Estimation of Wavelet Based Spatially Enhanced Evapotranspiration Using Energy Balance Approach

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INTRODUCTION

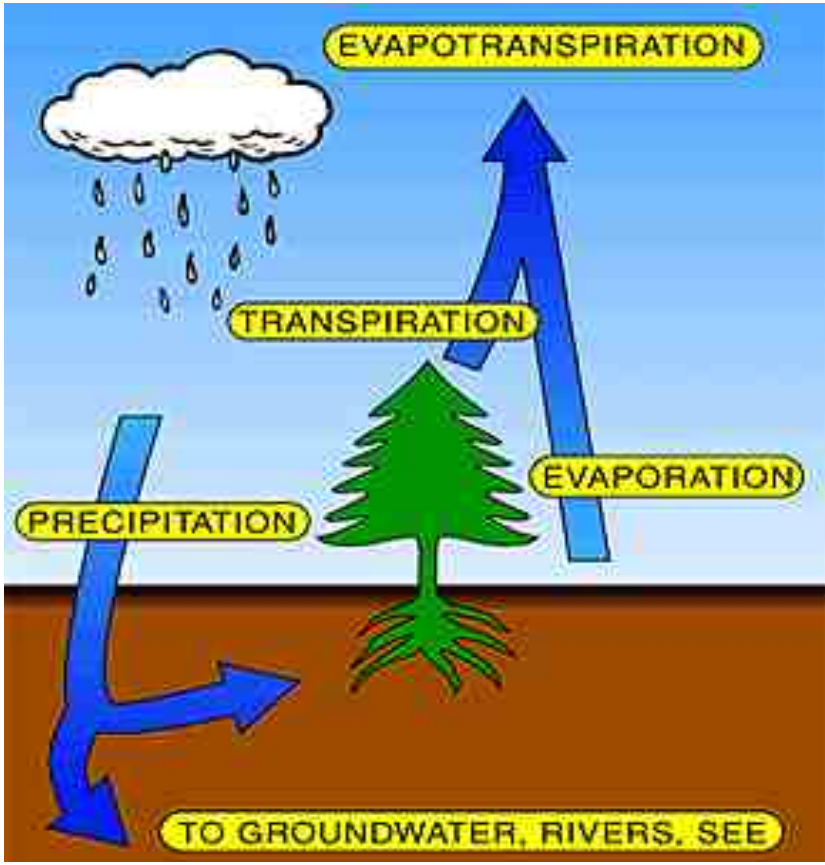
What is Evapotranspiration?

Evapotranspiration

= Evaporation + Transpiration

Knowledge of ET

- Is critical for irrigation management
- Effective utilisation of water
- Manage the scarce resource



NEED FOR THE STUDY

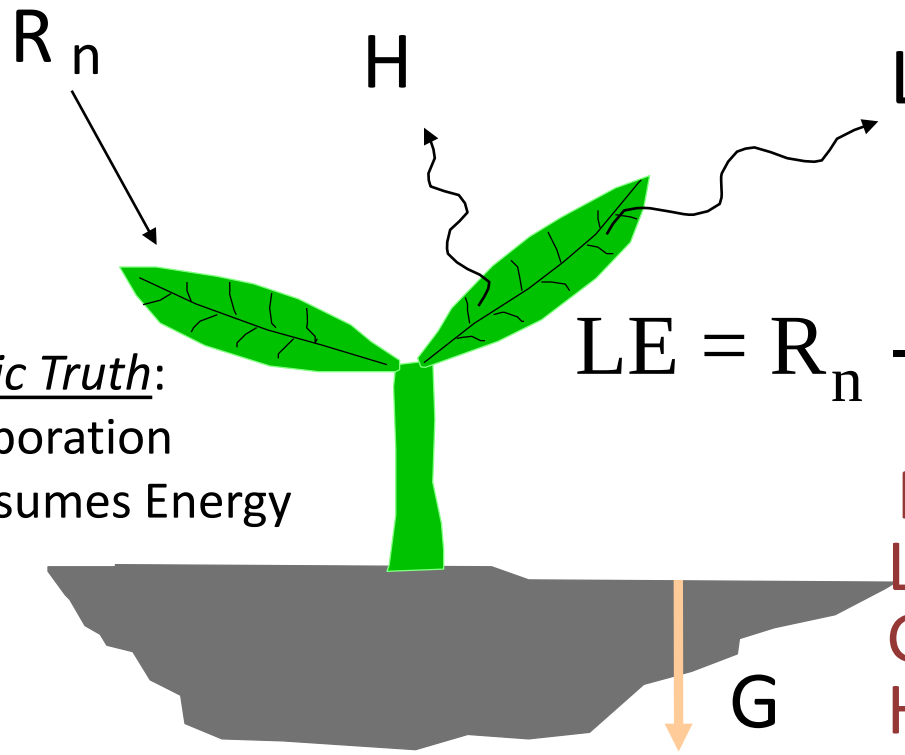
- Conventional methods estimate ET – based on point based measurements, Remote sensing based ET estimation- spatial distribution
- INPUT - Thermal Infrared (TIR) data and ground based meteorological data
- Spatial resolution of the thermal data is coarser
- Current ET estimating methods use coarse spatial thermal bands for analysis
- Spatial enhancement of the thermal data with the spatial resolution of visible bands

OBJECTIVES

- To spatially enhance the low spatial resolution TIR image by Multi Resolution Techniques
- To analyze the spatial variation of actual Evapotranspiration estimated from the enhanced TIR image.

