

**INSAT UPLINKED AGROMET STATION—A SCIENTIFIC TOOL WITH A NETWORK OF AUTOMATED MICROMETEOROLOGICAL MEASUREMENTS FOR SOIL-CANOPY-ATMOSPHERE FEEDBACK STUDIES**

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**ABSTRACT:**

The role of land surface in earth-atmosphere system is crucial to predict weather and future climate at meso (~10 km) and micro (~ 1 km) scales. Systematic measurements of Land Surface Processes (LSP) within boundary layer are extremely important to understand the vegetation-atmosphere feedback, to develop new parameterization schemes for Land Surface Models (LSM) and validation of satellite based estimates. Till now, India had no such network of regular micrometeorological observation system for recording, archiving and converting data into scientific usable format. A prototype model of 10 m tall micrometeorological tower known as Agro-Met Station (AMS) has been defined and designed for short canopies (maximum average height 3m) such as agriculture, grasslands, natural bush etc. This has sensors capable of measuring radiation, energy and soil water balance components continuously with a total of 26 quantities at half-an-hour interval. The data can be archived in and retrieved back from 16-channel datalogger alongwith station location and time stamping from in-built Global Positioning System (GPS). INSAT-uplinked AMS transmitter operates at a frequency of  $402.75\text{ MHz} \pm 200\text{ KHz}$ . This dessimilates in situ measured data every hour from any remote station installed in the footprint of INSAT / KALPANA-1 Satellite. The transmitter output is connected to crossed Yagi antenna through antenna port with antenna gain of 11.5 dBi with isotropic gain for both right-hand and left-hand polarization field. The data transmission rate is 4.8 kbps. Transmission format of AMS is programmed in such a way, that data can be transmitted in two bursts within one millisecond to accommodate a maximum of 26 measurement fields. The data are generally retransmitted through KALPANA-1 extended C-band transponder at 4.5 GHz frequency to earth which are received through antenna at earth station. This frequency is modulated at 2-3 times to reduce the frequencies and ultimately converted to rawdata, which were again converted to user-friendly data format. A 20 watt solar panel is used for charging the sealed maintenance free 12Volt /26AH Battery, which delivers typical peak power of 18 watts with full sunshine and acts as power source for AMS. A preliminary evaluation on functioning of prototype AMS has been carried out over four agricultural sites including C3 (rice, groundnut) and C4 (sorghum) crops over semi-arid climate in India. The seasonal variation of surface fluxes across the sites and crops have been well captured. The setting-up of network of such towers is in progress. This kind of in situ system with the aid of geostationary communication transponder is unique in the world and would help in systematic micrometeorological measurements for land surface studies also in other Asian countries within the satellite footprint.

## 1. INTRODUCTION

Vegetation growth depends on the ability of leaves or roots to capture and use solar radiation,  $\text{CO}_2$ , water and nutrients, with solar radiation providing energy to drive both  $\text{CO}_2$  assimilation and water transpiration processes. Growth engines can be categorized as ‘carbon-driven’, water-driven’, or ‘energy-driven’ (Steduto, 2005). The atmospheric clearness or turbidity determines amount of solar radiation reaching at and within canopy. Different atmospheric parameters such as: aerosol, water vapour, ozone content and cloudiness determine atmospheric clearness and turbidity, which, in turn, determine canopy radiation and energy budget. The exchange of heat and mass (water and  $\text{CO}_2$ ) between canopy and air is linked to vegetation water use. The changing pattern of atmospheric turbidity due to increase or decrease in aerosol loading, ozone (Yamasoe et al., 2006) alters insolation and

its proportioning to direct and diffuse components. Insolation and its partitioning influence fluxes, radiation and water use by vegetation. The responses vary with vegetation and climate types. Therefore, a modeling effort is needed to characterize the influence of diffuse radiation on energy and mass exchange processes, radiation and water use efficiencies, productivity of different vegetative systems. This can be achieved through systematic network of measurements from tower-based observations either with slow or high response sensors. Moreover, the measurements from a large network in different vegetative systems have multi-purpose usage such as defining new LSM (Land Surface Model) parameterization scheme for climate models, validation of LSM output, upscaling and downscaling of fluxes using satellite data. Globally, such network of measurements called FLUXNET (Balocchi, 2003) with high response sensors is existing. AsiaFlux is Asian arm of FLUXNET. In India, a Land Surface Processes

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Experiment (LASPEX) was conducted during 1997-98 using five 10 m micrometeorological measurements (Vernekar et al, 2003) with slow response sensors within 100 km x 100 km in semi-arid climate to validate GCM outputs ( $1^\circ \times 1^\circ$ ). With the time elapsed, no further effort was made to develop new LSM schemes or improve present LSMs relevant for Indian monsoon region. The present effort is to provide a network platform for recording systematic micrometeorological measurements over different vegetation types in India with the following objectives :

