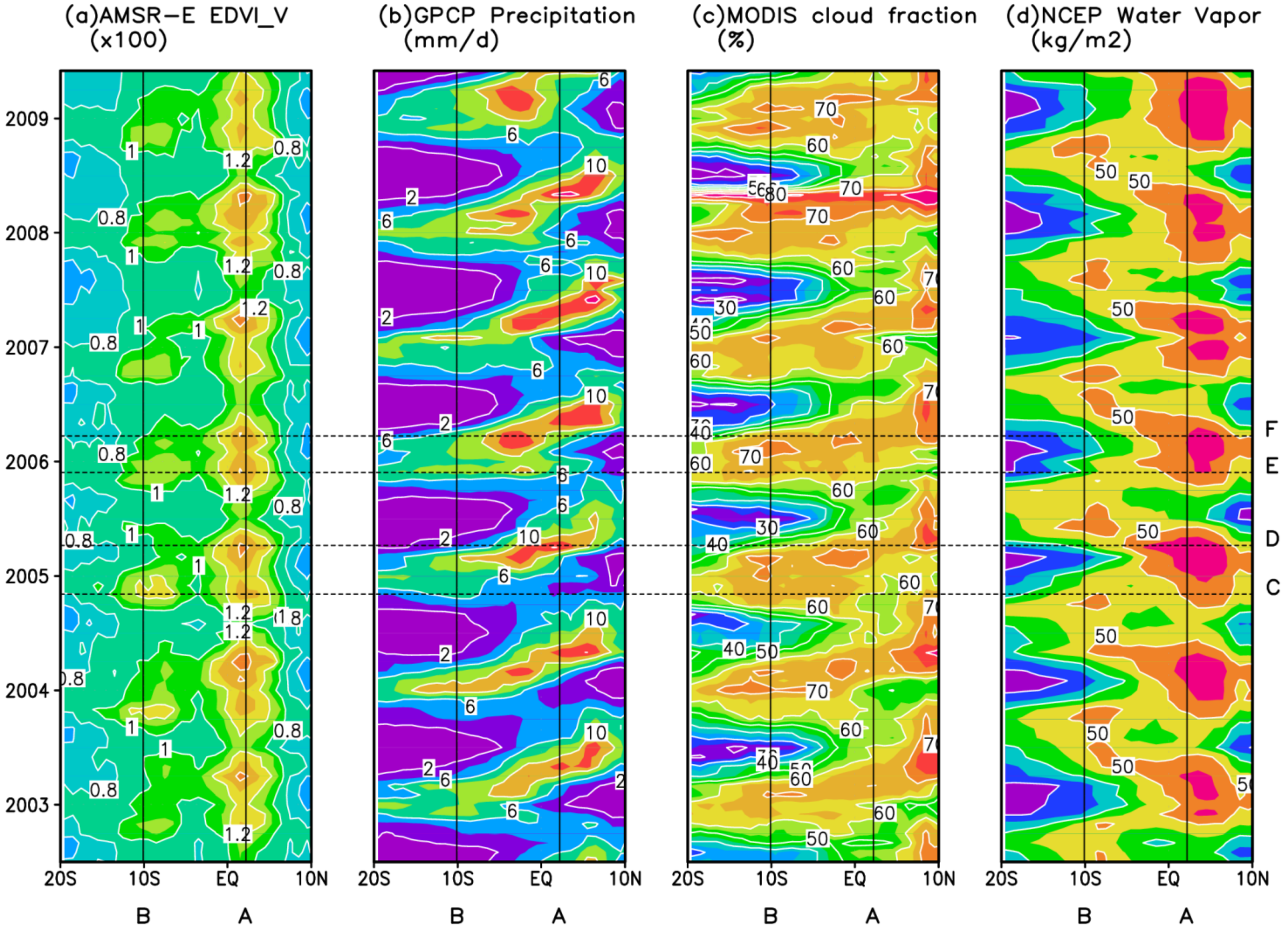
- ✓ EDVI, NDVI and EVI are well representing vegetation distribution from the dense tropical rainforest in the Amazonia basin, to the sparse vegetation area (savanna) in the south-east Brazil, and to the desert along the coast of east Pacific
- ✓ EDVI shows the greater spatial variation of vegetation, even with a coarser resolution (0.25 degrees), than NDVI and EVI.
- ✓ NDVI show quite uniform distribution (NDVI=0.6-0.8) in the large area in the Amazonia tropical rain forest area. However, EVI shows larger spatial variations in the same area. And
- ✓ It indicates that EDVI can represent more detailed vegetation properties in very dense vegetation conditions.