ENERGY BALANCE FOR ET

ET is calculated as a "residual" of the energy balance



$$LE = R_n - G - H$$

Basic Truth: Evaporation consumes Energy

R_n is the net radiation
LE is the latent heat flux
G is the soil heat flux
H is the sensible heat flux
(all in W/m^2 units)

PRIMARY DATA FOR ENERGY BALANCE MODELS

- Surface temperature is derived information
- Thermal infrared images in the wavelength range 8 to 14 µm

Sensor	Satellite	Visible/NIR bands	Thermal band	Revisit time
ETM+	Landsat 7	30 m	60 m	16 days
ASTER	Terra	15 m	90 m	On demand
TM	Landsat 5	30 m	120 m	16 days
MODIS	Terra, Aqua	250/500 m	1000 m	1 day
AVHRR	NOAA	1000 m	1000 m	1-2 days

REMOTE SENSING BASED ET

According to Courault et al (2005), classified as follows:

- Direct simplified methods
  - Semi empirical models (ET directly related to surface temperature)
- Residual methods of energy budget
  - Empirical and physical modules
  - Two Source Model
  - Surface Energy Balance Algorithm for Land (SEBAL)
  - Simplified Surface Energy Balance Index (S-SEBI)
  - Evapotranspiration Mapping Algorithm (ETMA)
  - Mapping Evapotranspiration with Internalized Calibration (METRIC)
- Deterministic methods
- Vegetation index based method

CHOICE OF SEBAL METHOD

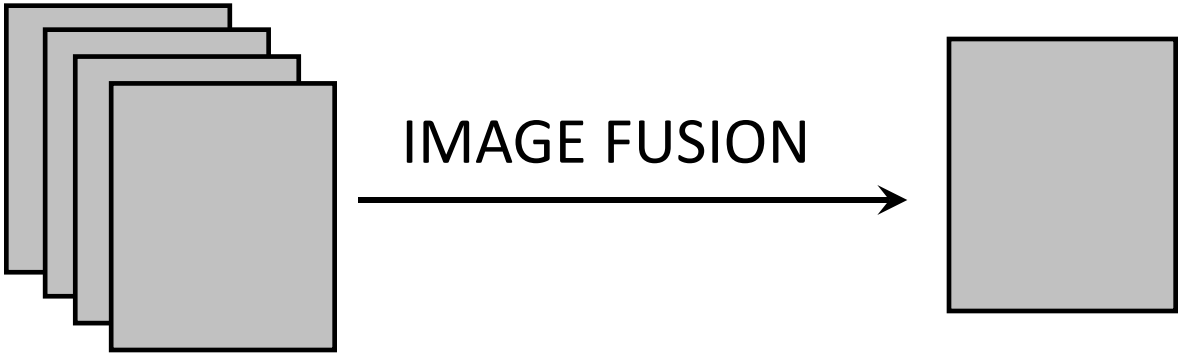
Developed by Bastiannssen et al 1998

- Minimum amount of ground measurements including meteorological measurements
- Based on physical concept - applicable for various climates
- No need for landuse classification
- Validated at various countries
- Procedures are satellite independent - can be used with other satellite images having thermal bands
- SEBAL calculates actual ET and no satellite based crop classification is needed
- SEBAL eliminates the need for atmospheric correction of surface temperature

LIMITATION

- Estimating ET at high spatial resolution - for field level analysis
- Spatial resolution of the estimated ET_{actual} is limited to the spatial resolution of the TIR image
- Spatial resolution of thermal band is often coarser than visible, near infrared and shortwave-infrared.
- Research need to utilize simultaneously acquired high resolution visible, VNIR and SWIR images to improve on the spatial resolution of the ET maps