1. To define and demonstrate a INSAT uplinked micrometeorological measurement system over short canopies (upto 3 m) using slow response sensors
2. To understand the vegetation-atmosphere response and feedback over Indian monsoon region

Upscaling and downscaling of surface fluxes for validation of satellite based estimates

## 2. BASIC PRINCIPLES OF MICROMETEOROLOGICAL FLUX MEASUREMENTS WITHIN SURFACE LAYER

Broadly, radiation, energy and water balance components as well as net CO<sub>2</sub> exchange rate are considered in most of the micrometeorological measurements within surface layer ( $\sim <15$  m) at local to landscape scales using portable or tower based system. The Bowen ratio or eddy covariance systems are placed on towers for such measurements. The tower height depends on the fetch ratio. The basic principles are outlined below :

### 2.1. Portable or Micromet tower

The surface energy balance at any instance can be written as:

$$Rn = H + G + \lambda E + M + S \quad (1)$$

Here, the net radiation ( $Rn$ ) is partitioned into heat fluxes such as: latent ( $\lambda E$ ), sensible ( $H$ ), soil heat ( $G$ ) and energy required for metabolic activities ( $M$ ) and canopy storages ( $S$ ). The terms,  $M$  and  $S$ , are very negligible (2-5%) for short canopies ( $< 3$  m). The equation 1 can be rewritten as (neglecting  $M$  and  $S$ ):

$$Rn = H + G + \lambda E \quad (2)$$

The radiation balance can be written as :

$$Rn = R_s \downarrow - R_s \uparrow + R_l \downarrow - R_l \downarrow$$

All the four radiation components, incoming ( $R_s \downarrow$ ) and outgoing ( $R_s \uparrow$ ) shortwave radiation, incoming ( $R_l \downarrow$ ) and outgoing ( $R_l \downarrow$ ) longwave radiation, are measured using net radiometer.

The soil heat flux ( $G$ ) can also be directly measured using heat flux plate or indirectly computed as:

$$G = K \frac{dT_{soil}}{dz} \quad (3)$$

Here,  $K$  is soil thermal conductivity and  $\frac{dT_{soil}}{dz}$  is soil temperature ( $T$ ) gradient with depth ( $z$ ). The sensible ( $H$ ) and latent heat flux ( $\lambda E$ ) components can be computed as a residual from energy balance through bowen ratio ( $\beta$ ) and net available energy ( $Q = Rn - G$ ). Independently,  $H$  and  $\lambda E$  can also be computed using aerodynamic flux-profile method.

#### 2.1.1. Bowen ratio method:

$$\lambda E = \frac{Rn - G}{1 + \beta}$$

$$H = \frac{(Rn - G)\beta}{1 + \beta}$$

Where,

$$\beta = \gamma \frac{dT_a}{de_a} \quad (4)$$

The air temperature ( $\frac{dT_a}{dz}$ ) and vapour pressure ( $\frac{de_a}{dz}$ ) gradients can be determined through multi-height measurements within surface layer (or laminar boundary layer) embedded in atmospheric boundary layer (ABL). The Bowen ratio energy balance method (BREB) is a residual method that assumes perfect closure of energy balance.

**2.1.2. Aerodynamic flux-profile method:** This is based upon determination of exchange coefficient from resistances through frictional velocity and atmospheric stability corrections to take care of proportions of free and forced convections. Based on similarity theory of all exchange processes between land and atmosphere, the functional forms can be written as:

$$H = \rho C_p \frac{dT_a}{r_{ah}} \quad (5)$$

$$\lambda E = \frac{\rho C_p}{\gamma} \frac{de_a}{r_{ae}} \quad (6)$$

The exchange coefficients ( $r_{ah}$  and  $r_{ae}$ ) can be determined from canopy height and vertical wind profile above canopy. The basic inputs are roughness length, displacement height and frictional velocity. The latter one can be computed through slicing of Richardson number ( $R_i$ ) and iterative solution for Monin-Obukov length ( $L$ ). The aerodynamic method can be used for energy balance closure correction.

### 3. METHODOLOGY

#### 3.1 Definition of tower Based INSAT- Uplinked Agromet Stations (AMS)

Initially, a micrometeorological tower of 10 m maximum height, named as Agromet Station (AMS), was defined to record automated measurements of radiation, energy and water balance components primarily for agricultural systems where mean maximum canopy height vary between 1 to 2.5 m. But the same data collection system can be extended to other vegetation types such as grasslands, natural shrub. In forest system, it may require modification. Prototype 10 m AMS was designed with three groups of sensors such as : radiation, energy and soil water balances. The sensors and technical specifications of prototype AMS are given in the Table 1.