A multi-year EDVI dataset in Amazon Seasonality

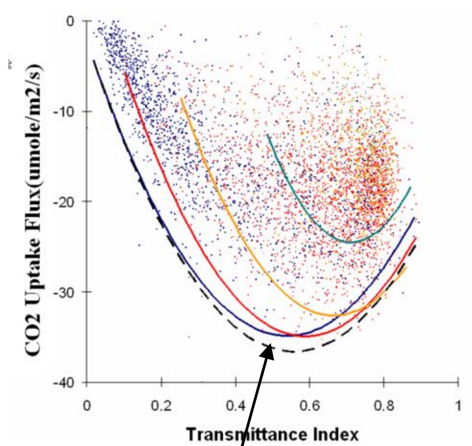


- ✓Inconsistencies between EDVI and NDVI (EVI) are mostly occurred during the wet seasons due to the cloud contamination in optical indexes
- ✓Phase-shifts suggest the seasonal variations of vegetation water content has a delay that of the leave color change

A multi-year EDVI dataset in Amazon
Sensitivity of vegetation to climate

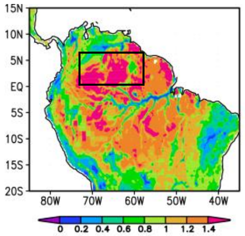


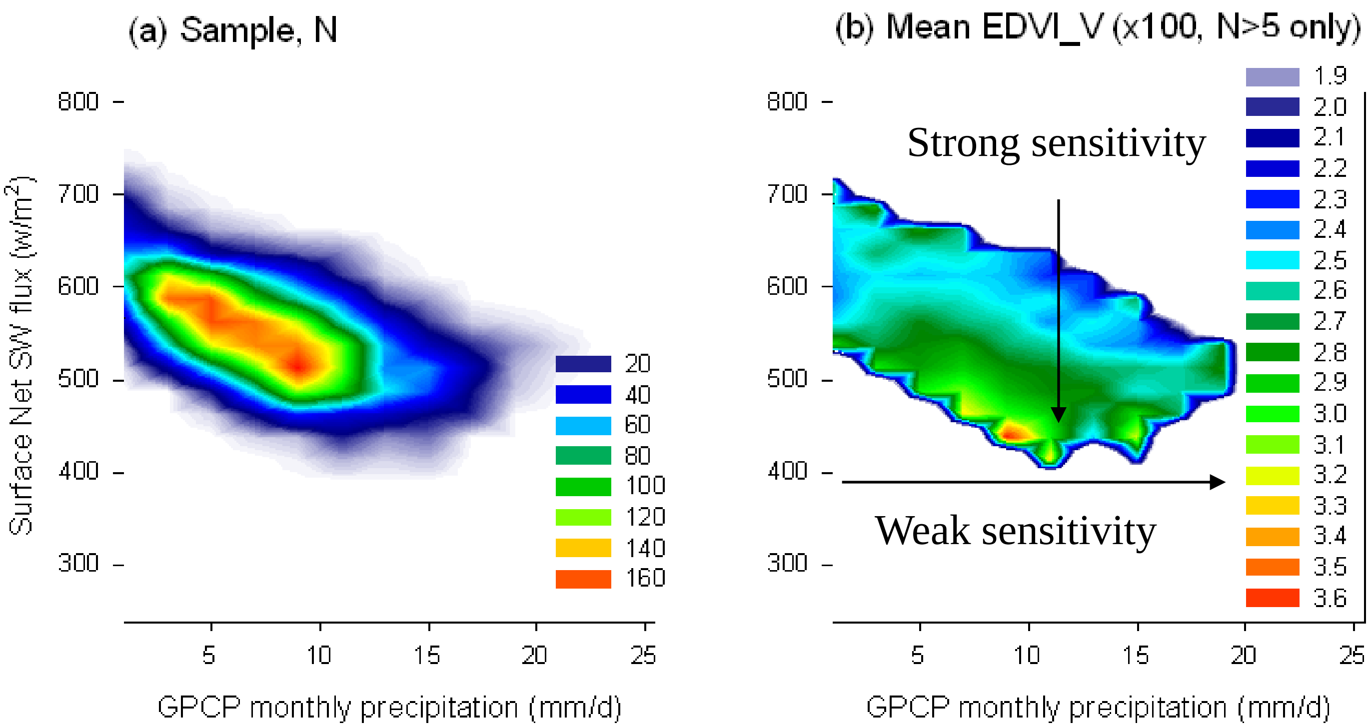
Min and Wang (2008): Clouds enhance radiation use efficiency of carbon uptake and modulate carbon uptake with optimal efficiency at moderate cloud cover