DATA FUSION



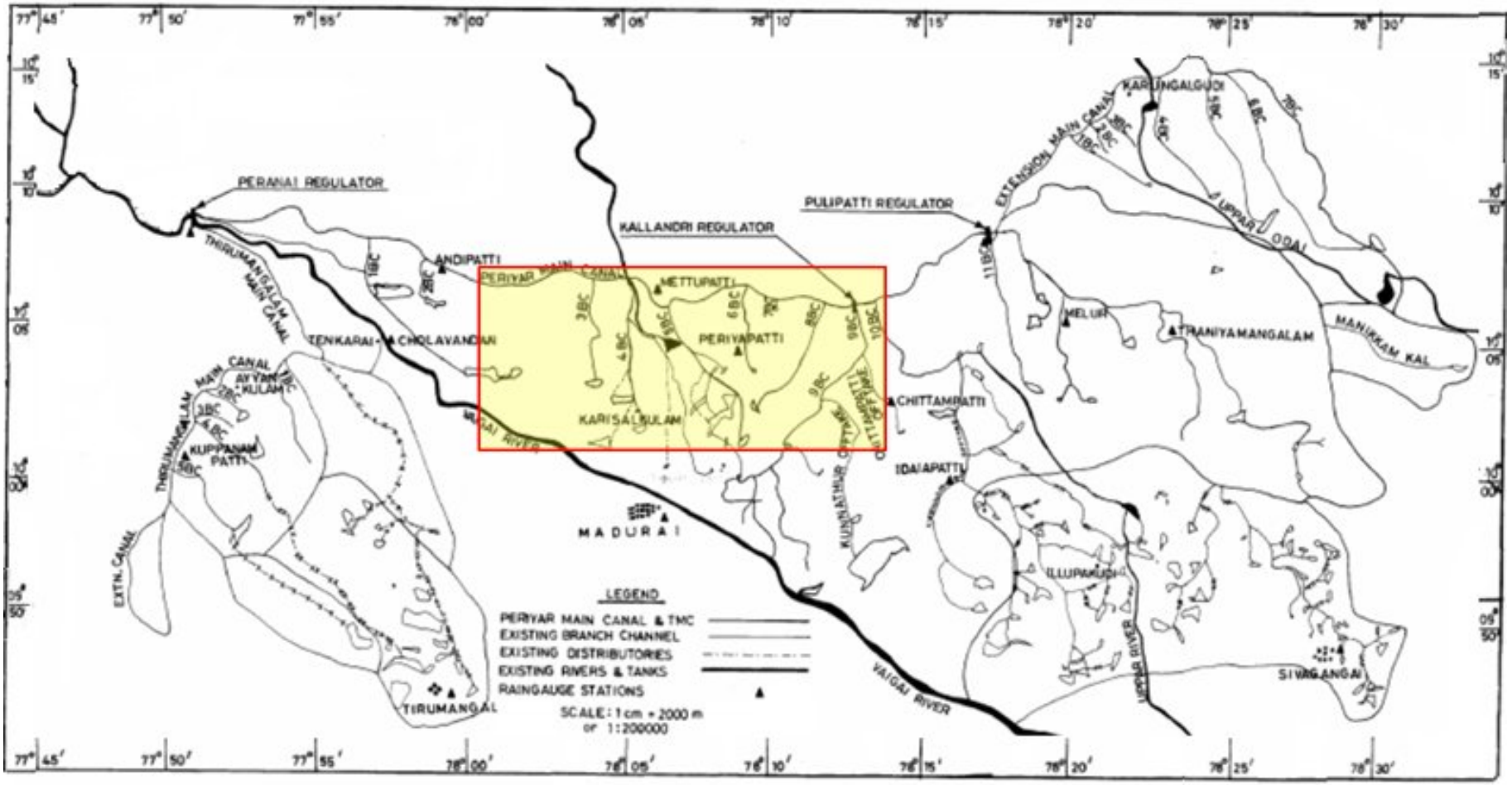
IMAGES

Same Sensor/Different Sensor

To keep maximum spectral information while increasing its spatial resolution

- Research has developed that aims at proposing algorithms for fusing high spatial and high spectral resolution images, in order to synthesise images with highest spectral and spatial resolutions available in the sets of images (Ranchin et al 2003).

Location of the Study Area

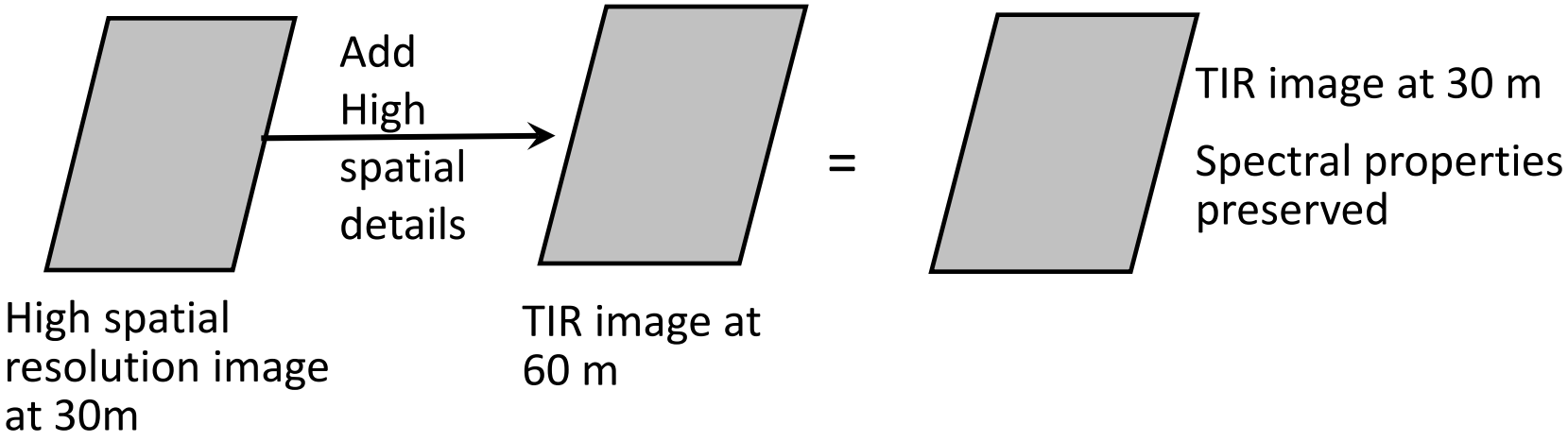


Acquisition data	Over pass time	Sun elevation (degrees)	Sun azimuth (degrees)
4 Dec 1999	10:28:21.89	49.60179	143.26033
19 Oct 2000	10:25:40.71	58.59446	129.34565

