Regional Scale Evapotranspiration from MODIS AQUA and NOAA AVHRR : Validation over Indian Agro-ecosystems

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Project : Energy and Water Balance Monitoring(2002 – 2007)

Collaborating centres

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ICAR : G. Kar (WTCER)

Relevance of spatial ET

- **In-season crop health monitoring (e.g. ET fraction)**
- **Regional hydrological applications (e.g. DHM)**
- **Biomass / productivity modeling (e.g. NPP)**

Existing satellite based approaches

Single source (Land = soil + canopy as one unit)

(a) *Residual Surface energy balance*

- Evaporative fraction (Roerink et al, 2000, Jiang and Islam, 2001)
- SEBAL / METRIC (Baastiaanssen, 1998, Tasumi et al, 2005)
- Surface decoupling (Boegh et al, 2002)

(b) *Radiation-Biophysical control*

- Penman-Monteith (Cleugh et al, 2007; Mu et al, 2008)

Two-source (Land = soil and canopy as separate components)

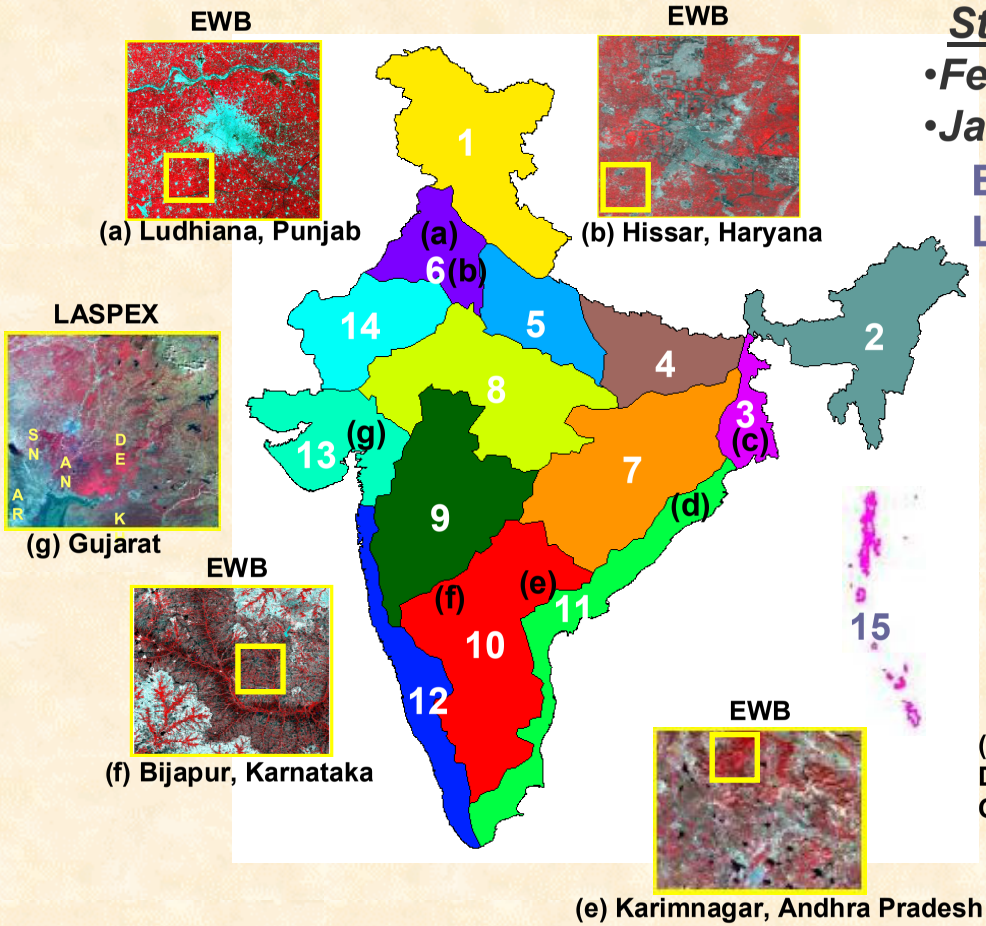
(c) ALEXI-disALEXI suite (Anderson et al, 2007)

(d) Component temperatures from dual angle (e.g. AATSR) for transpiration and evaporation

OBJECTIVES

- **Estimating Clear sky evapotranspiration using single noontime satellite data**
- **Validation over homogeneous and heterogeneous agroecosystems**

Agricultural landscapes for ET estimation and validation



Study period

- *February 2004 to May 2006 (EWB) : 7 no.*
- *January 1997 to February 1998 (LASPEX) : 5 no.*

EWB : Energy-water balance

LASPEX : Land surface Processes Experiment

Homogeneous (2km x 2km) within EWB (10km x 10km)