- ✓ Two dense vegetation belts (A and B) in Amazon response differently to the associated clouds, precipitation, and other atmosphere states.
- ✓ In both belts, the maximum of EDVI occurred at a modest cloud cover (~ 0.6) period during the wet season (adequate precipitation) but not at precipitation peaks, consisting with our previous finding.
- ✓ Vegetation grows better in wet seasons than in dry seasons, indicating drought has a negative effect on vegetation.

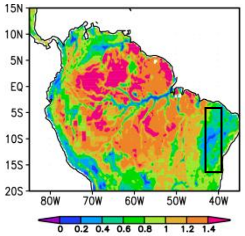
A multi-year EDVI dataset in Amazon
Sensitivity of vegetation to precipitation and radiation
Dense vegetation (rainforest)

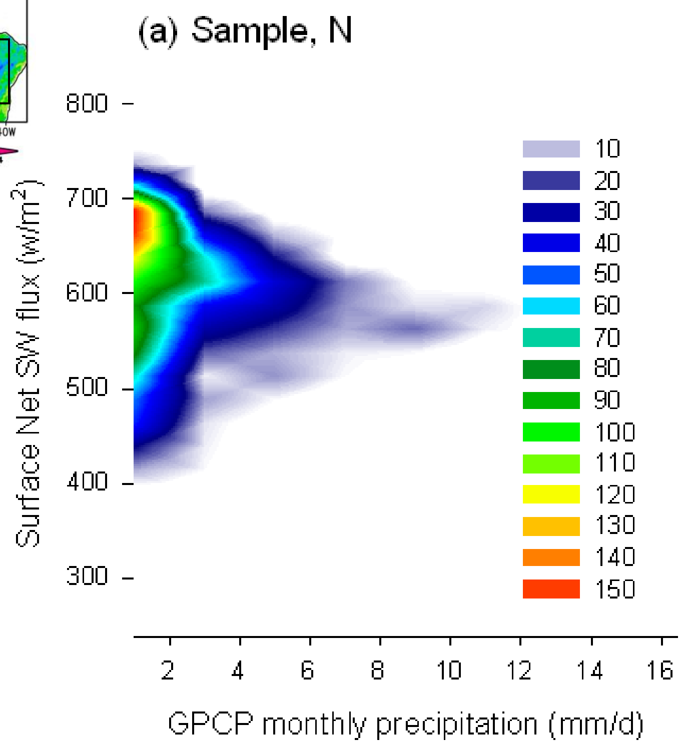


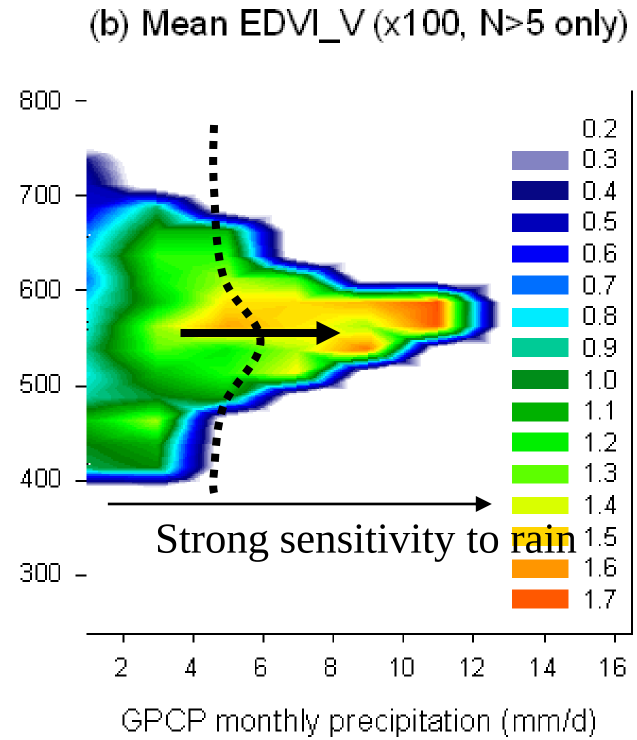


- ✓ Most EDVIs are larger than 0.02,
- ✓ For a given precipitation, EDVI decreases with increasing SW flux
- ✓ For a given SW, EDVI is insensitive to precipitation.