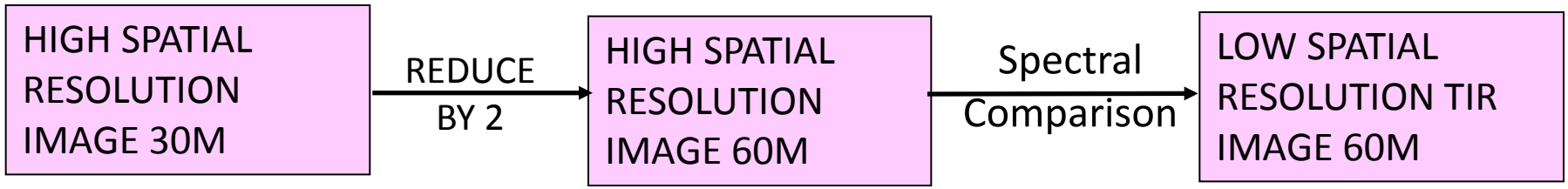
METHODOLOGY

- IMAGE SIMILARITY ANALYSIS
- SPATIAL ENHANCEMENT
- IMAGE QUALITY ASSESSMENT
- SEBAL ANALYSIS

SPATIAL ENHANCEMENT



- IMAGE SIMILARITY ANALYSIS



Wavelet Based Enhancement Scheme

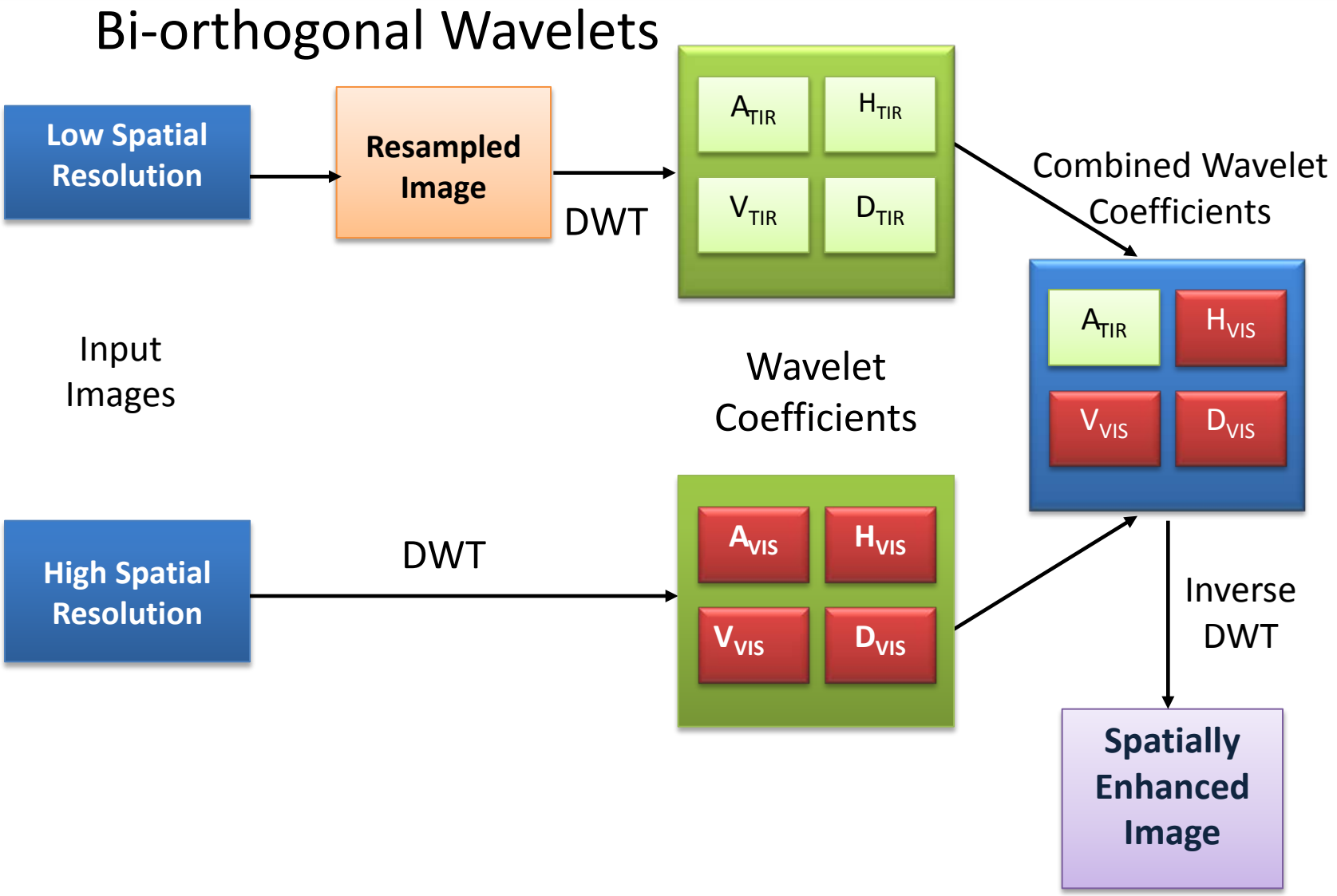
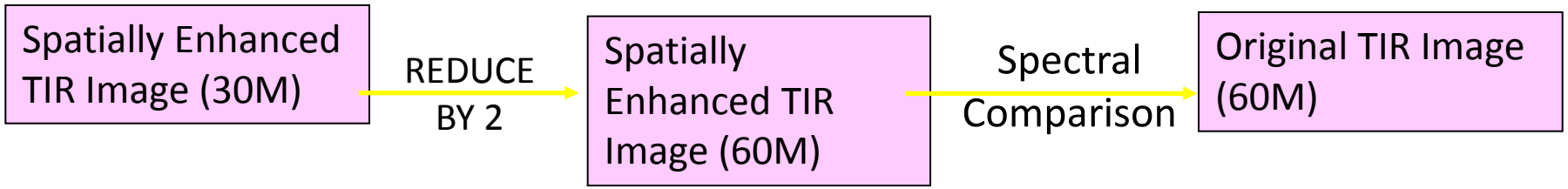
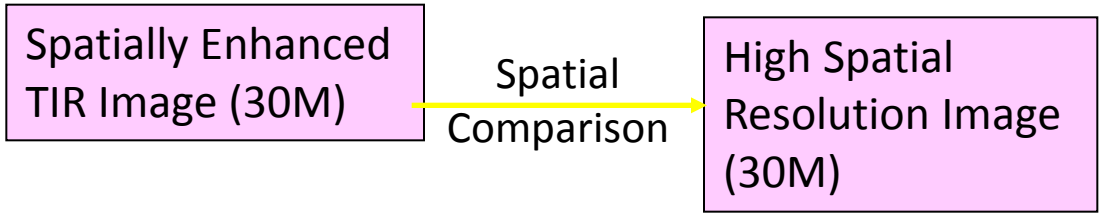