Heterogeneous (100km x 100km) in LASPEX region

EWB crops

Cereals (rice, wheat) : Ludhiana, Hissar, Kalyani, Khurda, karimnagar

Millets (Sorghum) : Bijapur

Fibre (Cotton) : Hissar

Oilseeds (groundnut) : Dhenkanal

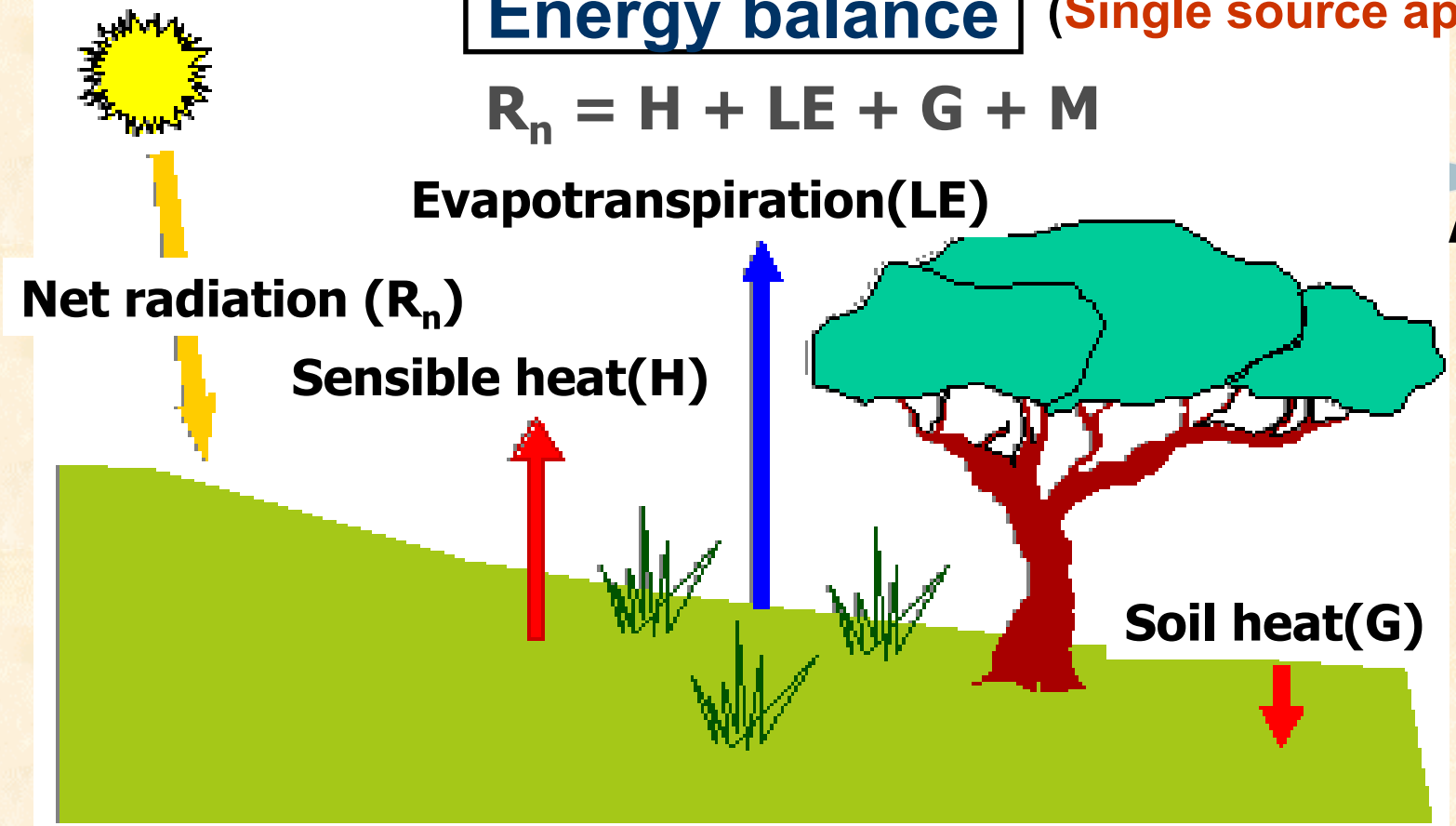
LASPEX : Mixed and Sparse crops

Intensive *in situ* measurements (IOP)

- At 14 days interval in EWB to measure hourly insolation, albedo, net radiation, Bowen ratio and LAI, PAR balance, soil moisture
- 13-17 of each month at minutes sampling interval to measure radiation components, soil heat flux (only at Anand), eddy correlation sensible heat flux (only at Anand), multiheight air temperature and humidity from 10m tower

Energy balance (Single source approach)

$$R_n = H + LE + G + M$$



$$R_n = R_s (1 - A) + \varepsilon_a \sigma T_a^4 - \varepsilon_s \sigma T_s^4$$

ε_a = air emissivity = f (T_a) (Campbell & Norman, 1998)

ε_s = surface emissivity = f (NDVI)

(Van de Griend & Owe, 1993)

$G = f(R_n, A, T_s, VI)$ (Baastianssen, 1998)

$(R_n - G)$ = net available energy (Q)

Evaporative fraction (EF) = LE/Q

$(\text{Latent heat flux})_{noon} = (\text{evaporative fraction})_{noon} . Q_{noon}$

Core satellite based inputs

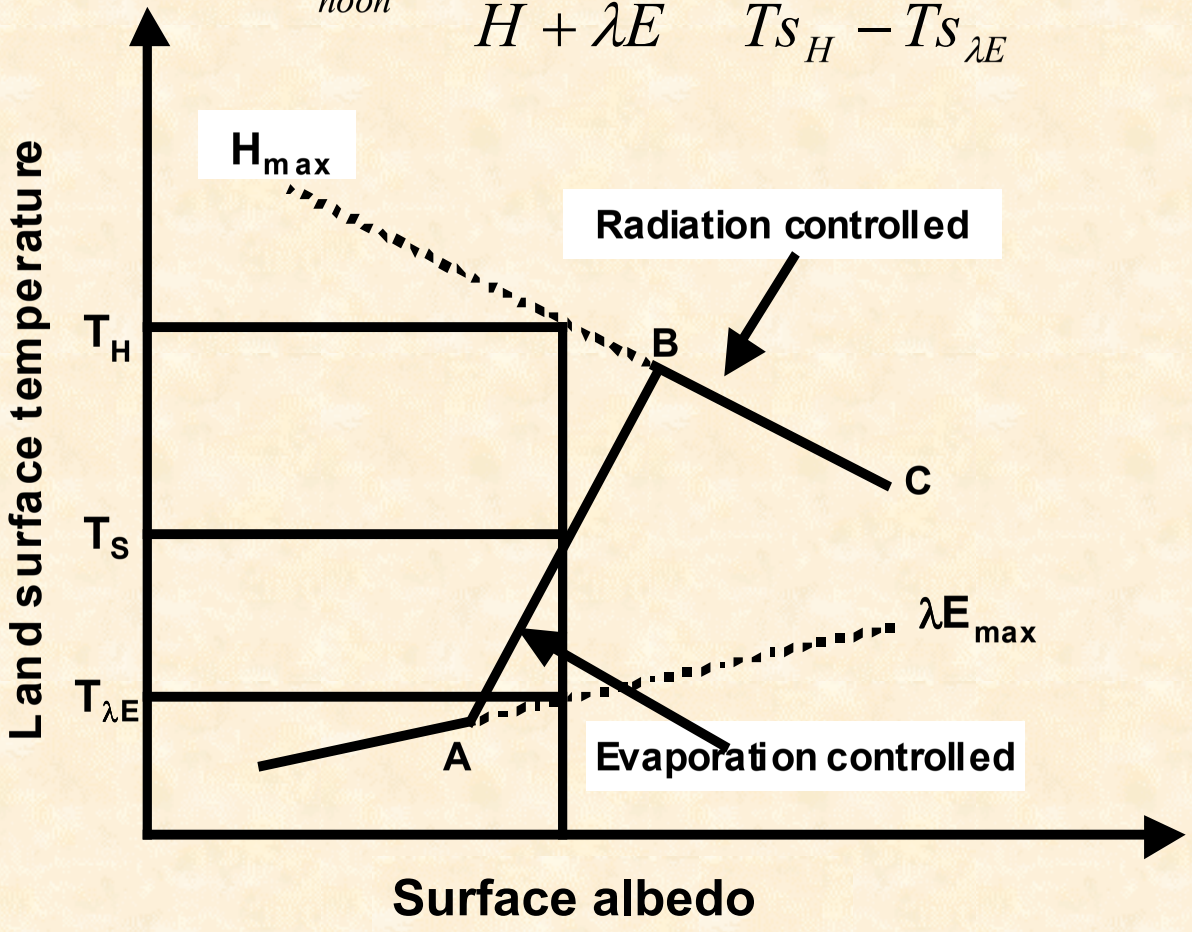
- *Land surface temperature(T_s)*
- *Surface albedo (A)*
- *Vegetation index (NDVI)*

