# Characterizing spatio-temporal dynamics of water use efficiency in citrus orchards of central India using Lansat-8 Imagery


*Presented by*

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GROUP ON EARTH OBSERVATIONS

Working Group 5 (Agriculture and Food Security)


**10th GEOSS Asia – Pacific Symposium**

Vietnam Academy of Science and Technology, Hanoi, Vietnam

*18 – 20 September, 2017*

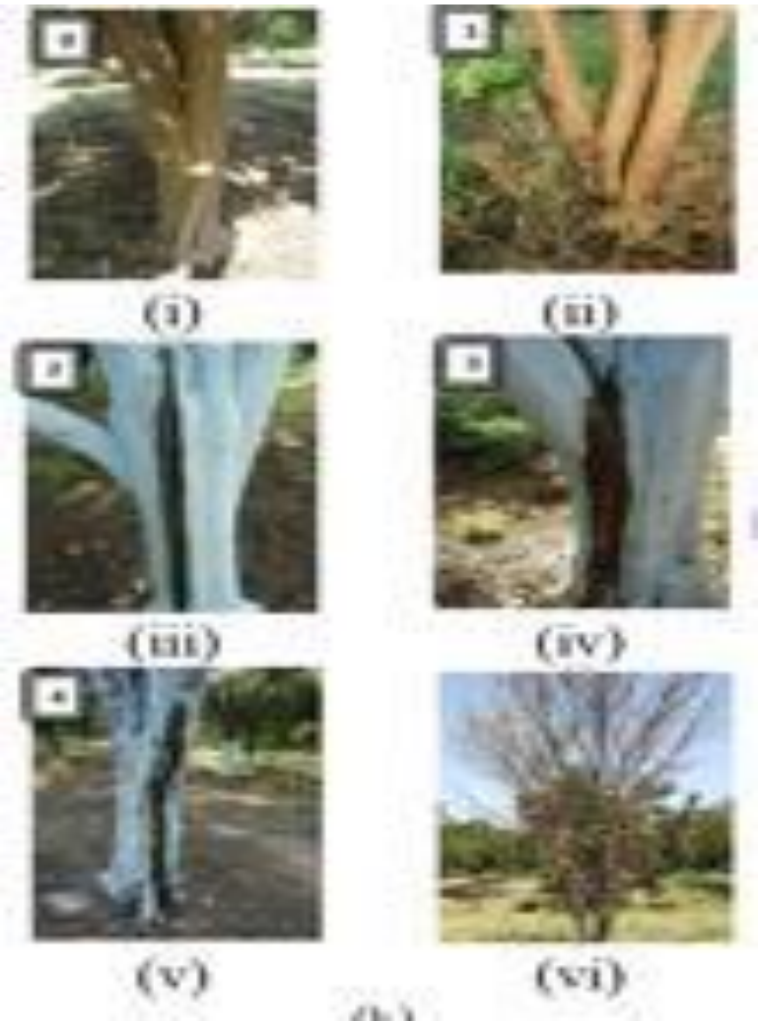
# Presentation Outline

- Motivation to Study
- Research Objectives
- Study Area
- Methodology
  - Tower based flux estimation
  - Satellite based flux estimation
- Analysis of Results
- Discussion
- Conclusion

# Motivation to Study

- India – $4^{th}$ in orange production (7.60 % of Worlds' tonnage)
  – $64^{th}$ in orange crop productivity ( 9.23 tons/ha)
  – Antithetical statements ???
- Vidarbha in central India is the leading producer of mandarin orange (*Citrus reticulata*) -- 40% of Country's production (yield: 6 tons/ha)
- Low citrus crop yield in central India is attributed to:
  - Erratic climate conditions
  - Improper management activities *(resulted in decreased water use efficiency, propagation of* Phytophthora *spp. root rot)*

# Motivation to Study ..




**Gummosis Infection on Trunk**
**i, ii, iii, iv, v shows oozing symptom**
**scale 0-4, vi shows highly infected citrus tree**

- The decreased yield is mainly attributed to the formation of Phytopthora root rot (Gummosis)
- Water (natural or irrigated), temperature, and environmental conditions are the main carriers of Gummosis causing fungi
- The fungi first attacks the root of the tree (invisible), germinate, and eventually results in Gummosis
- First visible impression of root rot is observed on the trunk (gumming)
- Disease symptoms: reduced fruit size and yield, yellow foliage, little water / nutrient uptake

# Motivation to Study ..

- Exchange of carbon and water fluxes between vegetation and atmosphere are crucial role in the metabolism of terrestrial ecosystems
- The key linking (eco-physiological) term is the ‘water use efficiency’ – WUE

$$WUE = \frac{Carbon\ used\ in\ production}{Water\ conmptively\ used} = \frac{GPP}{ET}$$