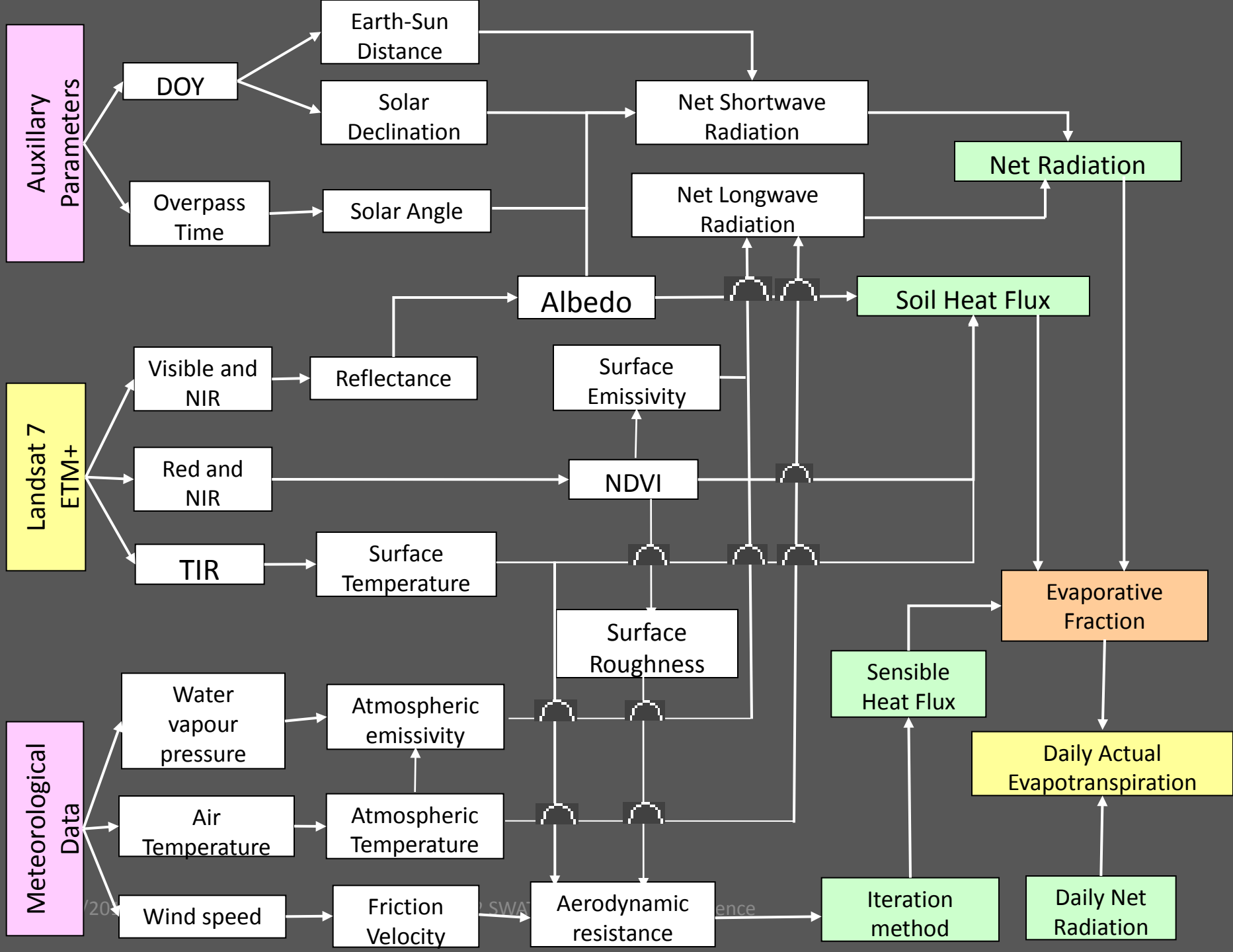
IMAGE QUALITY ASSESSMENT

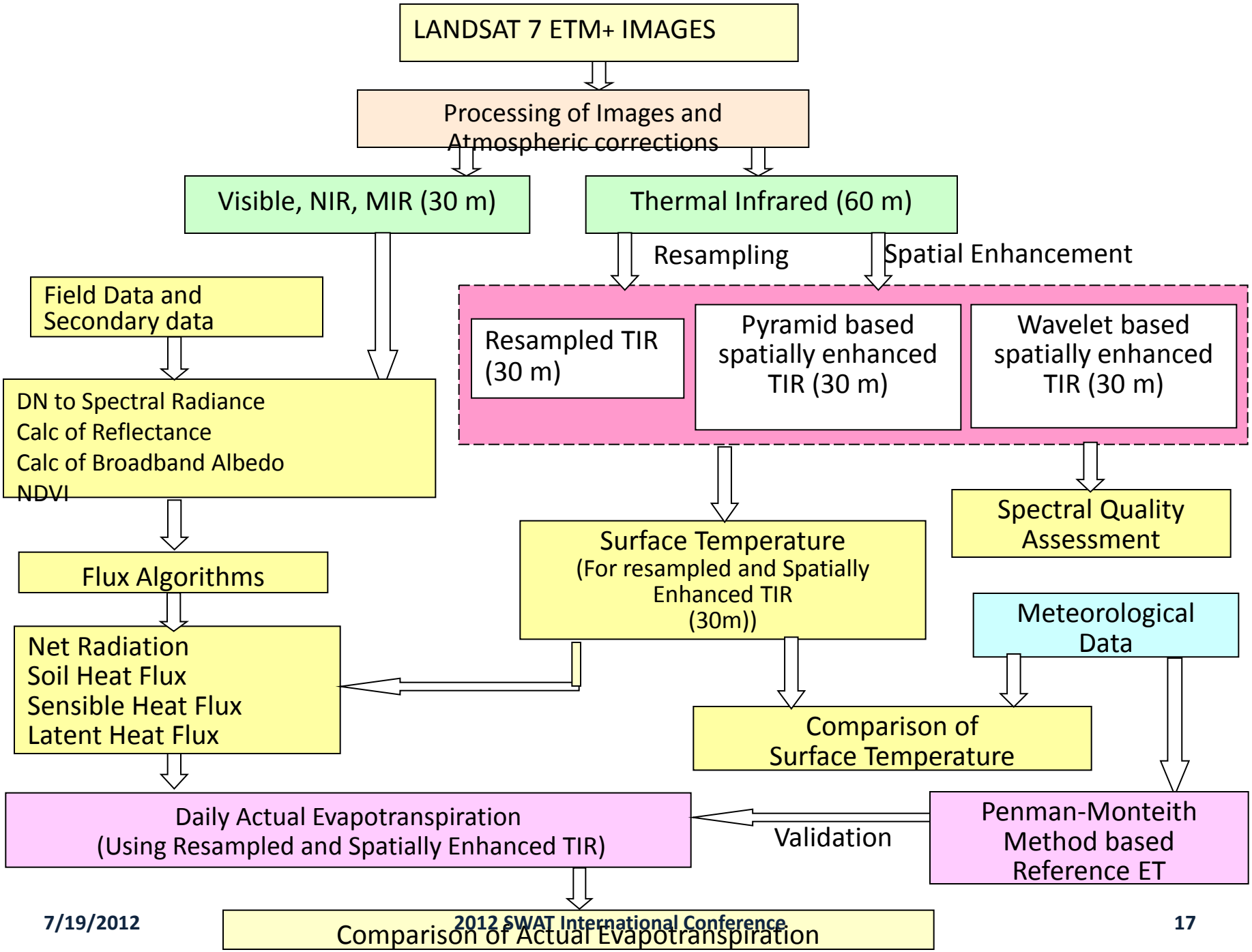
- VISUAL EVALUATION
- QUANTITATIVE EVALUATION
  - SPECTRAL QUALITY



  - SPATIAL QUALITY




Auxillary Parameters
DOY
Earth-Sun Distance
Solar Declination
Overpass Time
Solar Angle
Net Shortwave Radiation
Net Longwave Radiation
Net Radiation
Albedo
Soil Heat Flux
Landsat 7 ETM+
Visible and NIR
Reflectance
Surface Emissivity
Red and NIR
NDVI
TIR
Surface Temperature
Surface Roughness
Evaporative Fraction
Sensible Heat Flux
Meteorological Data
Water vapour pressure
Atmospheric emissivity
Air Temperature
Atmospheric Temperature
Daily Actual Evapotranspiration
Wind speed
Friction Velocity
Aerodynamic resistance
Iteration method
Daily Net Radiation