Meteorological inputs

- *Insolation : WMO model*
  [= $a.\varepsilon. S_0.(SIN\ \gamma)^b$]
- *Air temperature : TVX*

Evaporative fraction

$$\Lambda_{noon} = \frac{\lambda E}{H + \lambda E} \approx \frac{Ts_H - Ts}{Ts_H - Ts_{\lambda E}}$$



Ts_H = LST on dry edge computed as linear function of surface albedo, $Ts_{\lambda E}$ = LST on wet edge computed as linear function of surface albedo, Ts = Pixel LST

Satellite data & Methodology

MODIS AQUA : Daily land surface temperature (LST) (MYD11A1) – 1km
(135 clear days) (Tile dimension : 1200 x 1200 in ISIN grid)
Daily seven band surface reflectances (MYD09GHK) – 500m
(1:30pm) (Tile dimension : 2400 x 2400) in ISIN grid
(I) Albedo : narrowband-to-broadband conversion (Liang, 2004)
(ii) NDVI : $(NIR_{ref} - Red_{ref}) / (NIR_{ref} + Red_{ref})$

NOAA AVHRR-14 : LST : Split window technique (Becker and Li, 1999) – 1.1km
(12:30 – 3:30pm) using brightness temperatures in ch4 and ch5
(Bhattacharya & Dadhwal, 2003)
(22 clear days) Surface reflectances : TOA atmospheric correction (SMAC)
(I) Albedo : narrowband-to-broadband conversion
(ii) NDVI : $(NIR_{ref} - Red_{ref}) / (NIR_{ref} + Red_{ref})$

Clear sky insolation : Calibrated WMO model
(a = global transmissivity = 0.78 over India
b = Exponent = 1.25 over India)
Air temperature : LST at $NDVI_{min}$ in LST-NDVI triangular scatter

Computation of daytime latent heat flux & Evapotranspiration

Daytime average latent heat fluxes = $\lambda E_d = \Lambda_d . Q_d$

Daytime net available energy = $Q_d = \int_{t1}^{t2} Q(t)$

$$Q_d\,(Wm^{-2}) = \left(\frac{2Q_{noon}}{\pi SIN\left[\left(\left(\frac{t_{sat} - t_{rise}}{t_{set} - t_{rise}}\right)\right)\pi\right]} \right)$$

Assuming,

$$\Lambda_{noon} \approx \Lambda_d$$

Since evapotranspiration occurs during daytime hours only,

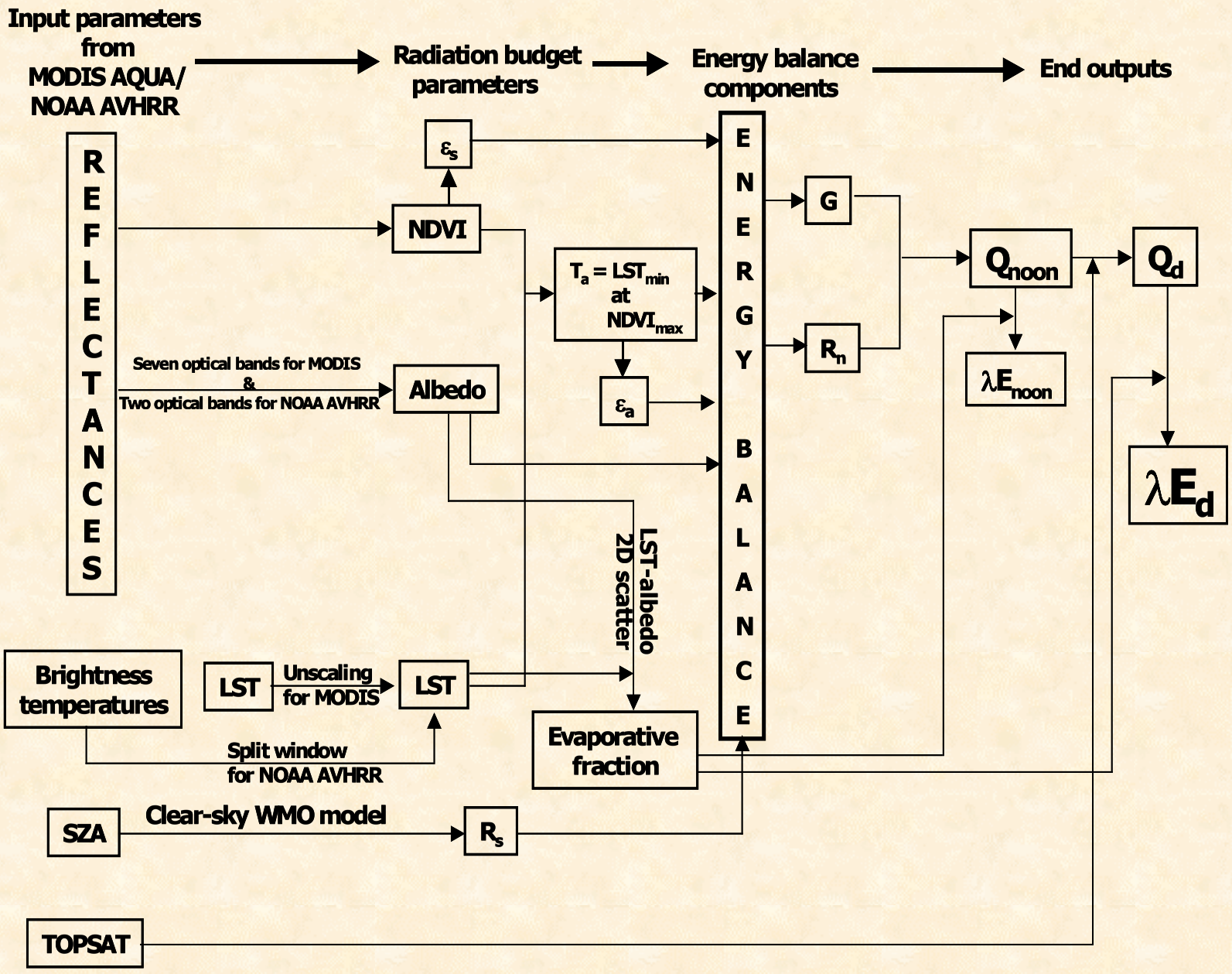
Daily evapotranspiration (ET) in mmd^{-1} = $\frac{daylength \times \lambda E_d}{24 \times 28.588}$