A multi-year EDVI dataset in Amazon
Sensitivity of vegetation to precipitation and radiation
Sparse vegetation (savanna)



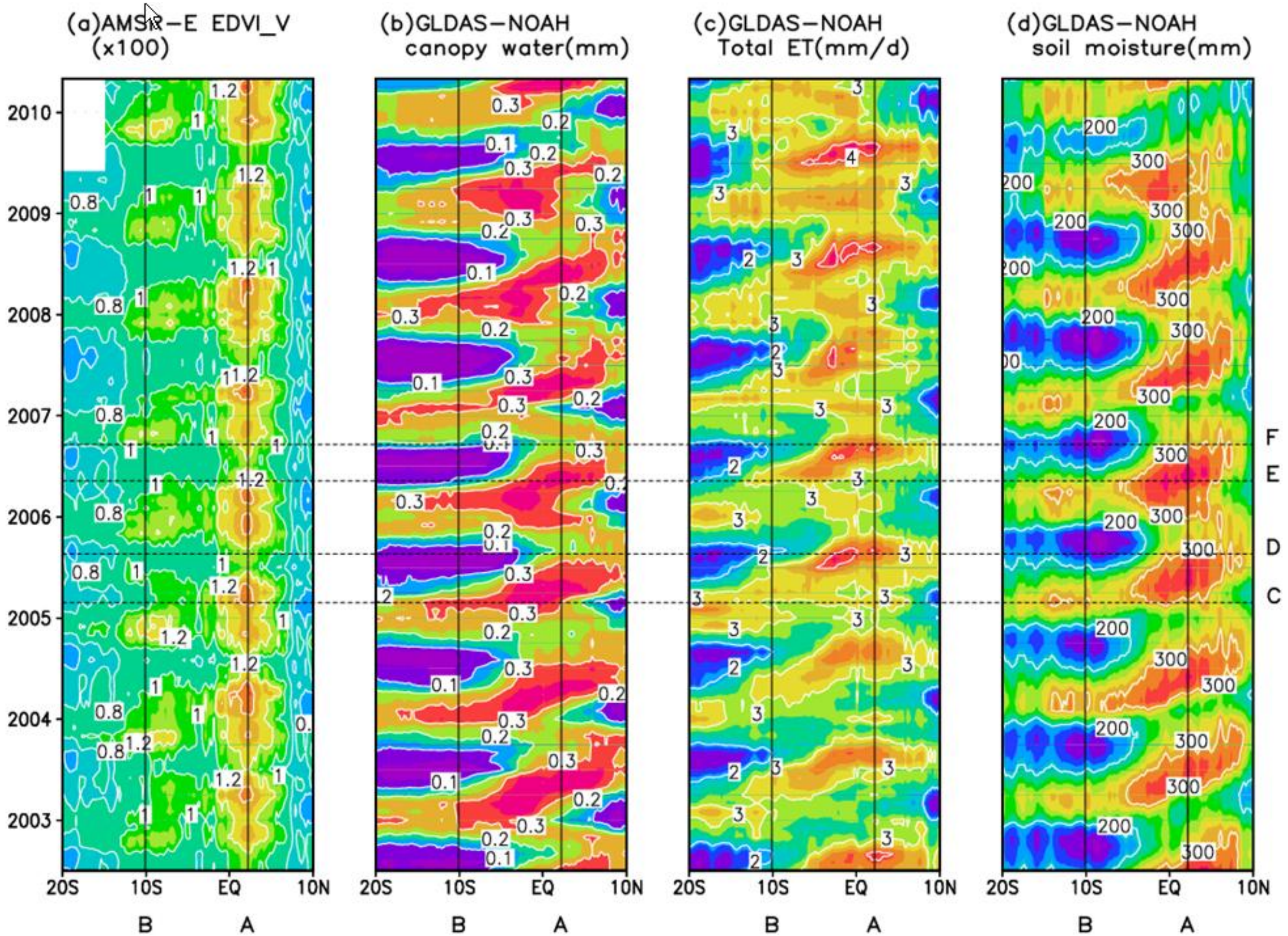




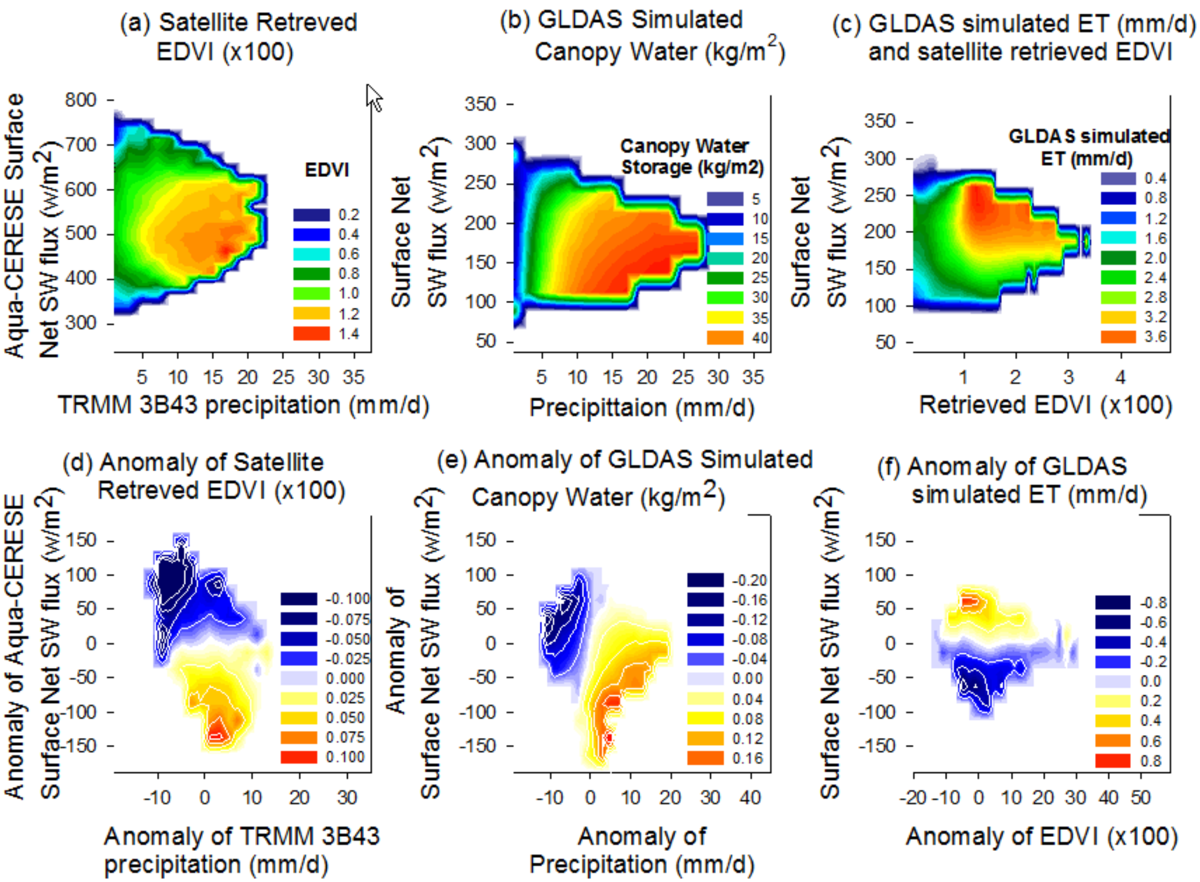
- ✓ The dependence of EDVI on precipitation for sparse vegetation (Savanna) is stronger than that in dense vegetation
- ✓ EDVI reaches a maximum at medium SW fluxes, or modest clouds

A multi-year EDVI dataset in Amazon Observation and GLDAS Simulation

The Global Land Data Assimilation System (GLDAS): the simulation was forced by combination of NOAA/GDAS atmospheric analysis fields, spatially and temporally disaggregated NOAA Climate Prediction Center Merged Analysis of Precipitation (CMAP) fields, and observation based downward shortwave and longwave radiation fields derived using the method of the Air Force Weather Agency's AGRicultural METeorological modeling system (AGRMET).



