"A Physics-based Surface Energy Balance Model for Estimating Evapotranspiration in Selected Agro-ecosystems Using High Resolution Thermal Infrared Observations from ECOSTRESS"

Devansh Desai[1] & Bimal K. Bhattacharya[2]

1. Department of Physics, Gujarat University, Ahmedabad- Gujarat, India
2. Space Applications Center (ISRO), Ahmedabad-Gujarat,India

Other Contributors: Dhawanil Gharekhan, Nirma University, Ahmedabad, Gujarat, India

Scientific Rationale

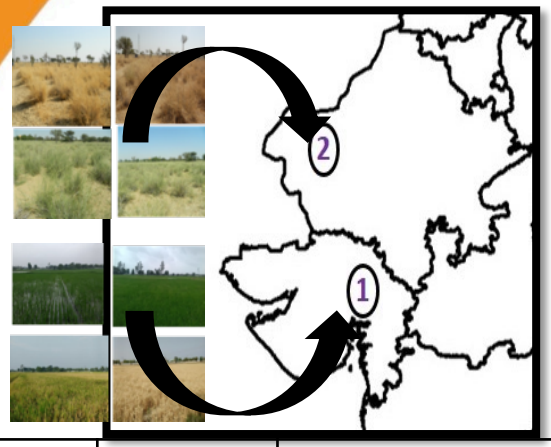
Crop Consumptive Water Use (CWU) and Water Productivity (CWP) **require a reliable Surface Energy Balance (SEB) modeling framework to generate high resolution Evapotranspiration (ET) data over Indian sub-continent which is free from uncertainty in conductance parameterizations.**

Objectives

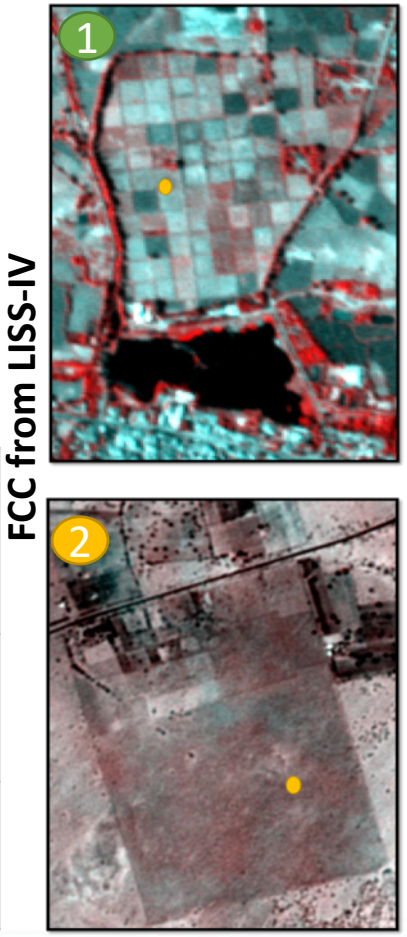
- To develop implementable SEB-based ET model with high resolution thermal remote sensing observations from ECOSTRESS.
- To validate ET model outputs with eddy covariance tower based measurements over two eco-hydrologically contrasting agro-ecosystems.
- To investigate relation between high-resolution ET and measured crop growth indicator in terms of net ecosystem exchange (NEE) of CO_2