Regional scale ET

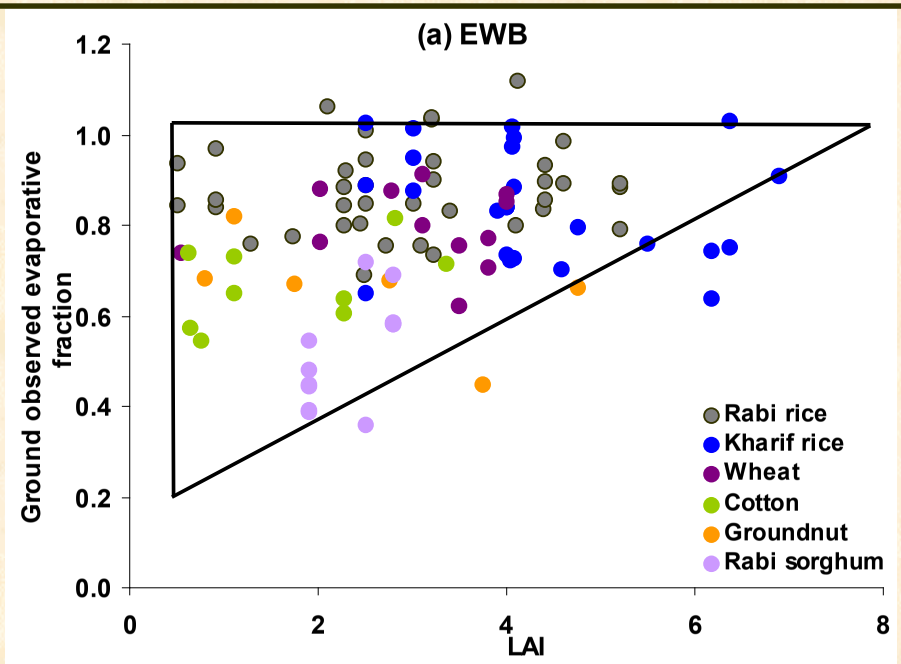
rabi **Nov., 2005 – April 2006 using MODIS AQUA eight day LST & surface eflectances**

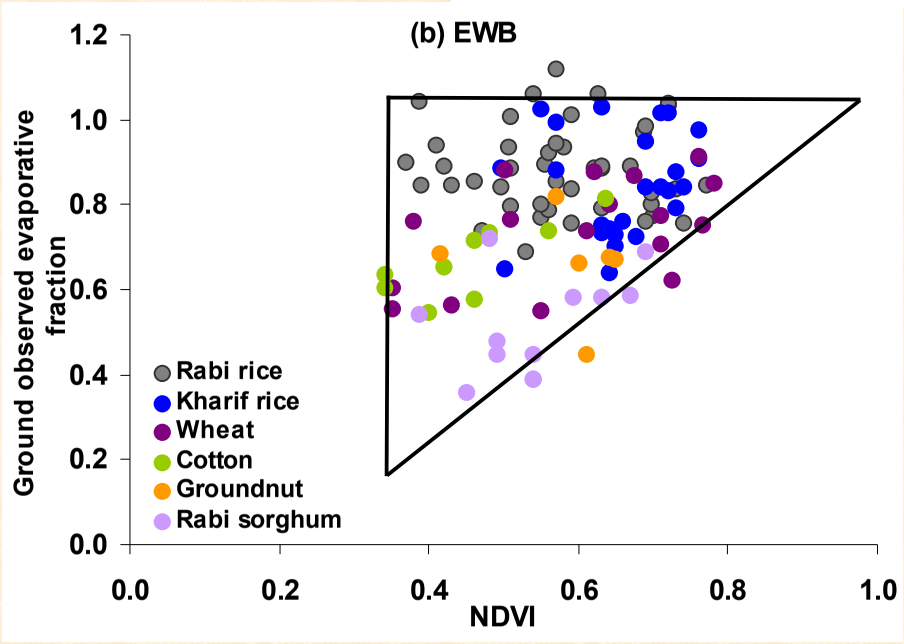
Indian sub-continent (8 - 37ºN and 68 – 97ºE)

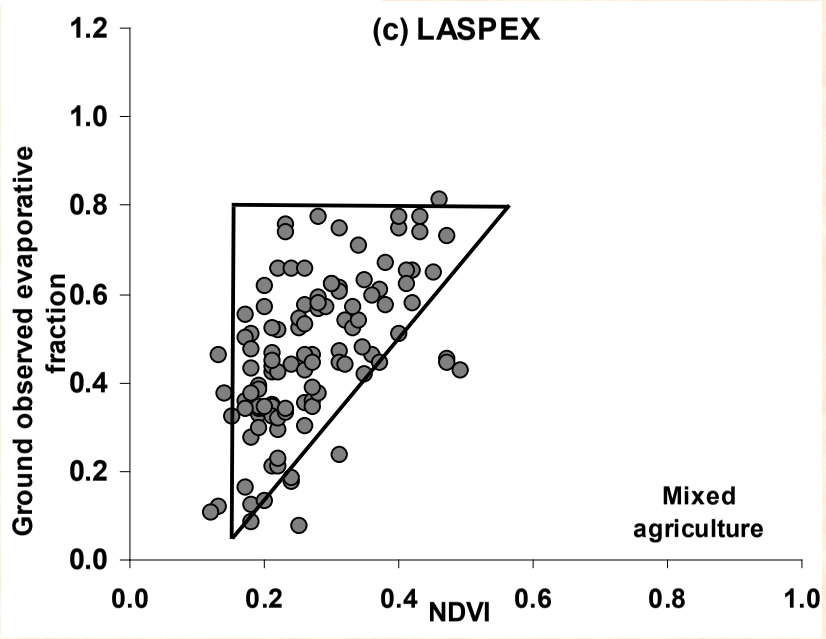
Flow chart for satellite data processing