- WUE can be analysed at three scales:

  i) Leaf level ii) Eco system level iii) Biomass level
- In agronomy, WUE is synonymously used with crop water productivity (CWP)
- Analyzing dynamics of WUE, and its dependency on climatic / environmental / biophysical factors can Improve our understanding on crop productivity and disease management

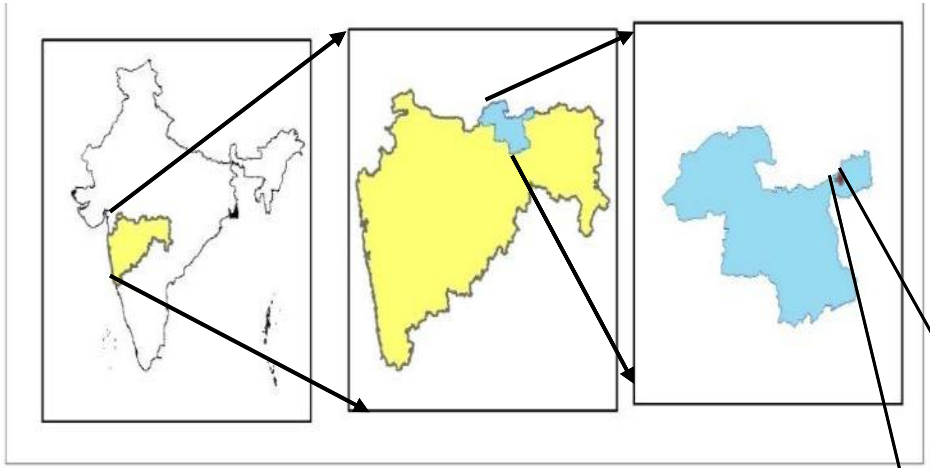
# Research Objectives

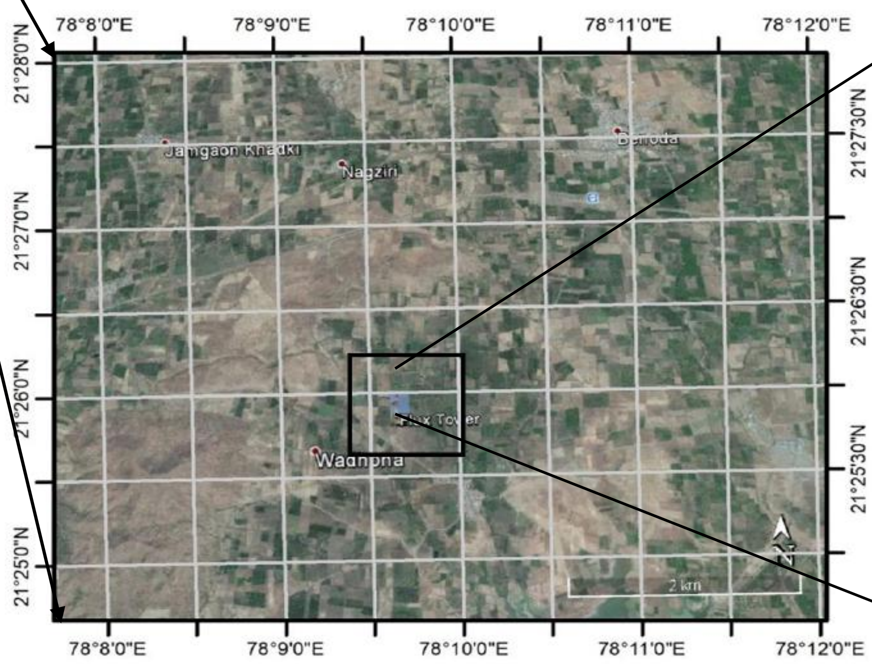
- Estimate WUE of flood irrigated citrus orchards of central India using eddy-covariance and LANDSAT measurements for one crop cycle
- Investigate the diurnal and seasonal patterns of ET, GPP and WUE
- Formulate ecosystem WUE of citrus orchards using spectral indices derived from LANDSAT imagery.

# Study Area

- Located in Benoda village, Maharashtra, central India
- Tropical Savanna climate (high temperature, low humidity and precipitation)
- Mean annual precipitation: 950 mm
- Situated on Deccan trap geologic system
- Orange crops of the region:
  - Three crop seasons (***February flowering – Ambia bahar*** ; June flowering – Mrig bahar ; Sept. flowering – Hast bahar)
  - Age: 8 years ; Spacing of trees: 5 m
  - Irrigation management: Flood , 15-20 day interval *(40 mm depth)*
  - Yield at harvest: 4 t/Ha to 12 t/Ha