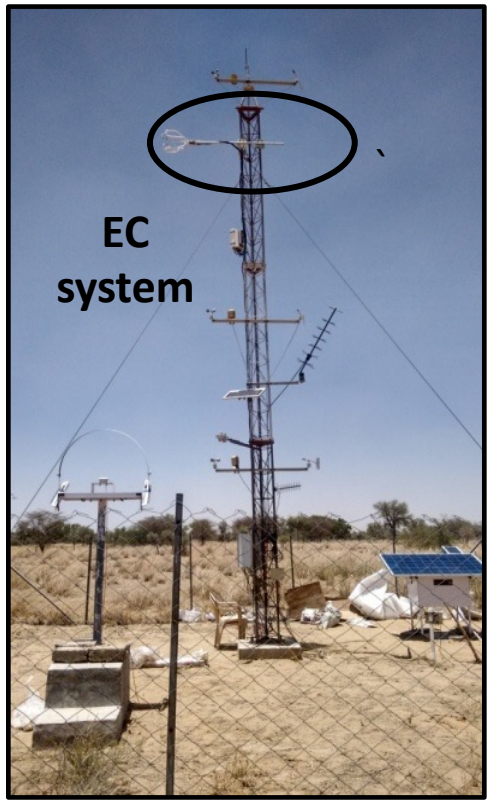
Study area

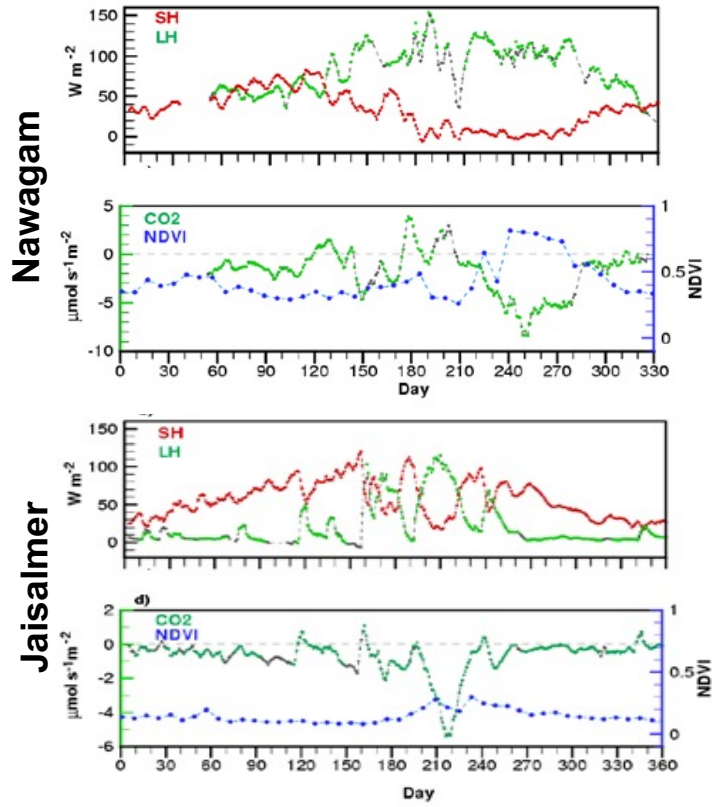
Agro-Met Station (AMS) augmented with high-response EC system under Indo-UK INCOMPASS program



Site	Latitude (° N) Longitude (°E)	Climate type & Agro-ecosystem Characteristics	P (mm)
1. Nawagam	22.80, 72.57	Semi arid Rice-wheat rotation, irrigated	700-850
2. Jaisalmer	26.99, 71.34	Arid Natural rainfed grassland	250-300







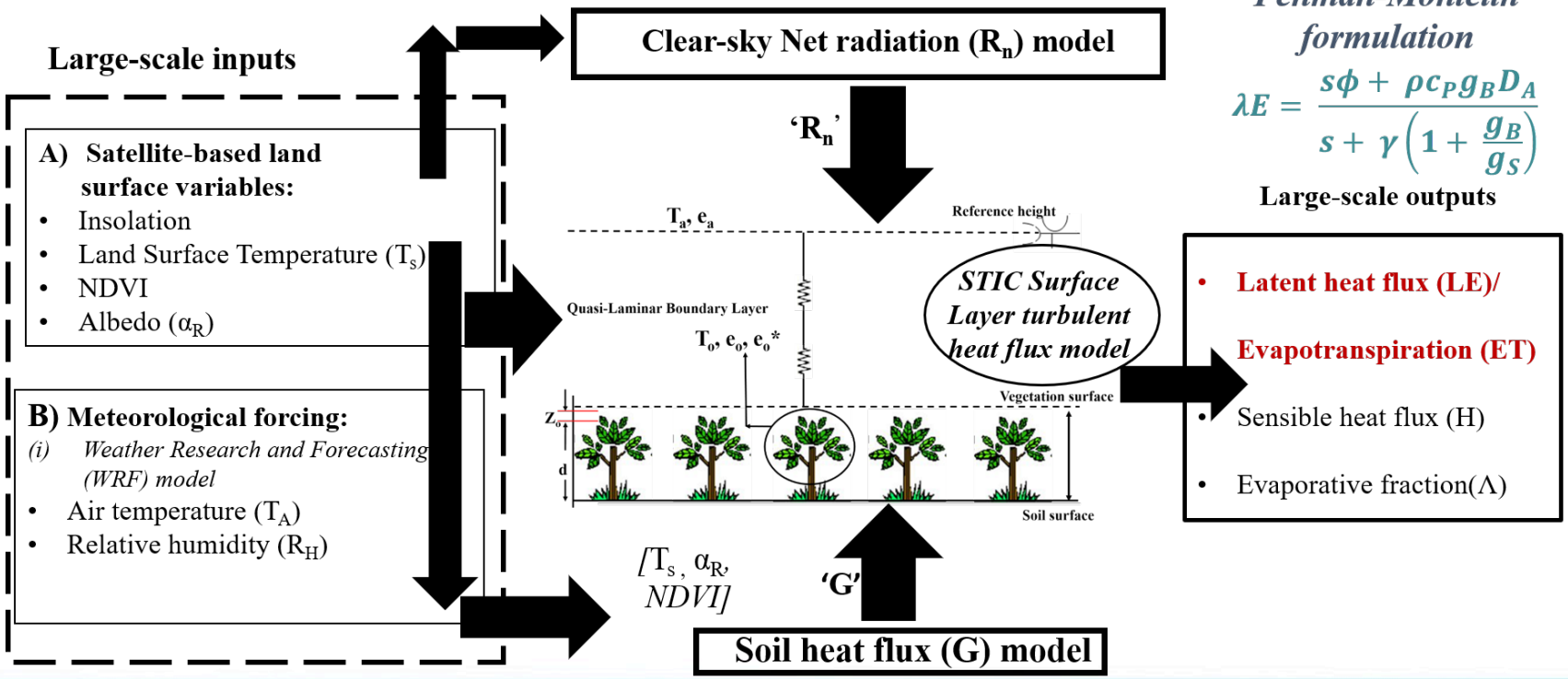
Air temperature, Humidity, Latent heat flux, Sensible heat flux, Frictional Velocity, CO_2 flux sampled at every 10 seconds interval.