A multi-year EDVI dataset in Amazon Observation and GLDAS Simulation



- ✓ The GLDAS shows the canopy water storage increase with precipitation, consisting with EDVI observation
- ✓ The GLDAS shows the canopy water storage decrease with increasing net SW, also consisting with EDVI observation
- ✓ The GLDAS ET increases with net SW, and also increases with EDVI sharply for small EDVI, and then slight decreases with EDVI

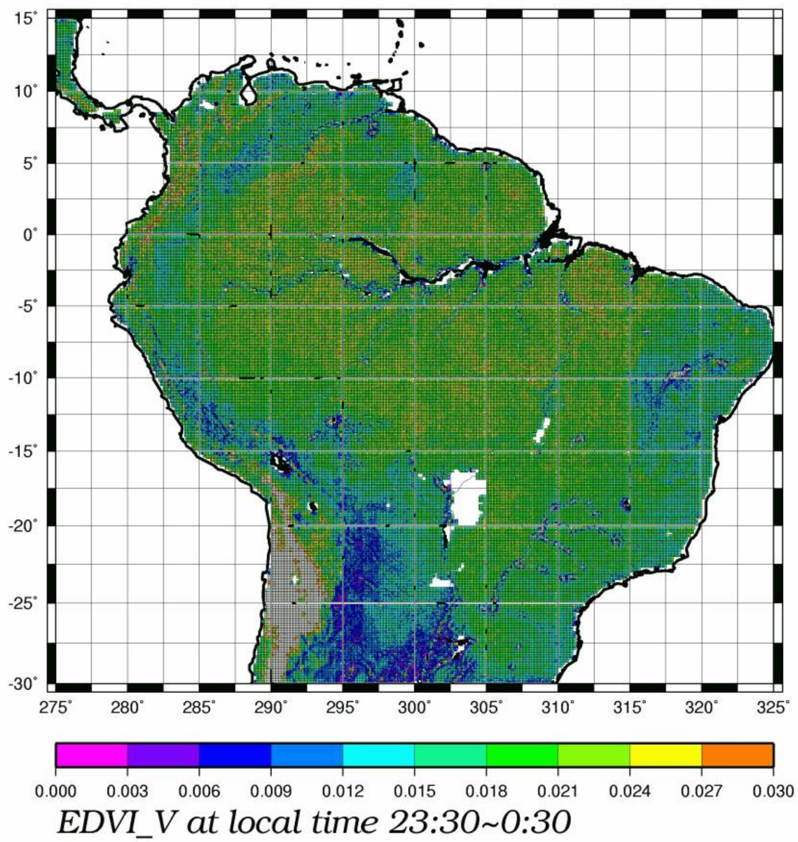
- ✓ The EDVI anomaly is primarily determined by SW anomaly,
- ✓ The GLDAS canopy water anomaly is dominated by precipitation anomaly.
- ✓ The ET anomaly is mainly controlled by available energy anomaly.

Diurnal cycle of vegetation water content in Amazon TRMM satellite

TRMM: Non-sun-synchronous orbit for monitoring the diurnal variations of vegetation

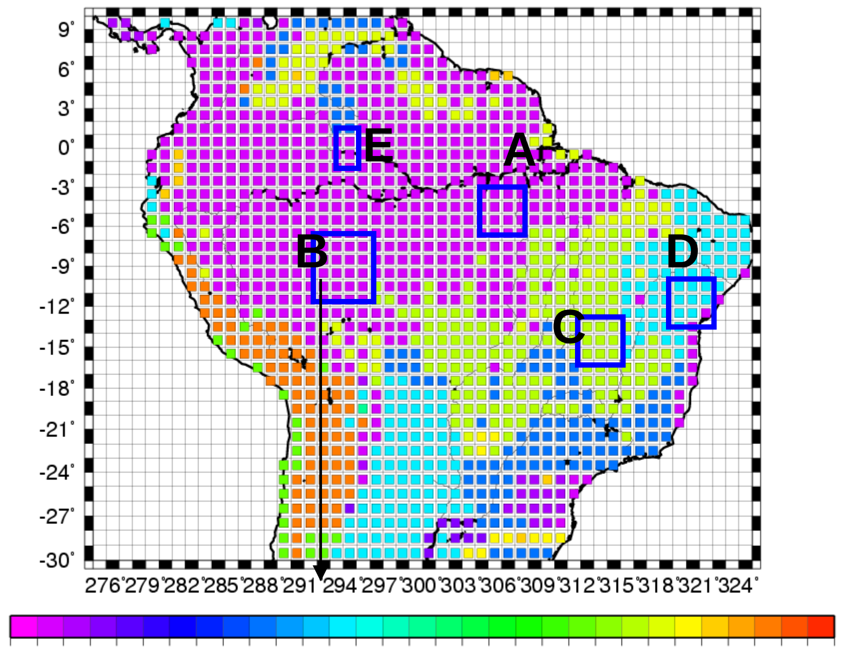
- ➢TRMM Microwave Imager (TMI)
- ➢Visible and Infrared Scanner (VIRS)
- ➢Precipitation Radar (PR):
- ➢Clouds and the Earth's Radiant Energy System (CERES)