LANDSAT 7 ETM+ IMAGES
Processing of Images and Atmospheric corrections
Visible, NIR, MIR (30 m)
Thermal Infrared (60 m)
Resampling
Spatial Enhancement
Field Data and Secondary data
Resampled TIR (30 m)
Pyramid based spatially enhanced TIR (30 m)
Wavelet based spatially enhanced TIR (30 m)
DN to Spectral Radiance
Calc of Reflectance
Calc of Broadband Albedo
NDVI
Spectral Quality Assessment
Surface Temperature
(For resampled and Spatially Enhanced TIR
(30m))
Flux Algorithms
Meteorological Data
Net Radiation
Soil Heat Flux
Sensible Heat Flux
Latent Heat Flux
Comparison of Surface Temperature
Daily Actual Evapotranspiration
(Using Resampled and Spatially Enhanced TIR)
Validation
Penman-Monteith Method based Reference ET
Comparison of Actual Evapotranspiration

RESULTS

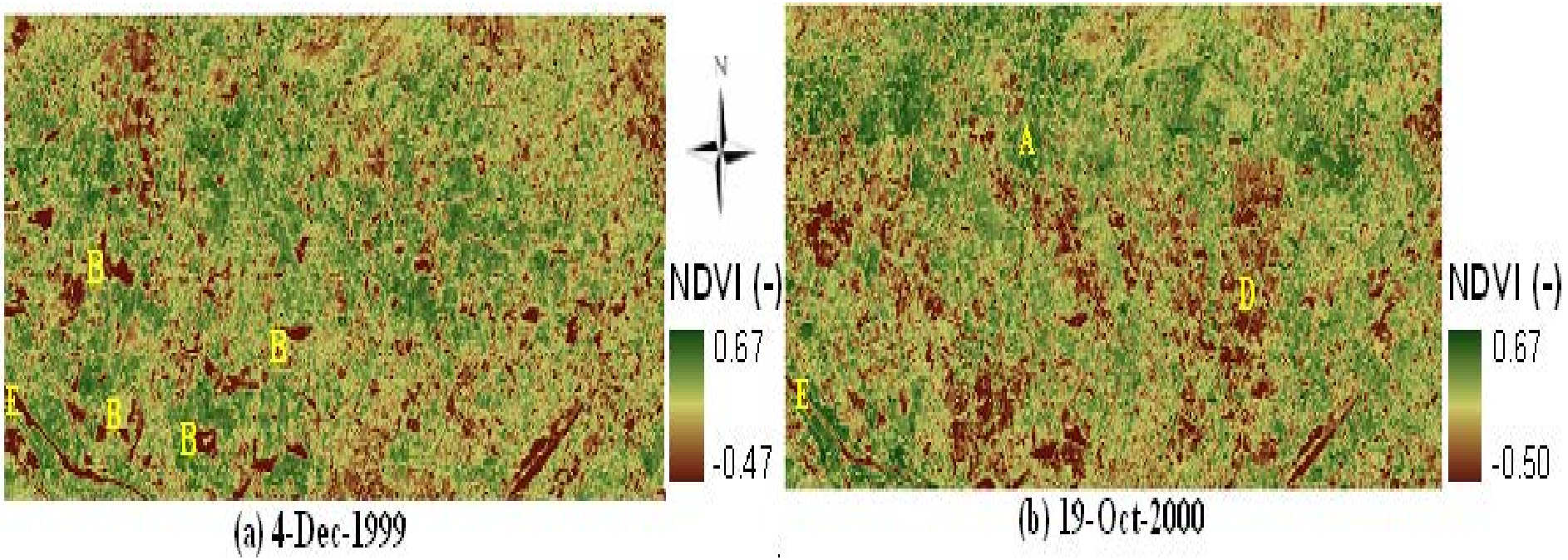
Spectral Quality Assessment

Image	TIR_{RES}			
	RMSE	CC	ERGAS	Q4
04-Dec-99	0.916	0.928	1.473	0.959
19-Oct-00	0.852	0.964	1.372	0.974
Image	TIR_{WAV}			
	RMSE	CC	ERGAS	Q4
04-Dec-99	0.591	0.949	2.644	0.915
19-Oct-00	0.778	0.989	2.853	0.928

Spatial Quality Assessment for Enhanced Images (at 30m Spatial Resolution)

Images	Standard Deviation (SD)		Mean Gradient (MG)	Correlation Coefficient (CC)	HighPass Correlation Coefficient (HPCC)
	TIR_{WAV}	TIR_{RES}	TIR_{WAV}	TIR_{WAV}	TIR_{WAV}
04-Dec-99	4.919	2.844	4.690	0.894	0.954
19-Oct-00	5.256	2.870	4.849	0.925	0.981