Large-scale ET modelling framework with STIC-LS

Surface Temperature Initiated Closure (STIC) (Mallick et al., 2014) is an analytical model, requires net radiation, soil heat flux, air temperature and relative humidity. It uses LST as only RS input. However, ***STIC-LS allows to simulate the SEB fluxes (net radiation, soil heat, latent and sensible heat fluxes) on large-spatial scale using high resolution LST, surface emissivity, albedo, vegetation index using space-borne thermal and optical data, ancillary meteorological inputs and their integration into STIC***

Surface Energy balance

$R_n = H + \lambda E + G$



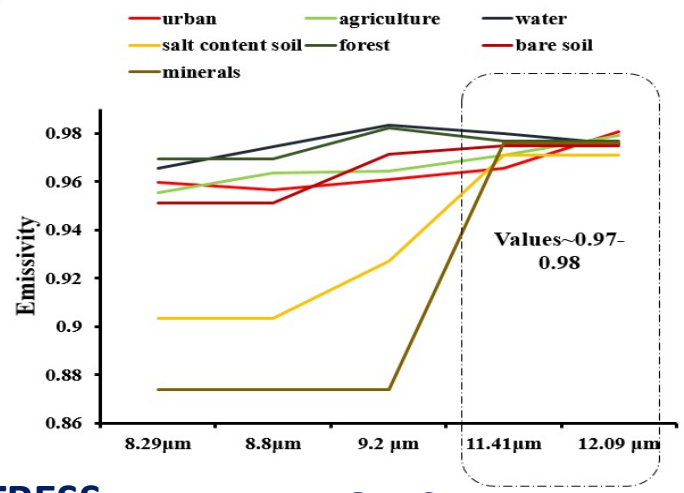
Input data used for STIC-LS Model simulation

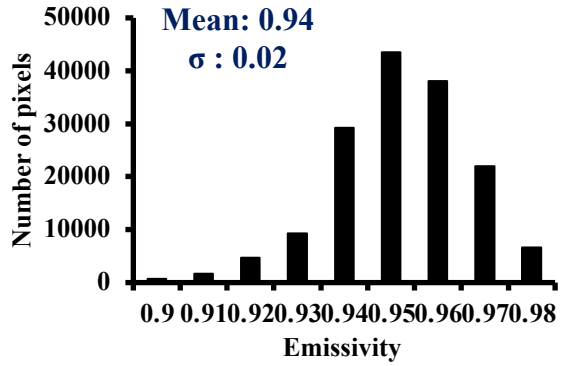
Period of acquisition: March 2019 to April 2020

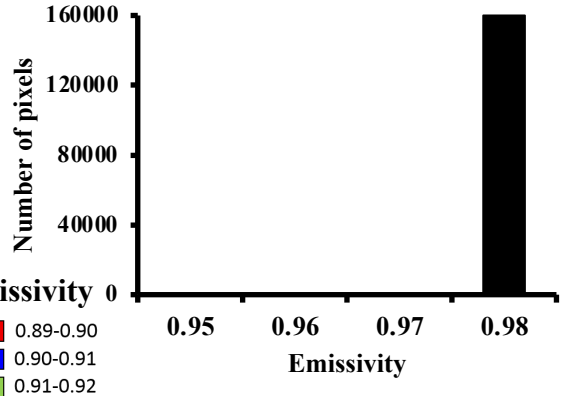
Data / product type	Data Source Pass time	Variables used	Parent spatial resolution (m)*	Purpose in energy balance computation	Date of acquisition (Pre-monsoon; Monsoon and Post Monsoon)
High-resolution Optical and thermal infrared Remote sensing	ECOSTRESS Pass time: 9:30 am-11:30 am IST	LST and Emissivity (T_S and ε_s)	65	R_{Ni}, LE_i	**Pre-monsoon:** April: 5,14, 26 May: 8,17,27 June: 4,17,23,30
	LANDSAT-8; (12); Pass time : 10:00 am - 11:00 am IST	Albedo (α_R) (from bands1,3,4,5,7) (ultra blue, Green, Red, NIR, SWIR-2)	30	R_{Ni}, G_i	**Monsoon:** July: 5, 17, 29 August: 8, 17, 27 September: 12,21,29
		NDVI (from bands 4 and 5) (Red and NIR)	30	R_{Ni}, G_i	
Meteorological	INSAT-3D	Downwelling instantaneous and daily shortwave radiation	4000	R_{Ni}, LE_i	**Post monsoon:** October: 11,19,29 November: 14, 22,30 December: 17, 28 January: 11, 24 February: 17,27 March: 5, 12, 29
	Weather Research and Forecasting (WRF) model	Air temperature (T_A) at 2m height	5000	R_{Ni}, LE_i	
	Weather Research and Forecasting (WRF) model	Relative humidity (R_H) at 2m height	5000	LE_i	

All the inputs were resampled to the ECOSTRESS resolution of 65 m

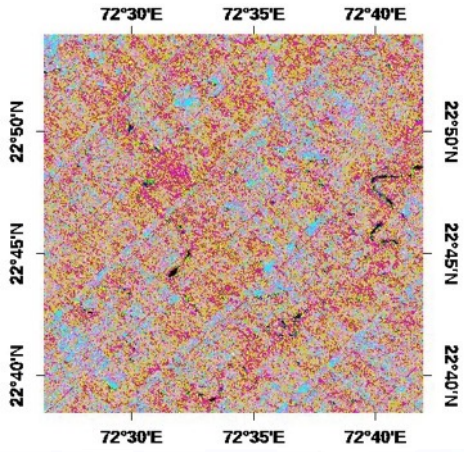
Comparison of T_S and ε_s of ECOSTRESS and MODIS-Terra over Nawagam- Gujarat