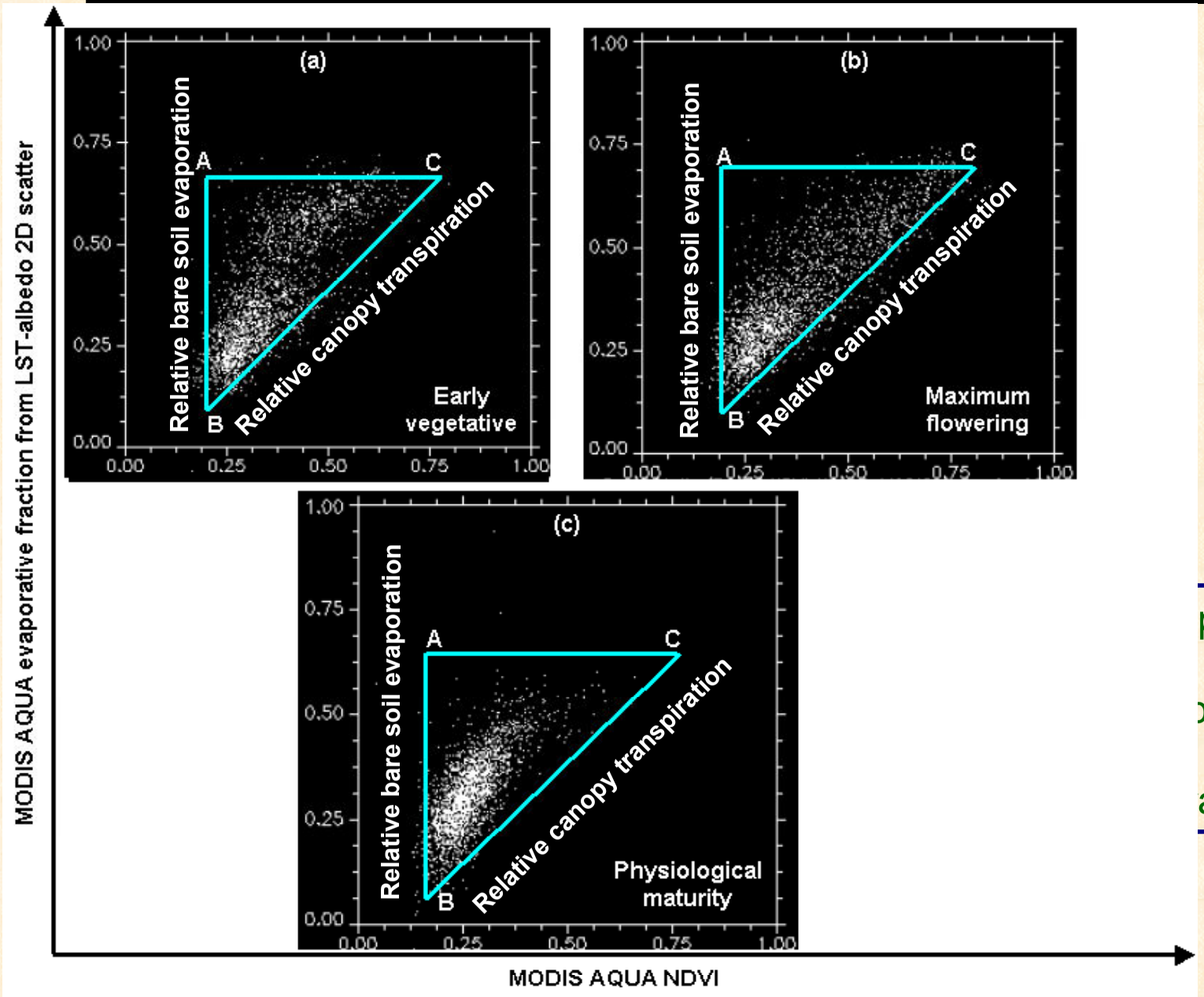
Evaporative fraction vs. LAI / NDVI







Evaporative fraction from LST- albedo 2D scatter vs. NDVI at spatio-temporal domain over irrigated wheat

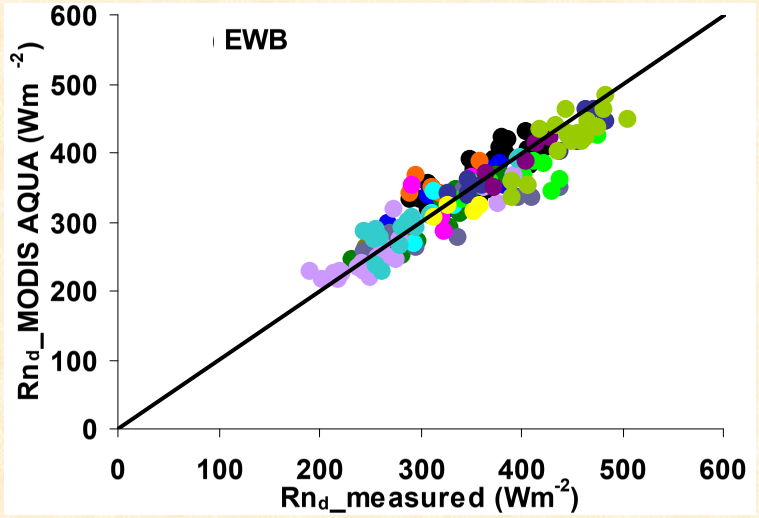


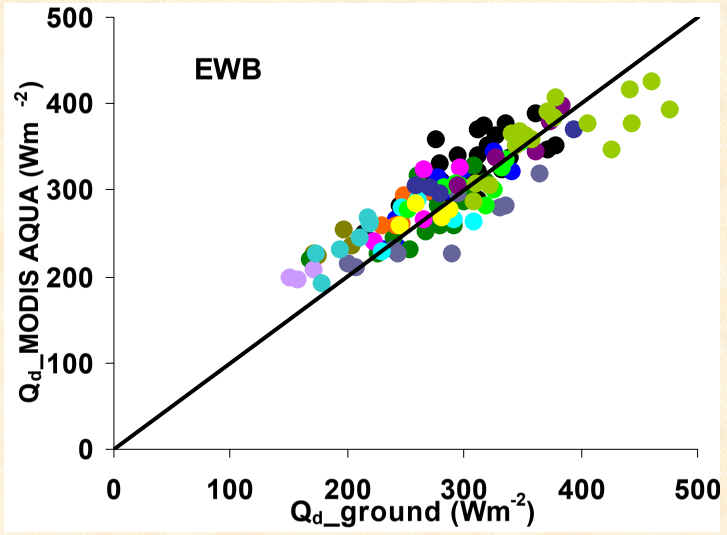
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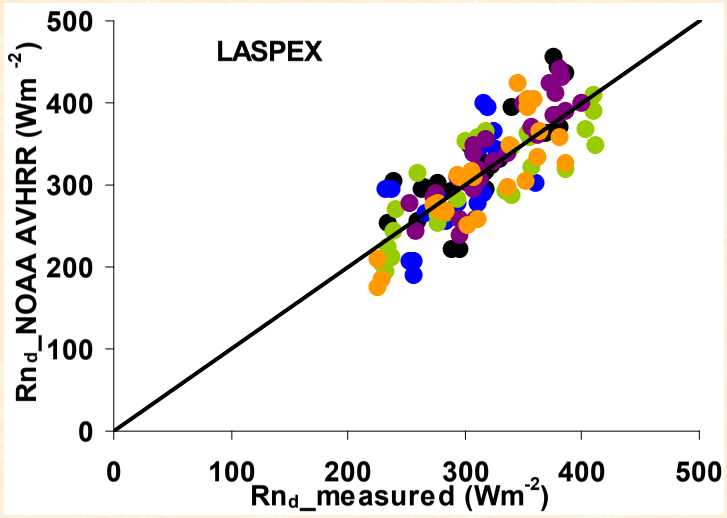
anspiration