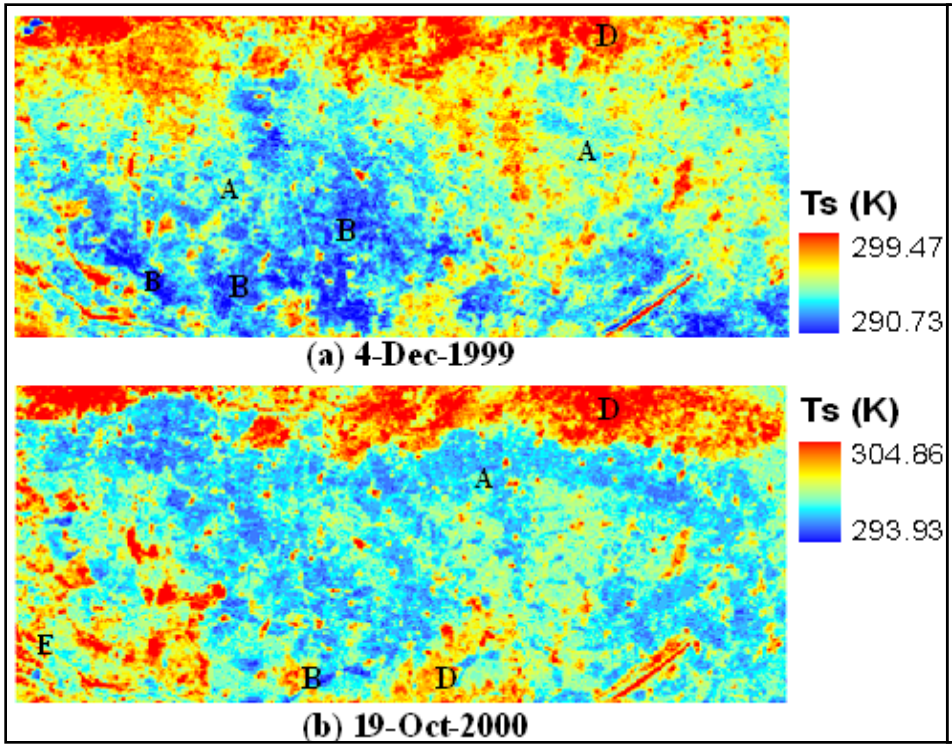
Spatial Variation of NDVI Image

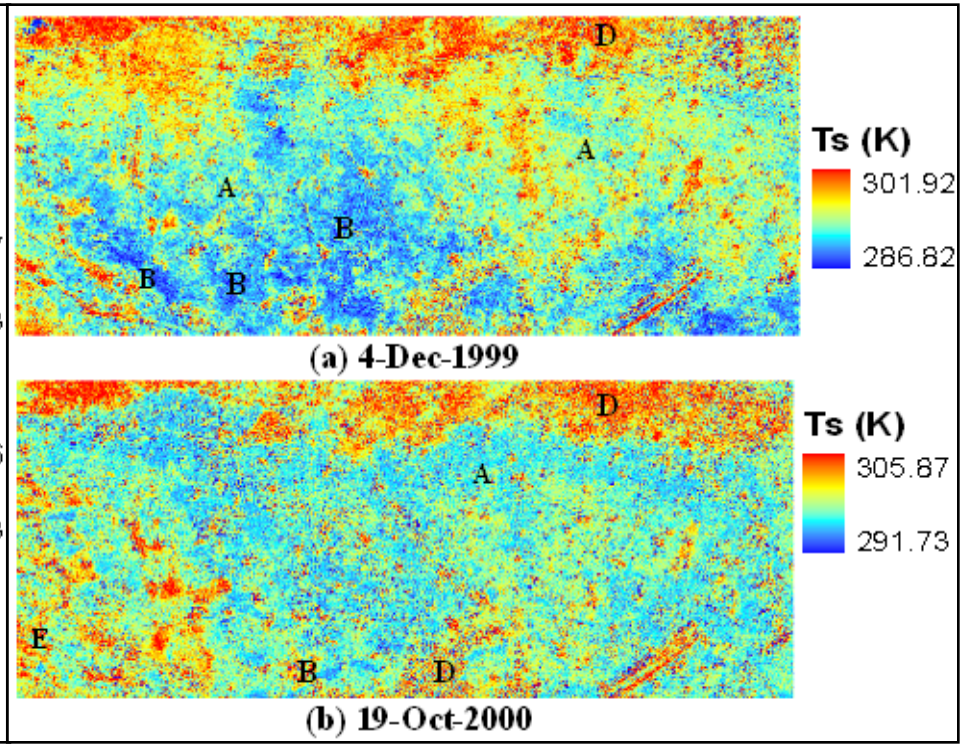


(a) 4-Dec-1999

(b) 19-Oct-2000

Surface Temperature Images from TIR_{res} and TIR_{wav} Image





Statistics of Estimated Net Radiation

Images	Rn with TIR_{RES} (W/m2)			Rn with TIR_{WAV} (W/m2)		
	Min	Max	Mean	Min	Max	Mean
04-Dec-99	172.37	410.03	330.16	169.37	412.29	331.42
19-Oct-00	180.87	454.58	374.55	183.13	460.96	374.40

Statistics of Estimated Soil Heat Flux

Images	G with TIR_{RES} (W/m2)			G with TIR_{WAV} (W/m2)		
	Min	Max	Mean	Min	Max	Mean
04-Dec-99	23.18	39.20	31.27	20.04	41.86	31.37
19-Oct-00	20.49	51.82	41.76	20.14	55.83	41.67

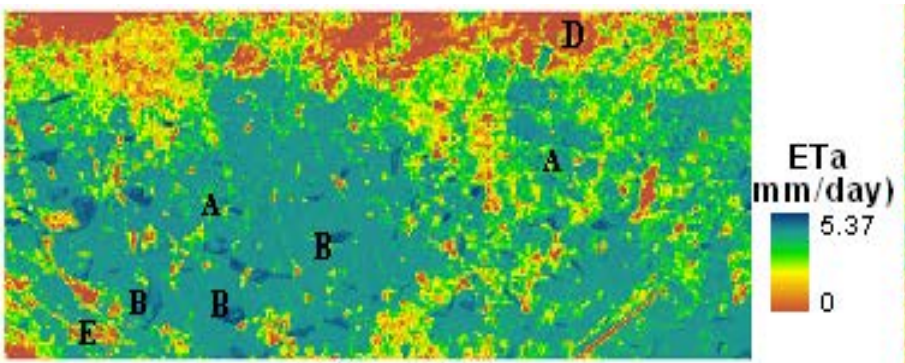
Statistics of Estimated Sensible Heat Flux

Images	H with TIR_{RES} (W/m2)			H with TIR_{WAV} (W/m2)		
	Min	Max	Mean	Min	Max	Mean
04-Dec-99	-18.43	294.78	110.63	-22.43	306.64	119.26
19-Oct-00	-18.63	297.41	134.28	-11.25	269.05	128.90