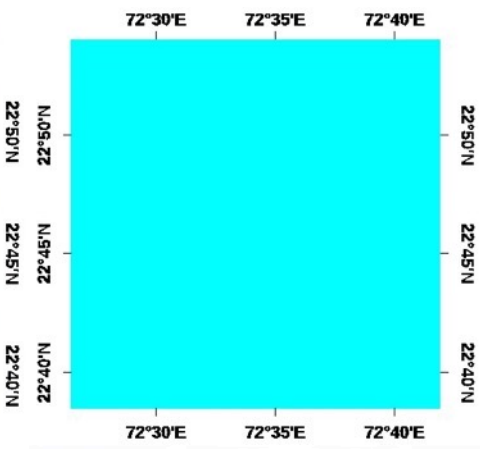




ECOSTRESS

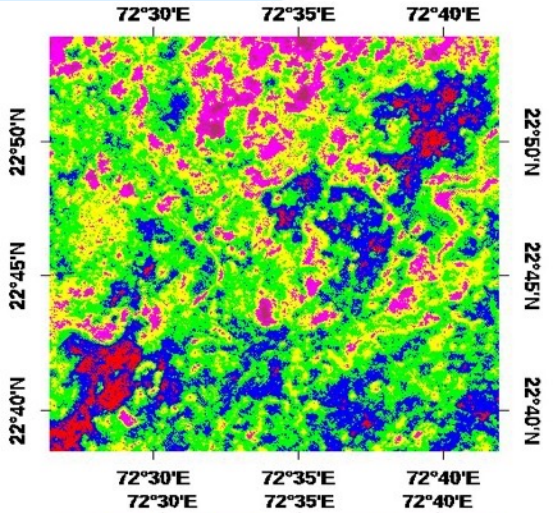


MODIS-TERRA



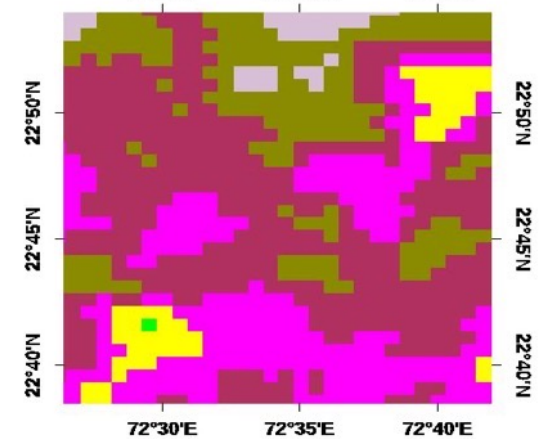
ECOSTRESS

σ : 3.6 K



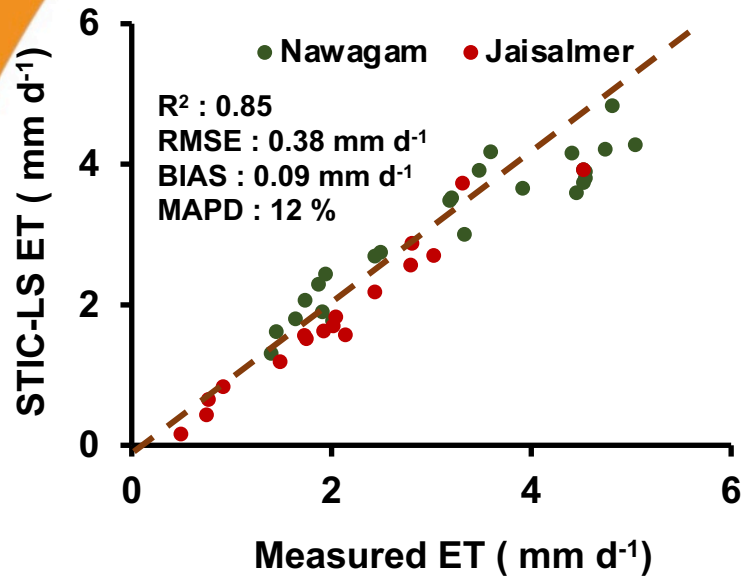
MODIS-TERRA

σ : 2.7 K



The variation in LST is due to variation in emissivity of ECOSTRESS and MODIS-Terra.