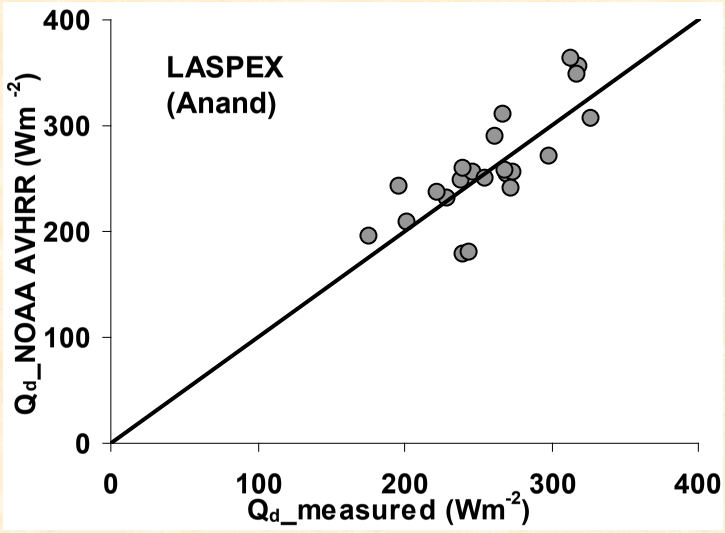
Validation of net radiation, net available energy estimates





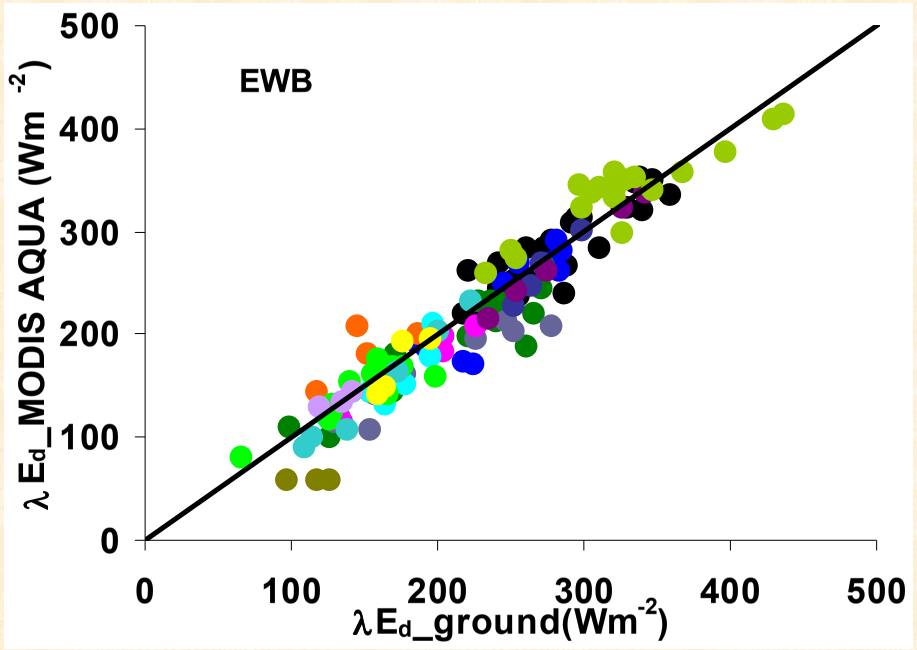
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- Kharif rice_Kalyani
- Fallow_Kalyani
- Wheat_Hissar
- Fallow_Hissar
- Cotton_Hissar
- Rainfed rice_Khurda
- Groundnut_Dhenkanal
- Rabi sorghum_Bijapur
- Wheat_Ludhiana
- Kharif rice_Ludhiana
- Fallow_Ludhiana
- Kharif rice_Karimnagar
- Fallow_Karimnagar
- Rabi rice_Karimnagar