# Study Area ..






Google earth image showing the flux tower location and fetch area

# Methodology – Data Collection

- Ecosystem level *(tower based)*:
  - Monitoring period: March – November, 2016
  - Air temperature, $H_2O$ and $CO_2$ fluxes at 10Hz frequency (Campbell – Irgason)
  - Flux corrections using Eddypro software
  - Meteorological parameters – 30 min. frequency (*precipitation, soil heat flux, solar radiation, soil moisture)*
- Regional level (Landsat):
  - Landsat-8 images (path: 145, row: 045)
  - Six cloud free images for analysis

# Methodology – $WUE_E$ estimation

- Eddy covariance method was used to estimate ET and GPP fluxes

$$WUE = \frac{GPP}{ET}$$

- Flux fetch / foot print: ~ 500 m
- Corrections applied:
  - Removal of bad data and gap filling
  - Tilt corrections on sonic measurements
  - Frequency response corrections
  - Webb-Pearman-Leuing (WPL) corrections
- Fluxes ($CO_2$ and $H_2O$) were averaged at 30-min interval for analysis

# Methodology – ET from METRIC

- Adopted satellite-based METRIC algorithm coded in open source 'R' to estimate ET at regional scale
- Energy balance approach: $LE = R_n - G - H$
- Sensible heat flux (aerodynamic function): $H = \rho_{air} C_p \frac{dT}{r_{ah}}$
- dT is linearly regressed with $T_s$: $dT = a + b\, T_s$
- *dT* is computed at two anchor pixels (cold – well watered and hot – bare soil pixels) of the image using inverse analysis
- Algorithm uses meteorological data at the flux tower to internally calibrate the energy balance at the anchor pixels

# Methodology – GPP from VPM

- Satellite-based LUE model to scale up GPP fluxes: $GPP = \epsilon_g \cdot FPAR \cdot PAR$
- FPAR is replaced with $FPAR_{PAV}$ (active vegetation) to improve GPP estimates

$$FPAR_{PAV} = \propto \times \ EVI$$

- Light use efficiency ($\varepsilon_g$) is estimated as a linear function of maximum LUE ($\epsilon_o$) and down-regulation factors

$$\varepsilon_g = \varepsilon_0 \times T_{scalar} \times W_{scalar} \times P_{scalar}$$

- Maximum light use efficiency ($\varepsilon_0$) -- By fitting a non-linear function between NEE and PAR at the flux tower during the peak of plant growing season

$$NEE = \frac{\varepsilon_0 \times PAR \times GPP_{max}}{\varepsilon_0 \times PAR + GPP_{max}} - R_e$$

# Methodology – Biophysical Indices

- Spectral indices derived from LANDSAT images were considered to investigate their dependence (correlation matrices) on $WUE_E$
- This can aid in:
  - Estimating $WUE_E$ directly from the dominant indices
  - Implementing management activities in response to changes in WUE

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

$$EVI = 2.5\ X\ \frac{\rho_{nir} - \rho_{red}}{[\rho_{nir} + (6\ \rho_{red} - 7.5\ \rho_{blue}) + 1]}$$