Diurnal cycle of EDVI: one hour interval

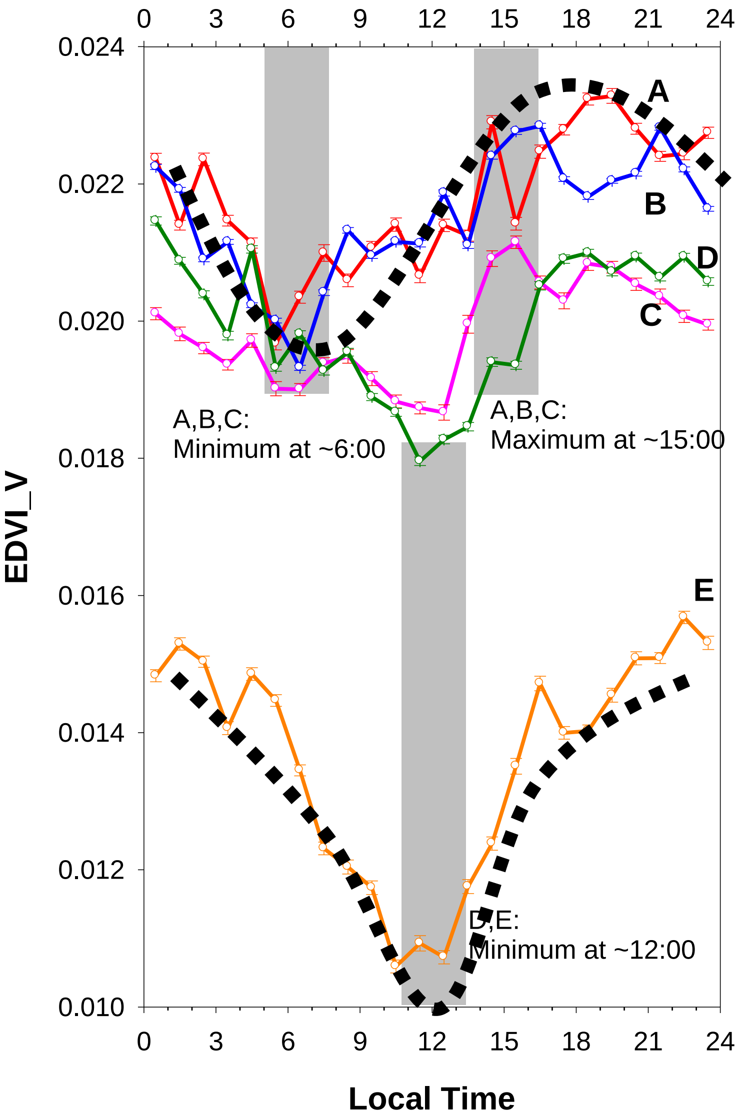


- ✓ The vegetation in Amazon exhibits significant diurnal cycle
- ✓ Different types of vegetation have different diurnal patterns.
- ✓ To our knowledge, this is the first time that satellite observations are used to characterize the diurnal pattern of Amazon forest.