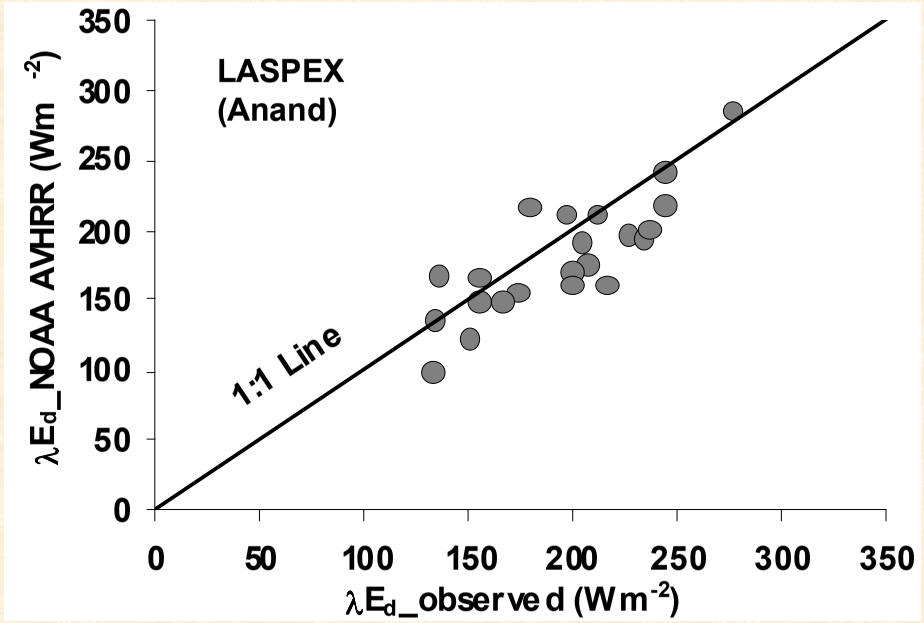




- Anand
- Arnej
- Derol
- Khandha
- Sanand

Validation of daytime latent heat flux / ET



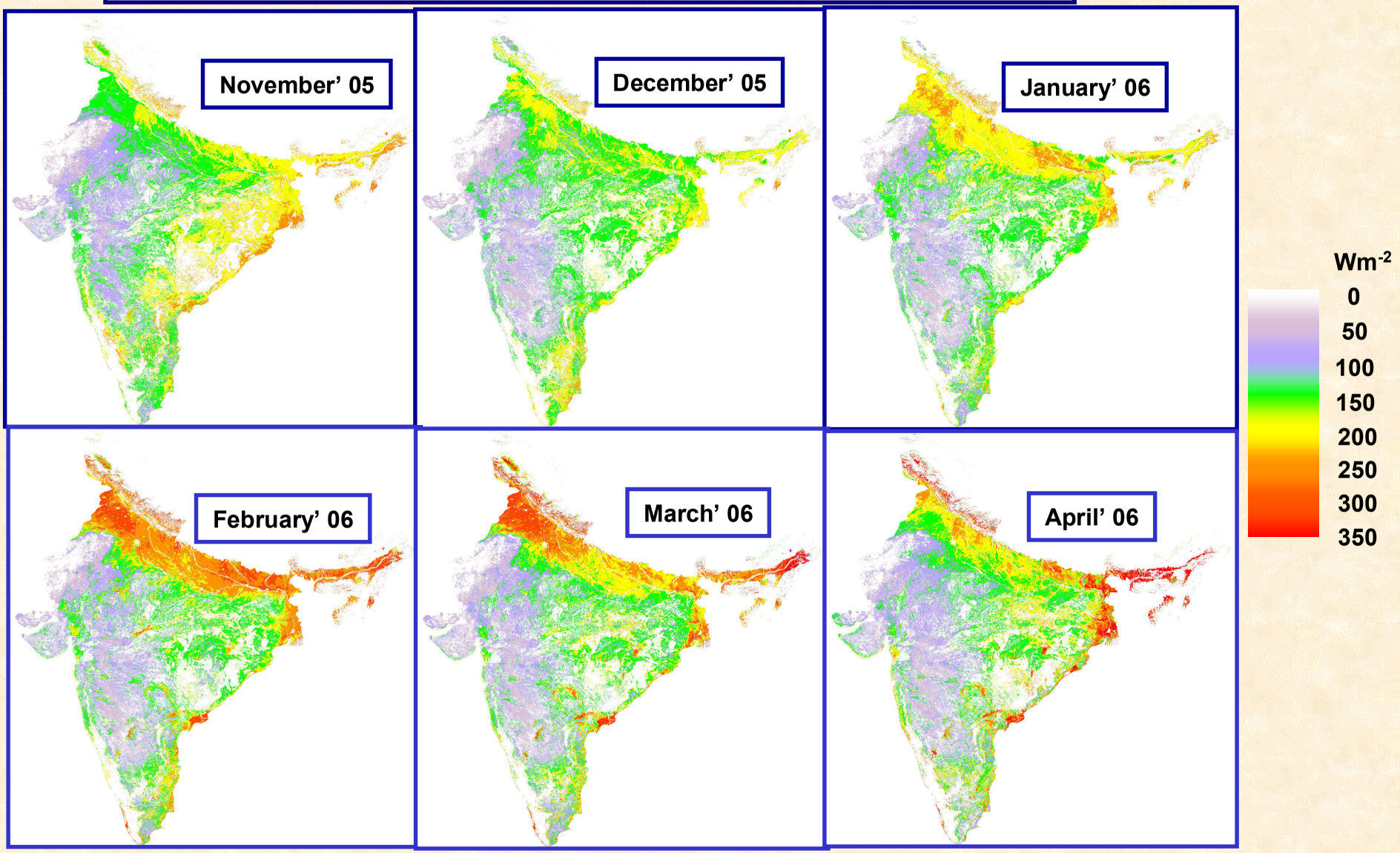


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Error statistics of satellite-based estimates

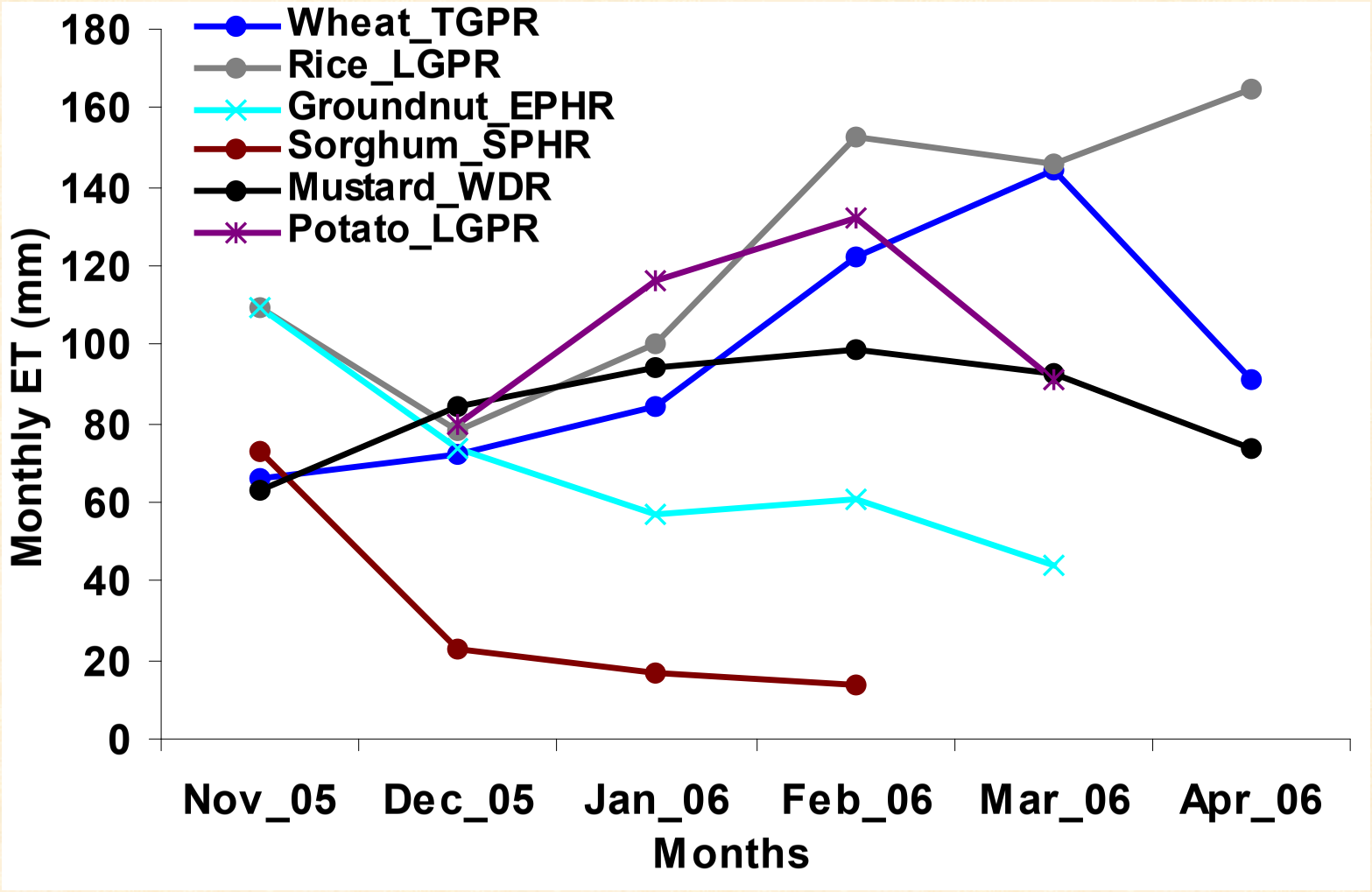
Study region	Energy balance components	Correlation coefficient	Root mean square error (RMSE)	RMSE (% of observed mean)
EWB (Homogeneous agroecosystem)	Daytime net radiation	0.92	29 Wm^{-2}	10.0
	Daytime net available energy	0.87	33 Wm^{-2}	11.0
	Evaporative fraction	0.77	0.12	15.5
	Daytime latent heat flux / ET	0.96	23 Wm^{-2}	10.5
LASPEX (Heterogeneous agroecosystem)	Daytime net radiation	0.81	37 Wm^{-2}	12.0
	Daytime net available energy	0.78	31 Wm^{-2}	12.0
	Evaporative fraction	0.79	0.18	31.0
	Daytime latent heat flux / ET	0.82	28 Wm^{-2}	15.0

Monthly regional ET (Wm^{-2}) at 0.01° from MODIS AQUA over Indian agroecosystems