$$SAVI = \frac{(1+L)(\rho_{nir} - \rho_{red})}{(\rho_{nir} + \rho_{red} + L)}$$

$$GNDVI = \frac{\rho_{nir} - \rho_{green}}{\rho_{nir} + \rho_{green}}$$

$$GCI = \frac{\rho_{nir}}{\rho_{green}} - 1$$

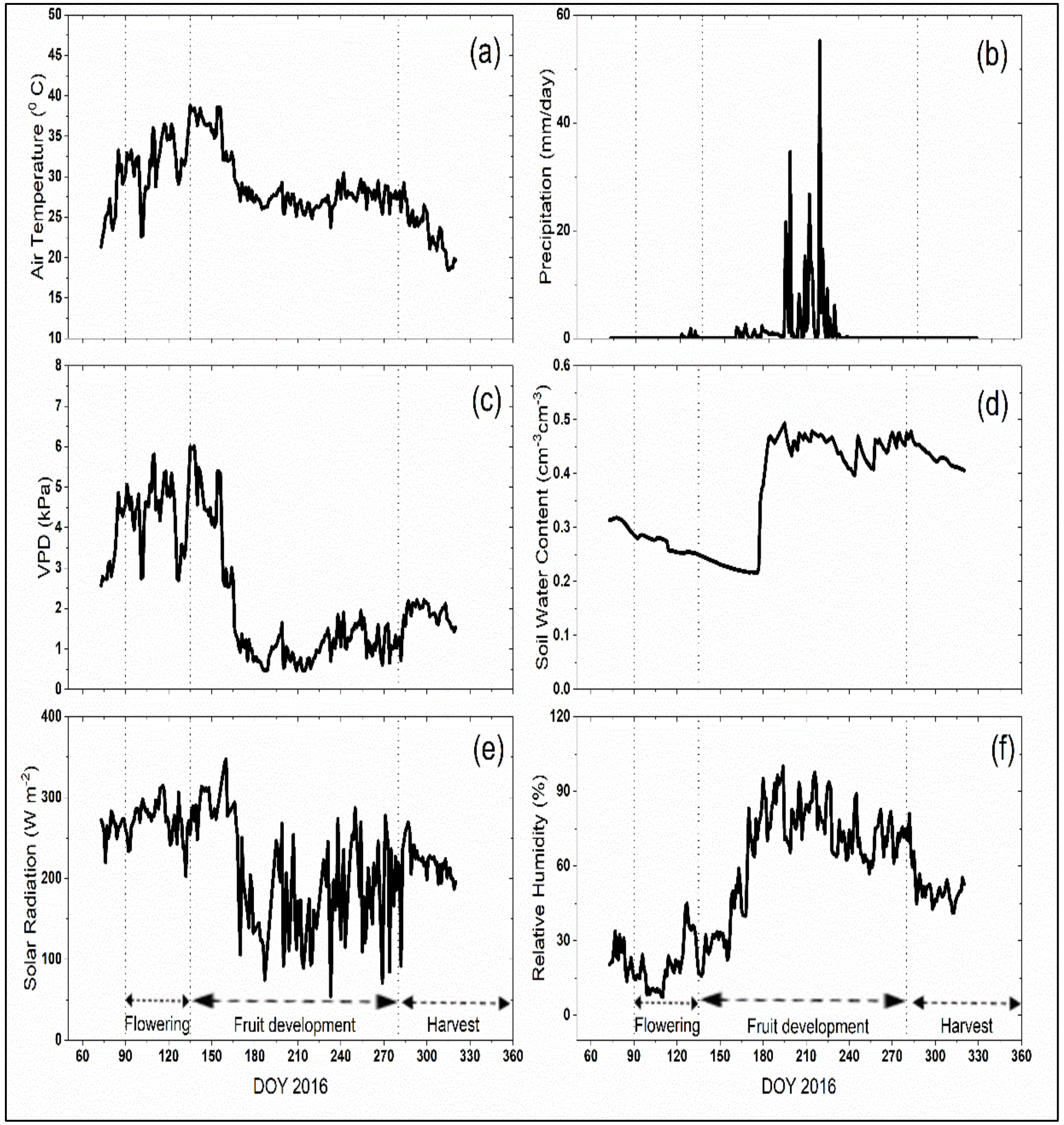
$$SR = \frac{\rho_{nir}}{\rho_{red}}$$

# Results and Discussion

- ***Environmental Conditions***

| Parameter | Max | Min | Mean |
|---|---|---|---|
| Air Temp (C) | 39 | 18.5 | 28.5 |
| VPD (kPa) | 6 | 0.46 | 2.36 |
| Solar Rad ($Wm^{-2}$) | 354 | 54 | 223 |

- Mean of monthly climatic variables have uni-modal distributions (peak during the early growth stage)
- Of the observed environmental parameters, precipitation, soil moisture, and LAI were the key drivers for photosynthesis and transpiration