Diurnal cycle of vegetation water content in Amazon
Selected regions

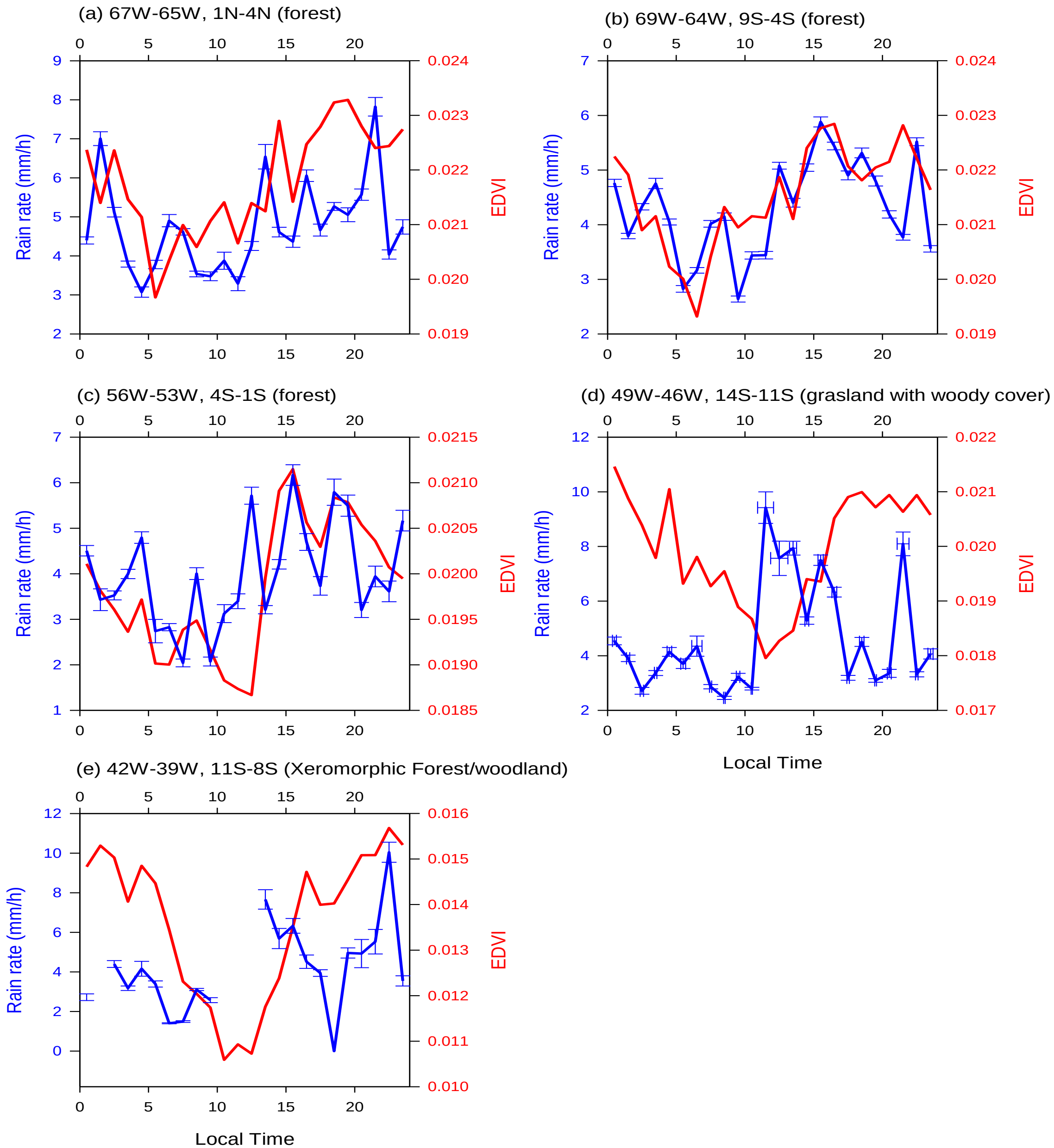


Matthew's GISS Global 1-Degree Vegetation data



A. Tropical evergreen rainforest, 56W-53W; 4S-1S
B. Tropical evergreen rainforest, 69W-64W; 9S-4S
C. Shrub/grass land; 49W-46W; 14S-11S
D. Xeromorphic forest/woodland: 42W-39W; 11S-8S
E. Tropical/subtropical drought-deciduous forest: 67W-65W; 1S-4N

Diurnal cycle of vegetation water content in Amazon
Selected regions



- ✓ Good correlation between the diurnal cycles of EDVI and precipitation in tropical forest area (i.e. A,B,C). It indicates strong vegetation-atmosphere coupling
- ✓ Poor correlations in grassland, xeromorphicorest, and woodland. It indicates weaker vegetation-atmosphere interaction.

Summary

- ✓ We proposed a novel microwave vegetation index: microwave emissivity difference vegetation index (EDVI), and developed a retrieval algorithm by combining visible, infrared, and microwave measurements
- ✓ EDVI provides a reliable measure of vegetation states during both day and night times under all-weather conditions
- ✓ EDVI is capable to monitor all ranges/types vegetation from dense vegetation to short and/or sparse vegetation, and shows no sign of saturation even for the tropical rain forest in the Amazon Basin
- ✓ Seasonal and diurnal variations of vegetation in Amazon are captured by EDVI.
- ✓ This dataset provides unique opportunities to study vegetation-atmosphere interactions in broad time scales.