Validation of STIC-LS Evapotranspiration (ET) with in-situ observations

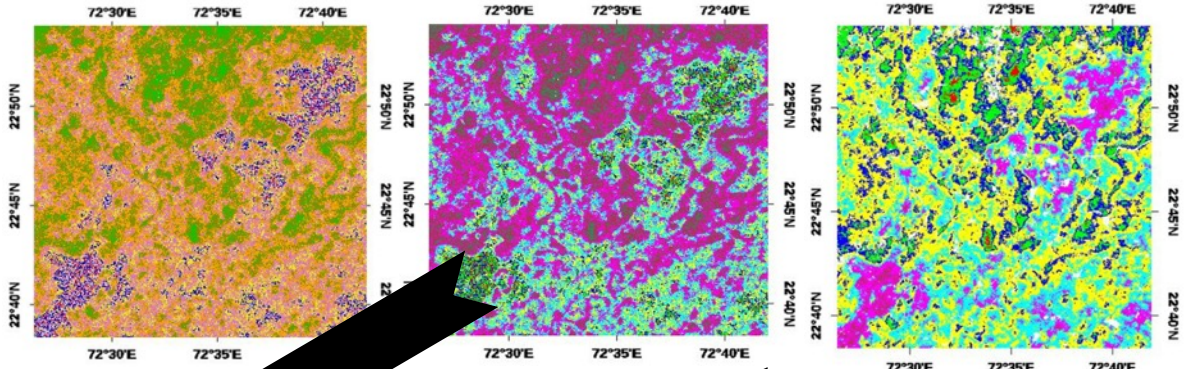


Nawagam

17th June

27th August

12th March



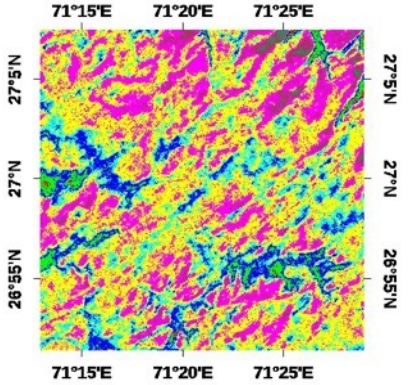
ET (mmd-1)

1.9-2.0, 2.0-2.2, 2.2-2.3, 2.3-2.4, 2.4-2.5, 2.5-2.6, 2.6-2.7, 2.8-2.9, 2.9-3.0, 3.1-3.2, 3.2-3.3, 3.3-3.4, 3.4-3.5, 3.5-3.6, 3.7-3.8, 3.8-3.9, 3.9-4.0

Higher magnitude of ET were observed during the rice peak growth stage in September

Jaisalmer

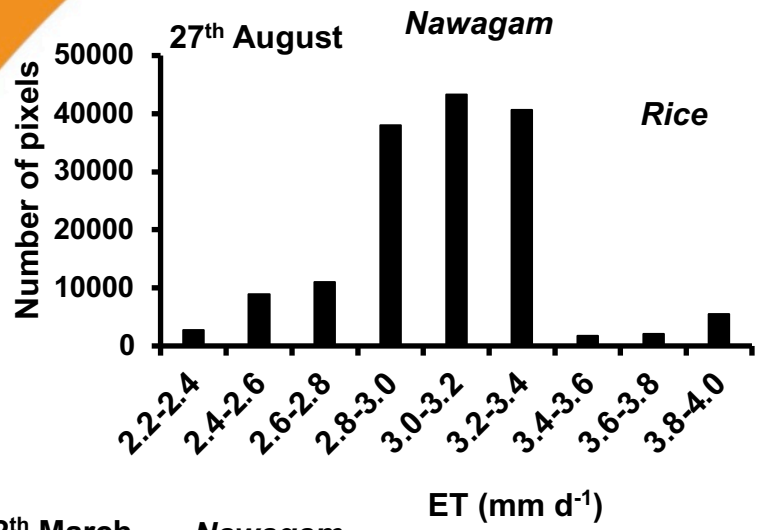
15th February

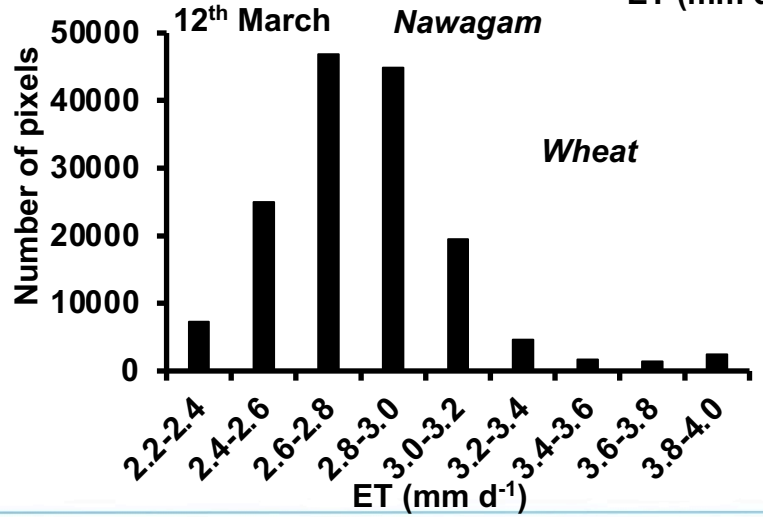


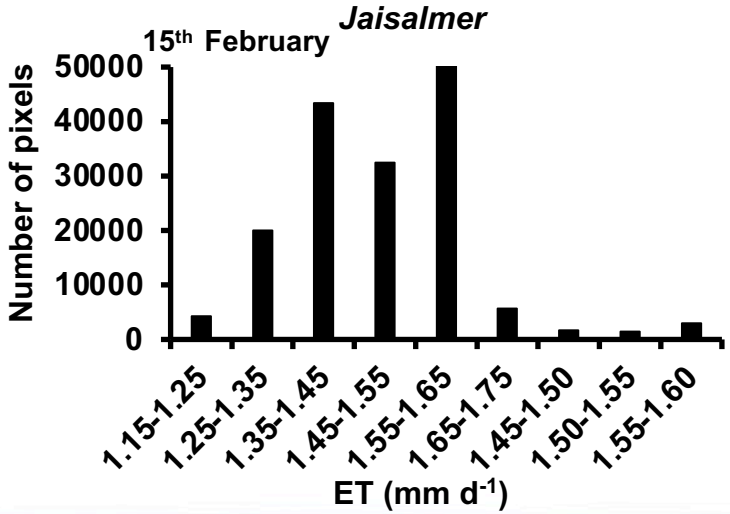
ET (mmd-1)