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# Results and Discussion

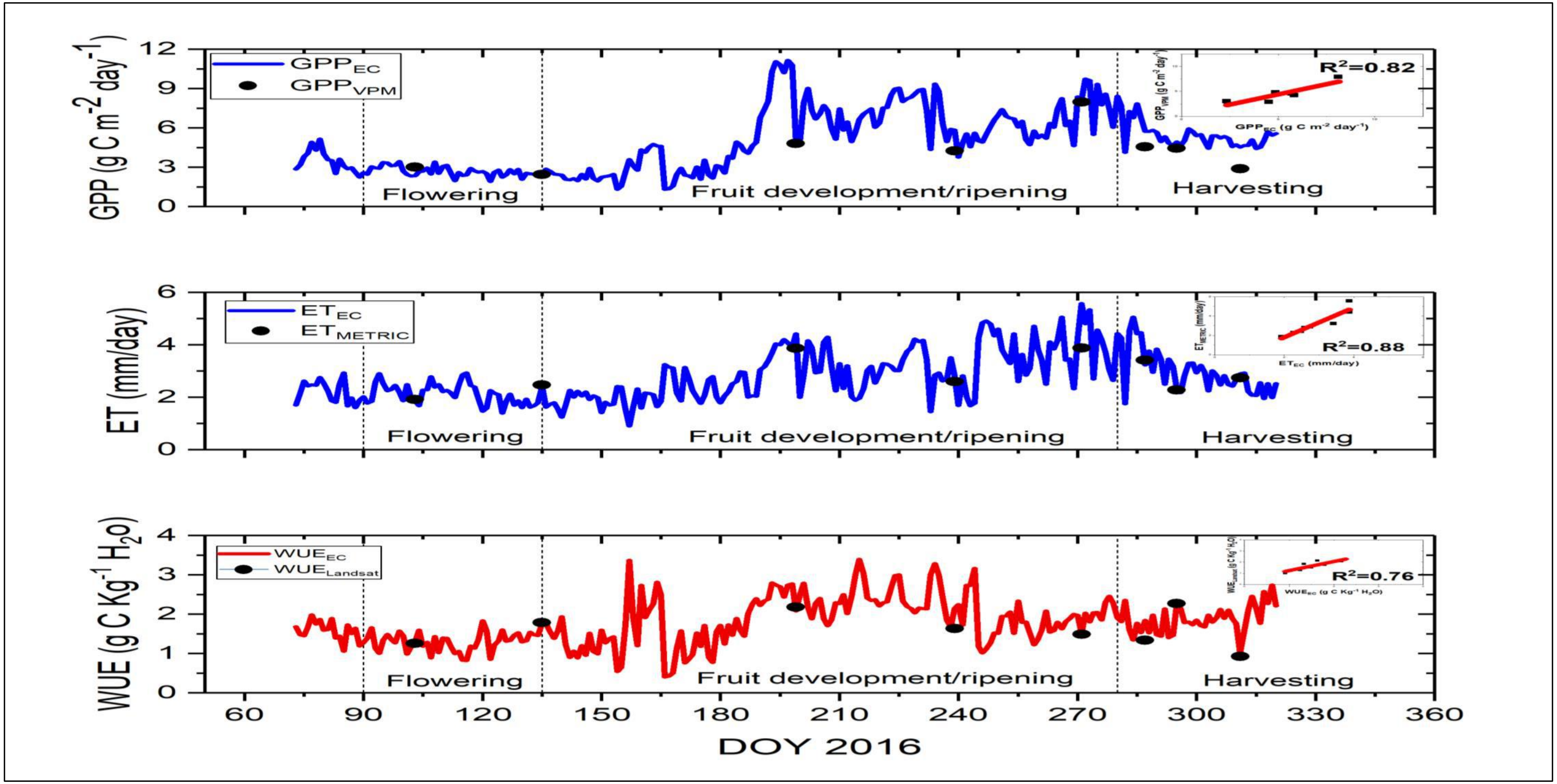
- ***Seasonal variations in ET, GPP, and WUE***

| Flux | Max | Min | Mean |
|---|---|---|---|
| ET (mm $day^{-1}$) | 5.8 | 1.1 | 2.4 |
| GPP (g C $m^2$ $day^{-1}$) | 11.2 | 1.3 | 5.8 |
| WUE (g C $Kg^{-1}$ $H_2O$) | 3.4 | 0.2 | 1.9 |

- Landsat derived fluxes were well in agreement at the flux tower location
- During winter (pre-flowering), farmers water stress the orange pants to initiate blooming – less RWU and less ET
- During winter, the crop is mostly dormant (shorter and cooler days) – less GPP
- During summer (flowering), low precipitation, high air temp and VPD – less ET and GPP
- During fruit development stage, precipitation paired with soil moisture increased GPP, ET and WUE fluxes

# Results and Discussion

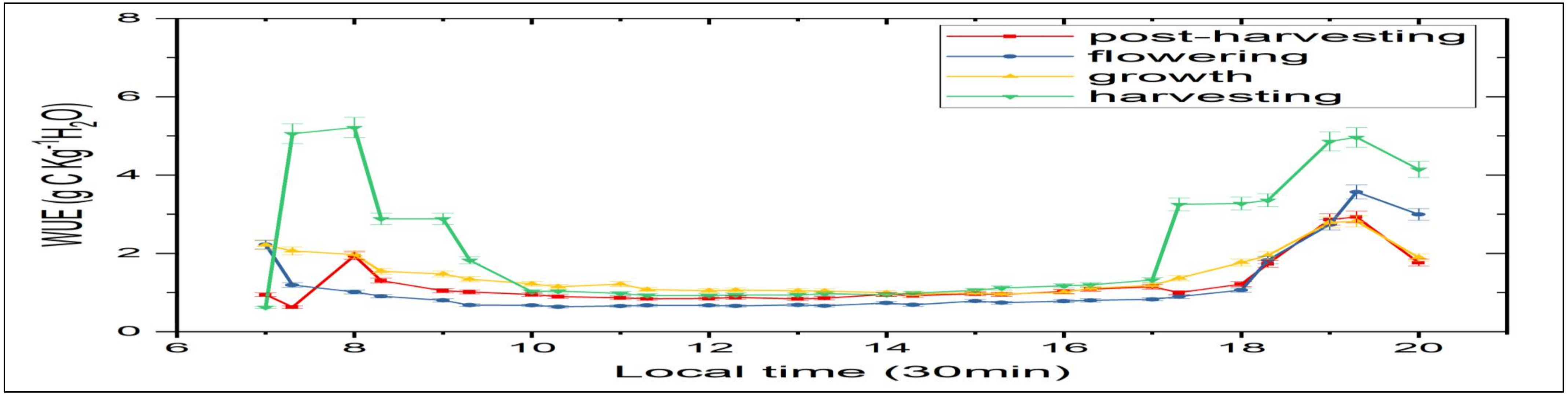
- ***Seasonal variations in ET, GPP, and WUE ..***