Statistics of Estimated Evaporative Fraction

Images	Evaporative fraction with TIRRES (-)			Evaporative fraction with TIRWAV (-)		
	Min	Max	Mean	Min	Max	Mean
04-Dec-99	0	0.96	0.69	0	0.98	0.78
19-Oct-00	0	0.98	0.68	0	0.97	0.79

Spatial Distribution of ETact Using TIR_{res} Image and TIR_{wav} Image



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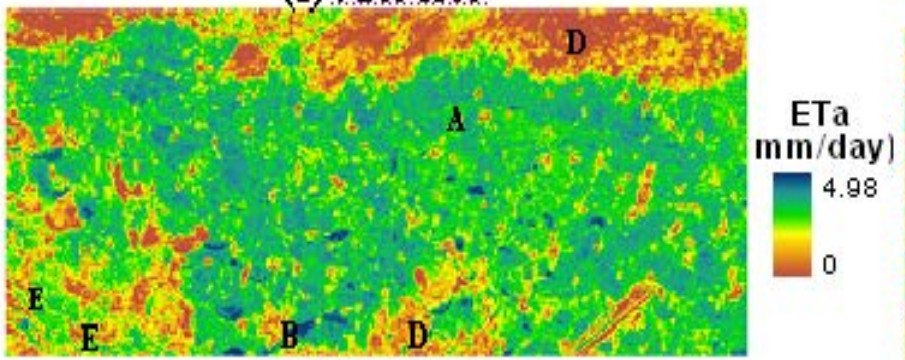
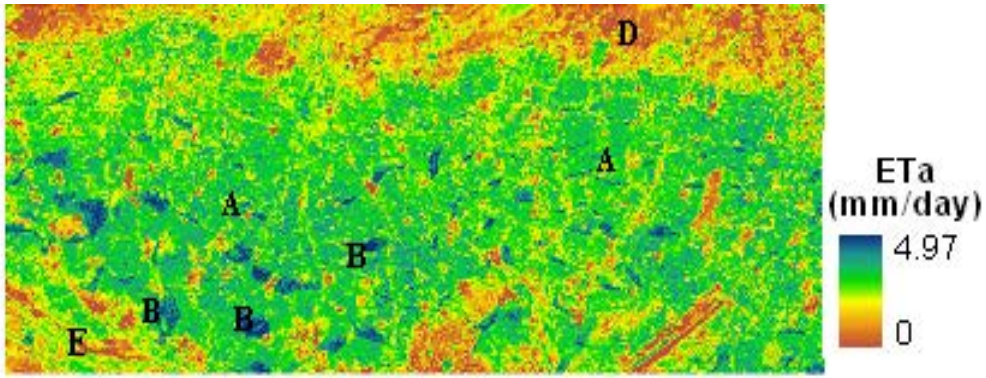


(b) 19-Oct-2000



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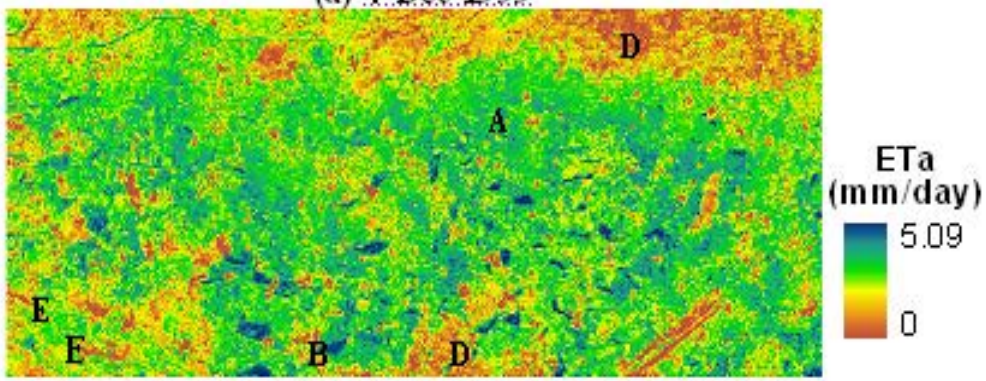

(b) 19-Oct-2000

Summary of SEBAL Estimates at Different Scale and the Point Estimate of Reference ET

Images	ET_o Penman-Monteith (mm/day)	ET_o (Pan evaporation) (mm/day)	ET_{act} Station Pixel (mm/day)		ET_{act} Vegetation (mm/day)		ET_{act} (whole scene) mm/day	
			ETact-RES	ETact-WAV	ETact-RES	ETact-WAV	ETact-RES	ETact-WAV
04-Dec-99	4.32	3.19	4.17	4.12	3.56	4.18	3.24	2.41
19-Oct-00	4.65	4.4	4.27	4.24	3.71	4.27	2.89	2.62

Percentage Difference between ET Estimates for Agricultural Land Type

Images	ETo Penman-Monteith (mm/day)	ET_{act} Vegetation (mm/day)		Percentage Difference (%)	
		$ET_{act-RES}$	$ET_{act-WAV}$	$ET_{act-RES}$	$ET_{act-WAV}$
04-Dec-99	4.32	3.56	4.18	17.59	3.24
19-Oct-00	4.65	3.71	4.27	20.22	8.17

CONCLUSION

- Wavelet enhanced images have the advantage of high spatial resolution while retaining spectral content from the original TIR images
- NDVI and surface temperature images have a negative correlation.
- ET and NDVI have a high agreement in terms of spatial distribution based on the positive relation of vegetation index and evapotranspiration.
- Overall accuracy of ET from SEBAL estimated using wavelet enhanced TIR image is within a margin of 10% compared to the Penman-Monteith method.

SCOPE FOR FURTHER STUDIES

- High spatial microwave data can be used to estimate ET
- To enhance the spatial resolution of freely available high temporal satellite images
- Stages of the crop growth can be incorporated in the estimation of actual ET
- need to formulate approaches that utilize low-resolution (greater than 1 km) satellite platforms, to inform upon the field scale

THANKYOU