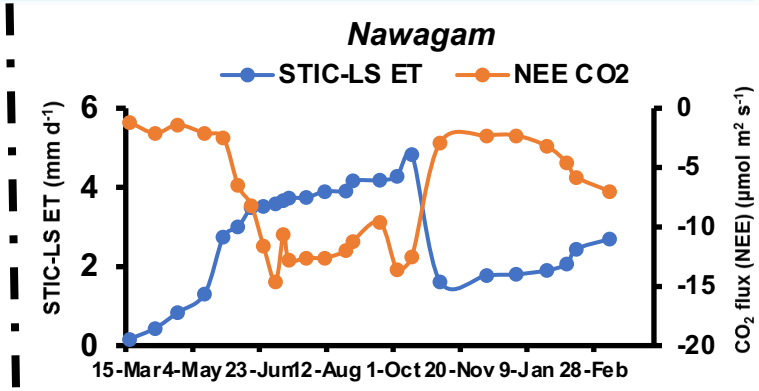
1.15-1.20, 1.20-1.25, 1.25-1.30, 1.30-1.35, 1.35-1.40, 1.40-1.45, 1.45-1.50, 1.50-1.55

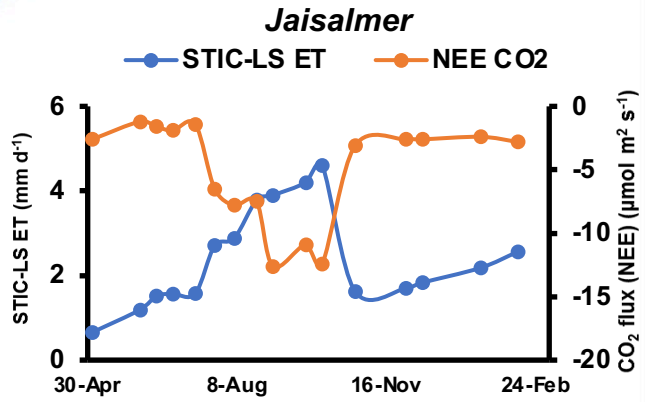
ET estimates with respect to crop growth