# Results and Discussion

- ***Diurnal variations in WUE***

- Diurnal cycle trends are identical between the growth stages
- Diurnal trends have two peaks (early morning and evening) with a low steady-state WUE in between
- Sharp increase in WUE during wee hours of the day (06:00 to 08:00 am)
- As the time of the day progressed, WUE decreased



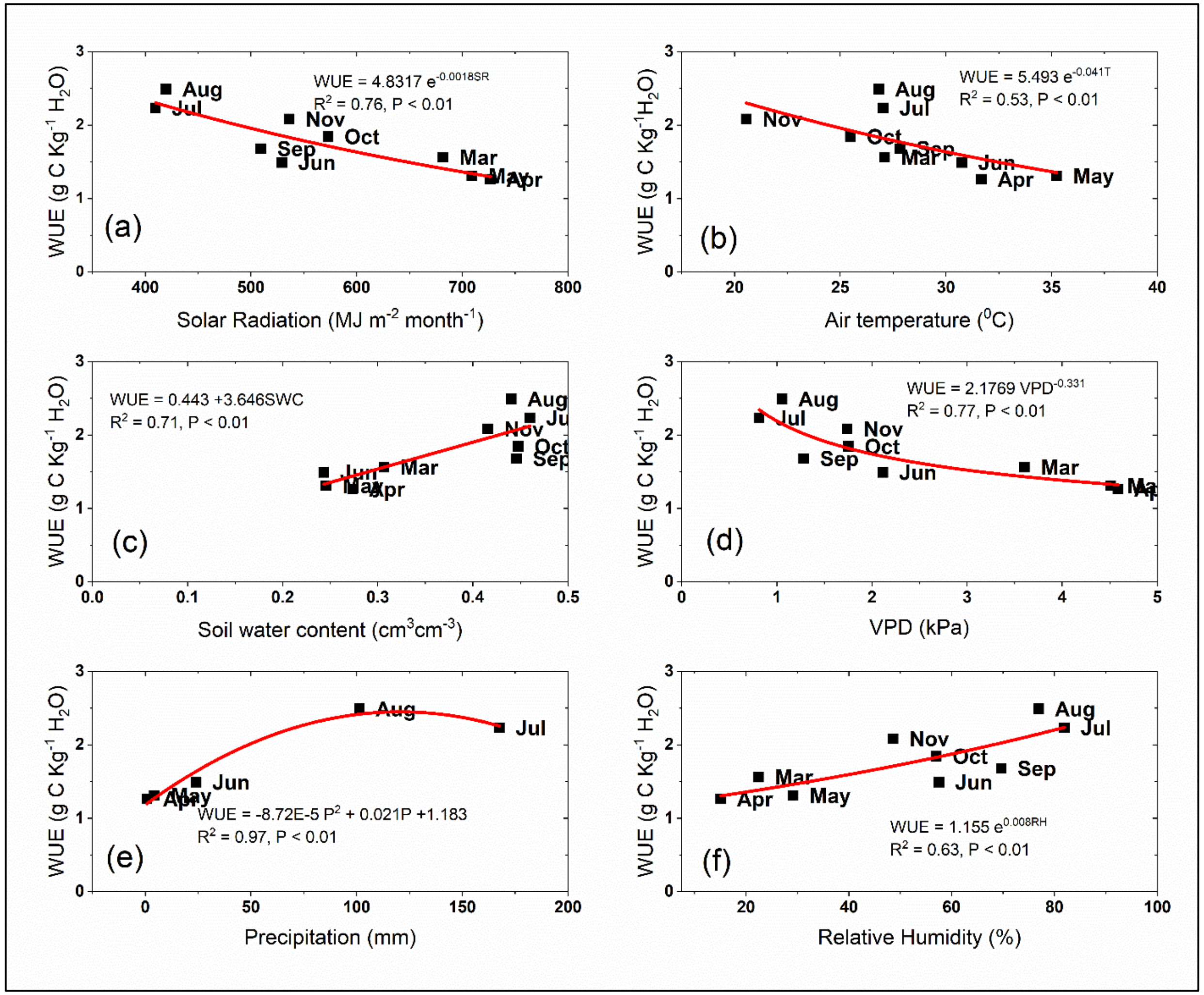
# Results and Discussion

- *Role of climate indices on estimated fluxes*

- Asynchronous response of ET and GPP fluxes -- decreasing trend in WUE with an increase in VPD