SPOT-VGT based land use map (~1km) (Agrawal et al, 2003) was used

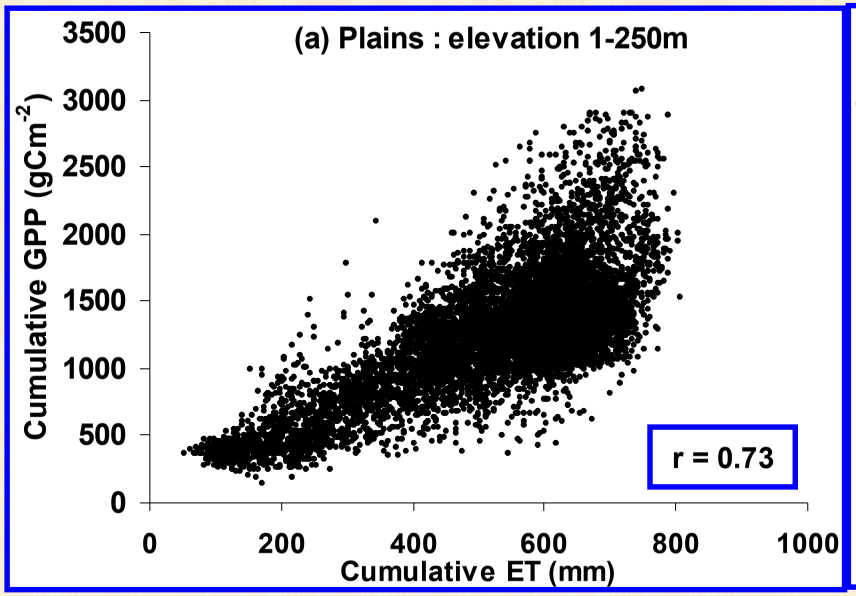
Monthly cumulative ET (mm) profile from MODIS AQUA over *rabi* crops in different agroclimatic regions

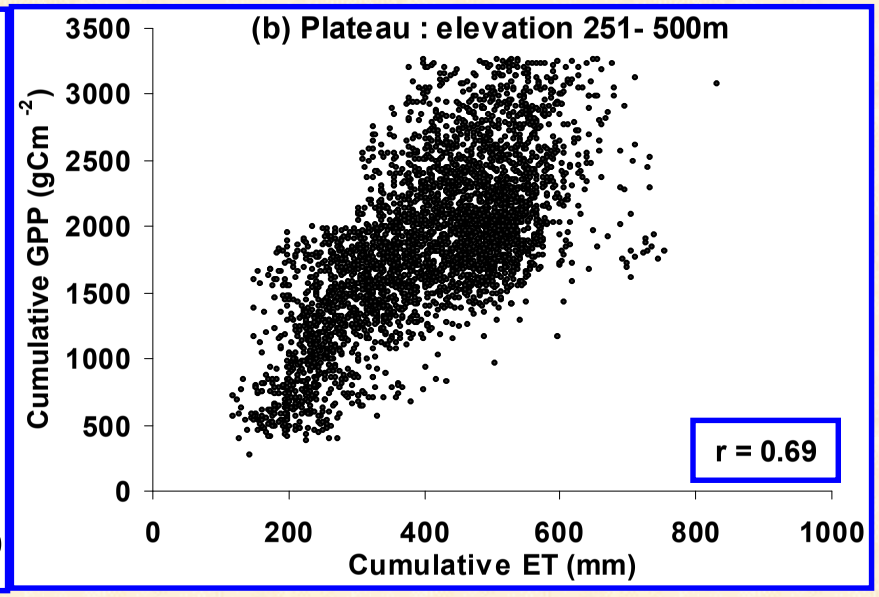


TGPR = Trans-Gangetic Plains Region
LGPR = Lower-Gangetic Plains Region
EPHR = Eastcoast Plains and Hills Region

SPHR = Southern Plateau & Hills region
WDR = Western Dry Region

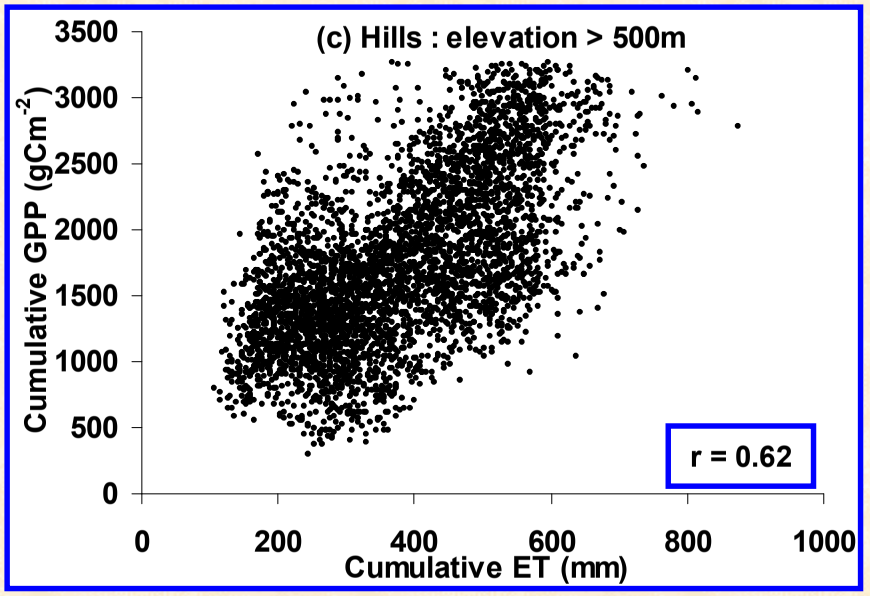
Evapotranspiration vs. Photosynthesis at regional scale: An indirect assessment over Indian agro-ecosystems





GPP = Gross primary productivity

Eight day MODIS AQUA GPP product (MYD17A2) at 1km were used



Summary of major findings

- **Present approach is solely satellite based without any ground data support producing errors in ET/ daytime latent heat flux between 10.5 to 15% over agro-ecosystems. These are close to globally reported errors.**
- **Errors were more in heterogeneous agro-ecosystems as compared to homogeneous one. Major reason is:**

  Constant evaporative fraction applicable over homogeneous systems (hourly/ daytime ~ 1.0), but not applicable over heterogeneous systems (hourly/ daytime ~ 0.7 to 1.3) due to differential coupling of canopy and soil with overlying atmosphere.
- **Evapotranspiration and photosynthesis estimates were found to be positively & linearly correlated at regional scale, but correlation decreases from plains (r = 0.73) to hills (r = 0.62).**

Conclusions

- **Diurnal ET (clear & cloudy) to be attempted to construct more realistic daily integrals.**
- **A two-source energy balance scheme to be implemented keeping in view of its applicability across all the agroecosystems.**
- **DEM correction to be incorporated to apply over all topographical conditions**