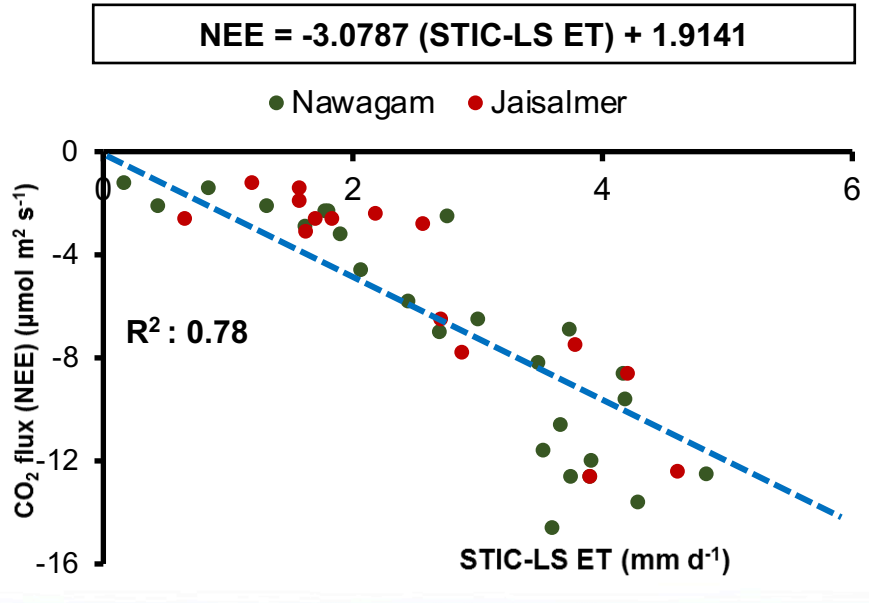






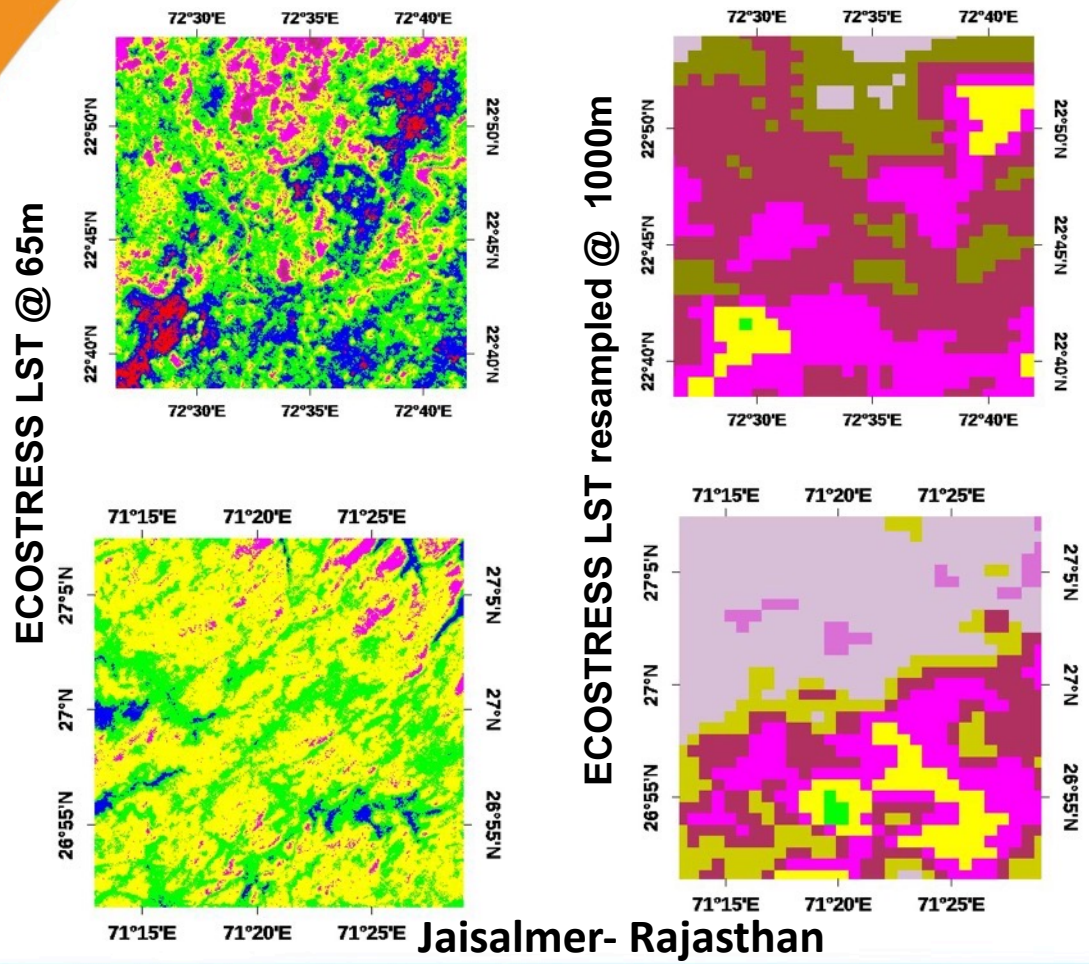




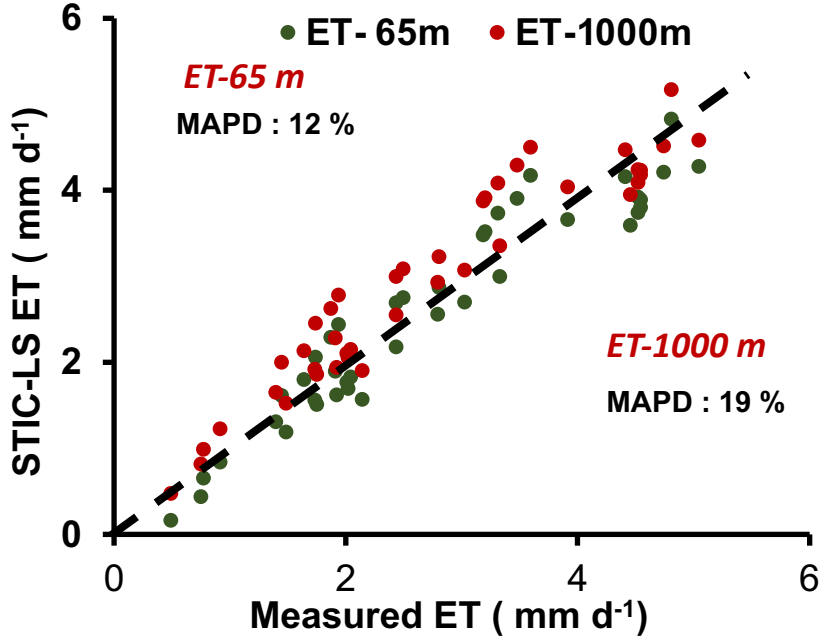


Impact of spatial resolution on ET estimation: A case study

Nawagam- Gujarat



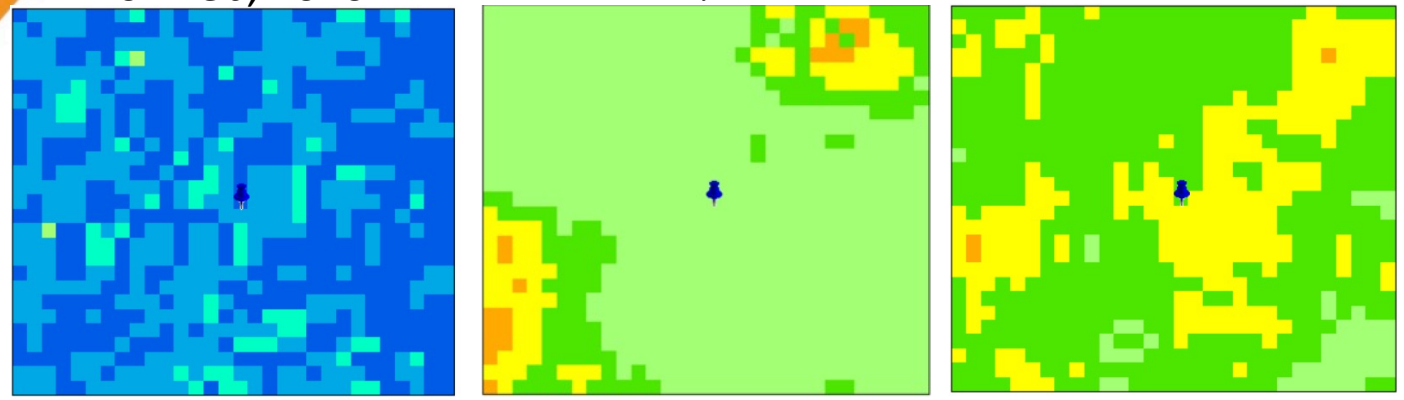
LST variability within agricultural patches was found to be higher from finer thermal IR resolution from ECOSTRESS as compared to when resampled at 1000m.



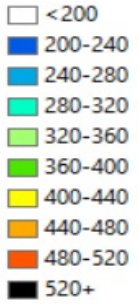
*All the other inputs insolation, NDVI, α_R , T_A , R_H were also resampled to 1000 m

Validation of Clear Sky Net-radiation outputs using ECOSTRESS LST with in-situ observations

02 Feb, 2020 | 19 Jun, 2020 | 10 Oct, 2020



Net radiation R_N Wm^{-2}



$$R_n = (1 - \alpha) R_{si} - L\uparrow + L\downarrow$$

Parameter	Symbol	Source	Spatial Resolution
Insolation	INS	INSAT 3D	4km
Albedo	α	MODIS	500m
Air Emissivity	ε_a	$1 - (INS/R_{ext})$	4km
Air Temperature	T_a	MOSDAC WRF	5km
Surface Emissivity	ε_s	MODIS	5km
Land Surface Temperature	LST	ECOSTRESS	70m

3kms by 3kms (Spatial Points) (To highlight Diversity)

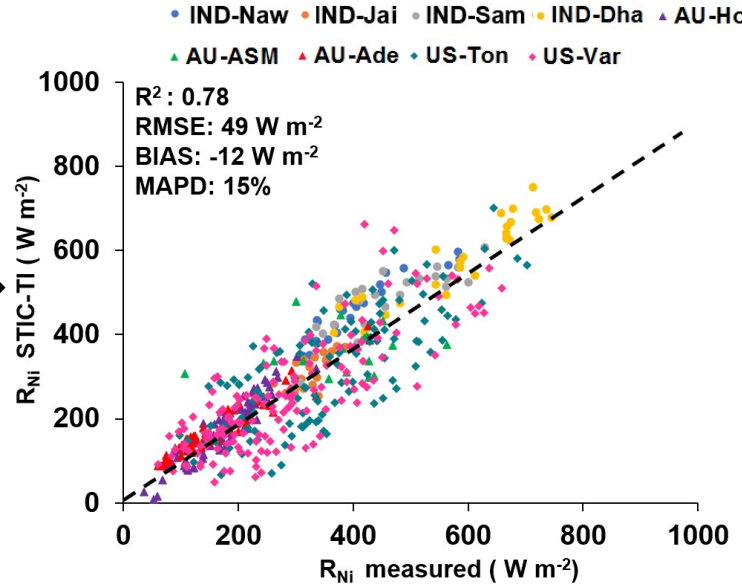
Incoming longwave Sensor (Pyrogeometer) (4 – 42 µm)

Incoming shortwave Sensor (Pyranometer) (0.3 – 3 µm)

Outgoing shortwave Sensor (Pyranometer) (0.3 – 3 µm)

Outgoing longwave Sensor (Pyrogeometer) (4 – 42 µm)

Ground measurements done for validation of model at different agro-ecosystems



Conclusions

- ✓ Spectral thermal emissivity below 11µm showed distinct differences among different land use types.
- ✓ LST variability within agricultural patches was found to be higher from finer thermal IR resolution from ECOSTRESS as compared to MODIS TERRA at 926m.
- ✓ High resolution evapotranspiration estimated from STIC-LS model showed MAPD of 12% with ECOSTRESS TIR data while it was higher (19%) with 1000 m thermal data from MODIS
- ✓ Spatio-temporal variability in ET was captured across contrasting agro-hydrological ecosystems and stages of crop growth
- ✓ Good relation (R^2: 0.78) was found between high-resolution ET estimates and measured crop growth indicator in terms of net ecosystem exchange (NEE) of CO_2.
- ✓ Analysis and use of such high-resolution TIR observations would help in understanding of data processing, parameter retrieval and applications from ISRO-CNES future TRISHNA high-resolution (57m) Spaceborne thermal IR mission. It will also help in synergistic use of TIR data from other future missions such as SBG, LSTM

THANK YOU ☺