More than 70 % of variations in ET, GPP, and WUE were explained by:

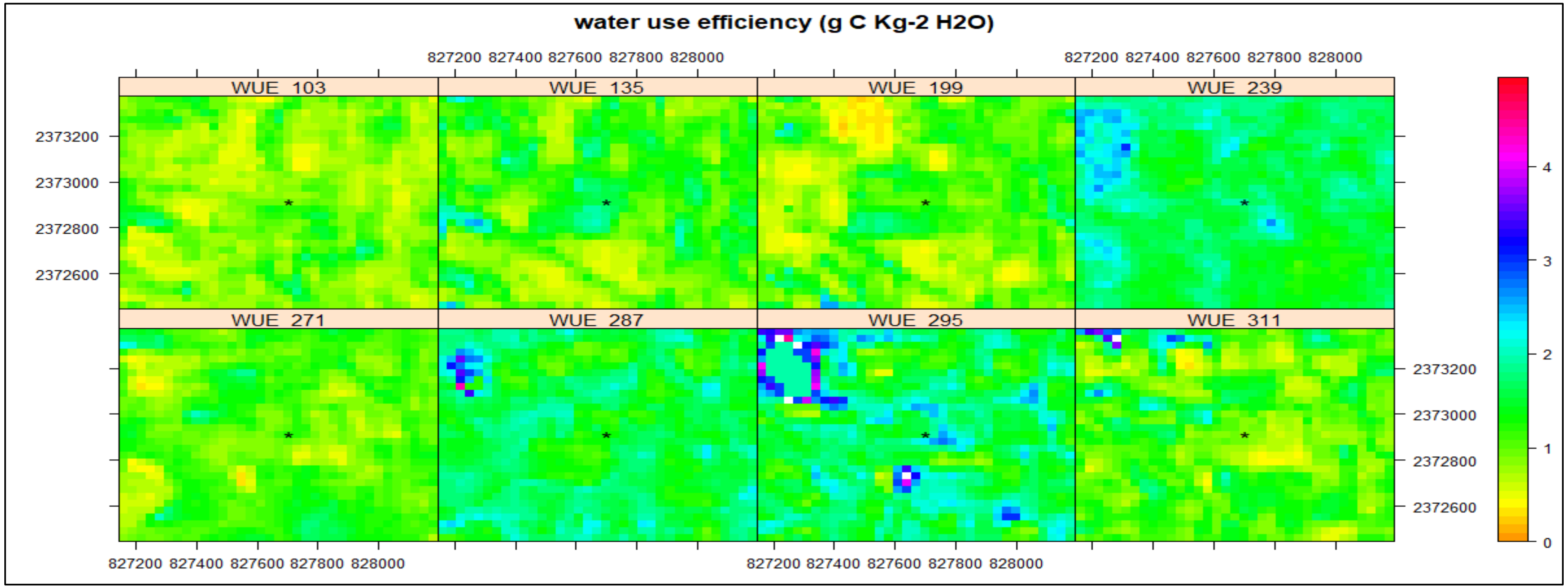
- Solar radiation
- Soil moisture
- VPD
- Humidity and P
- Precipitation



# Results and Discussion

▪ ***Spatio-temporal distribution of WUE fluxes***

- Spatially, WUE is uniformly distributed – Homogeneous crop conditions
- At flux tower, WUE from Landsat is correlated with EC measurements
- WUE is low (< 1 g C $Kg^{-1}$ $H_2O$) during pre-flowering; maximum ( 3 to 4 g C $Kg^{-1}$ $H_2O$) during fruit development, and minimum (< 1 g C $Kg^{-1}$ $H_2O$) during post-harvest



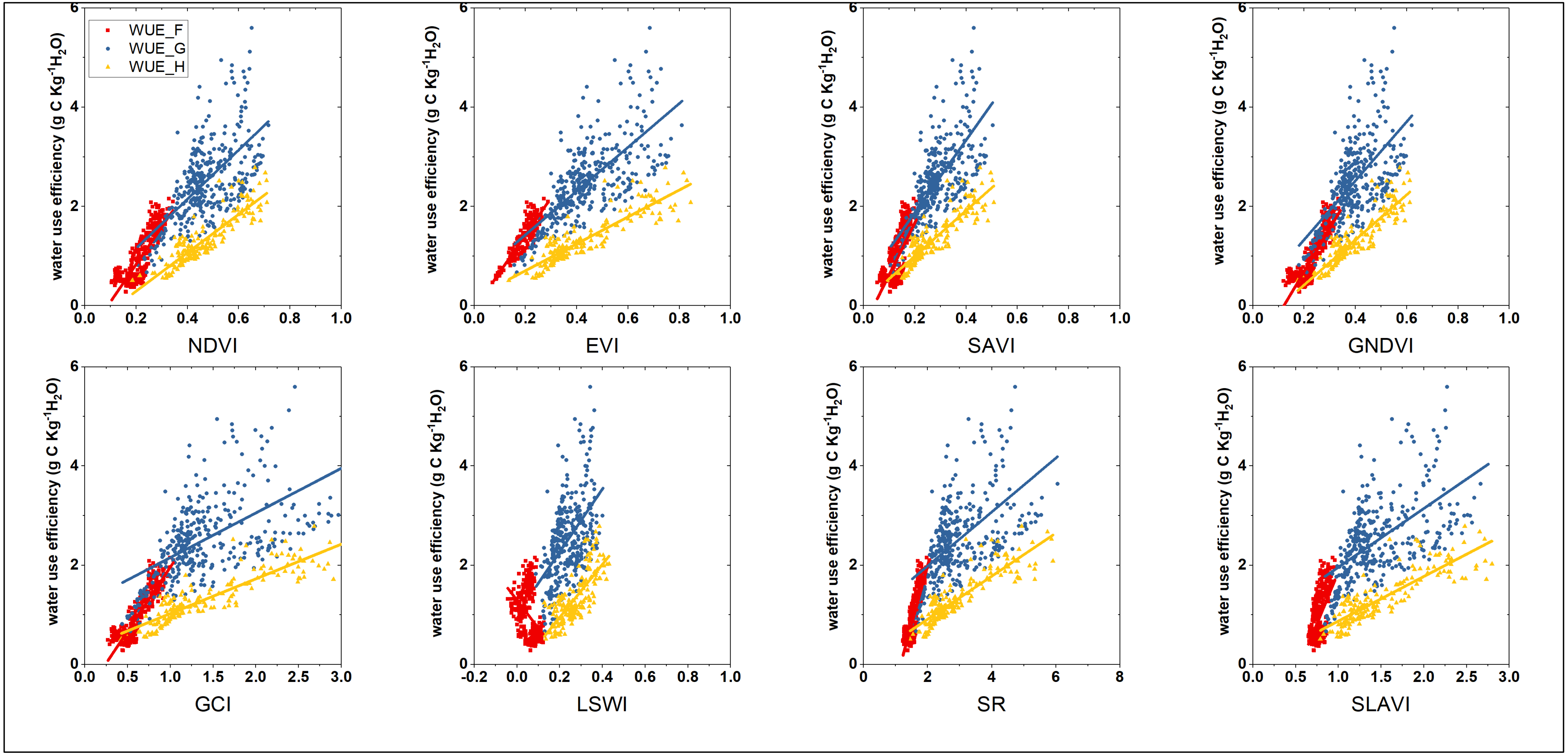
# Results and Discussion

- ***Spectral dominance of WUE fluxes***

- Landsat derived spectral indices were used to capture WUE dynamics
- Of all indices, the following have a strong dependency on WUE estimates:
  - NDVI ($R^2$ = 0.62 – flowering ; 0.41 – growth ; 0.79 – harvest)
  - EVI ($R^2$ = 0.80 – flowering ; 0.51 – growth ; 0.81 – harvest)
  - SAVI ($R^2$ = 0.41 – flowering ; 0.51 – growth ; 0.81 – harvest)
- Spectral indices are linearly related to WUE fluxes
- Low correlation during flowering and harvest stages
- Spectral indices that considers the relative reflectance's between bands were able to explain WUE dynamics in comparison to the absolute reflectance's

# Results and Discussion

- ***Spectral dominance of WUE fluxes ..***



# Conclusion

- $CO_2$ and $H_2O$ flux densities were measured for citrus orchard at regional scale
- Ecosystem GPP, ET and WUE fluxes were observed to be lower during flowering and harvest and peaked during fruit development and ripening
- Diurnal WUE was peaked at early morning and evening hours of the day and persistent for rest of the day
- VPD has a strong negative correlation with ET and GPP, but WUE is decreasing with increase VPD
- 70% of variations in ET,GPP and WUE were explained by climate parameters
- METRIC and VPM models were well suited for Indian semi-arid region to estimate ET and GPP at regional scale
- At spatio-temporal scale WUE having good correlation with flux tower data
- WUE at regional level lower at initial stages and increasing trend toward flowering and development stages
- NDVI, EVI and SAVI are the dominant spectral indices to explain WUE at regional level ecosystem of this region

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# Acknowledgements

1) Mr. P. Srinivasa Rao, PhD student, IIT Hyderabad, India

2) Prof. J. Adinarayana, CSRE, IIT Bombay, India

3) Prof. Seishi Ninomiya, University of Tokyo

4) ITRA-Water (Media Lab Asia), Ministry of ICT, Govt. of India