Basic Observable Parameters	Sensor Name & Model	Accuracy	Heights (m)
Air temperature	Platinum resistance (Pt 1000 or CS500 or HMP45C)	$\pm 0.1^{\circ}\text{C}$ range: -20 to $60^{\circ}\text{C}$	1.25, 2.5, 5
Relative humidity	Capacitor type (HMP45C)	$\pm 1\%$ (range: 0-100%)	1.25, 2.5, 5
Wind speed	Anemometer 3-cup rotor	$\pm 2\%$ of FSQ (range : 0.2- $60\text{ms}^{-1}$ )	2, 4, 8
Atm. pressure sensor	Transducer	$\pm 2\%$ of FSQ	2
Rainfall	Tipping bucket	$\pm 1 \text{ mm}$	1
Net radiation (Incoming, outgoing shortwave, Incoming and outgoing longwave)	Four component net radiometer	$\pm 5 - 10\text{Wm}^{-2}$ Range (0- $1000\text{Wm}^{-2}$ )	4
Diffuse radiation	Shaded pyranometer	$\pm 5 - 10\text{Wm}^{-2}$ Range (0- $1000\text{Wm}^{-2}$ )	4
Ground heat flux	Heat flux plate (HFP01SC)	$\pm 3\%$ of FSQ	- 0.1, - 0.2
Soil temperature	Soil thermometer	$\pm 0.1^{\circ}\text{C}$	- 0.05, - 0.1, - 0.2
Volumetric soil moisture	Soil moisture sensor	$\pm 5\% \text{ FSQ}$ range 0- $0.45\text{cm}^3 \text{cm}^{-3}$	- 0.05, - 0.1, - 0.2

Table 1: Sensor Specifications of AMS

#### 3.2 Power Source and Battery Back-up

A 20 Watt solar panel is used for charging the Sealed Maintenance free 12Volt /26AH Battery, which delivers typical peak power of 18 watts with full sunshine. This panel consists of series connected monocrystalline silicon solar cells. The glass is self-cleaning in most climates, retains its excellent transmissivity indefinitely, and

is extremely resistant to mechanical stress. The module is framed with lightweight corrosion-resistant anodized aluminum sections with silicon edge sealant around the laminate. As per the power budget calculation 12 V/ 26 AH battery with 20 Watt solar panel for charging the battery is adequate to give 30 days backup for all the places of the country except the snow bound areas.

#### 3.3 Datalogging, Storage, Transmission and Reception

The datalogger gathers the data from different sensors. It is 25-channel datalogger. The collected data are also stored in the datalogger memory. The powerful micro-controller of datalogger does all the functions of data collection, storage and transmission in the programmed time slots. A real time clock in the data logger unit controls timing accuracy. To improve the timing accuracy, GPS receiver is used to update once. The overall timing accuracy can be maintained to a millisecond. A Keyboard is provided with user programmable capability and LCD display. User defined password enables the programming facility. The micro controller formats the data to be transmitted as per given format and enables the transmitter 30sec before transmission. This time is programmable and it can be adjusted depending on the frequency stability requirements of the transmitter. UHF(Ultra High Frequency) transmitter is designed to operate under the control of the micro controller. It has BPSK modulation capability with RF (Radio Frequency) power more than 10W operating in a fail-safe mode. The frequency and power of the transmitter can be selectable through data logger. INSAT-uplinked AMS transmitter operates at 402.75 MHz  $\pm$  200 KHz. AMS transmitter disseminates *in situ* measured data every hour from any remote station installed in the foot print of INSAT 3A / KALPANA-1 Satellite. The transmitter output is connected to crossed Yogi antenna through antenna port with antenna gain of 11.5 dBi with isotropic gain for both right-hand and left-hand polarization field. The effective isotropic radiative power, EIRP, (transmitted power + gain amplifier) is about 30dB. The data transmission rate is 4.8 kbps. This Yogi antenna has provision to change the LHCP and RHCP polarization on field. The antenna gain is fixed in such a way that the data from tower location falling apart from contours of primary and secondary zones can be captured and transmitted to the satellite. Therefore, data transmission from any remote location within the satellite footprint is possible. The antenna is made of rust-resistant material and is moisture-proof. This antenna has been designed and developed for wider bandwidth ( $> 40^{\circ}$ ). Data transmission format of AMS is programmed in such a way, that data can be transmitted in two bursts within one millisecond to accommodate a maximum of 26 measurement fields. The data are generally retransmitted presently through KALPANA-1 extended C-band transponder at 4.5 GHz frequency to earth which are received through antenna at earth station. This frequency is modulated at 2-3 times to reduce the frequencies and ultimately converted to rawdata which were again converted to usable dataformat. The life of Kalpana-1 satellite is expected upto end of 2010. Afterwards, similar transmission would be possible with INSAT 3A transponder.

#### 3.4 Data Processing

The processing software of transmitted data has the following features :

1. Complete intelligent telemetry processing system
2. Operates on windows operating system

3. Toolkit available for customized local data processing and storage manager
4. User interface for all the configuration regarding the individual station and sensor setup
5. Parity errors check in the received AMS messages
6. Facility to view the data in tabular format
7. Facility to export data into text, excel (CSV) files format.

The overall dataflow is shown in Figure 1

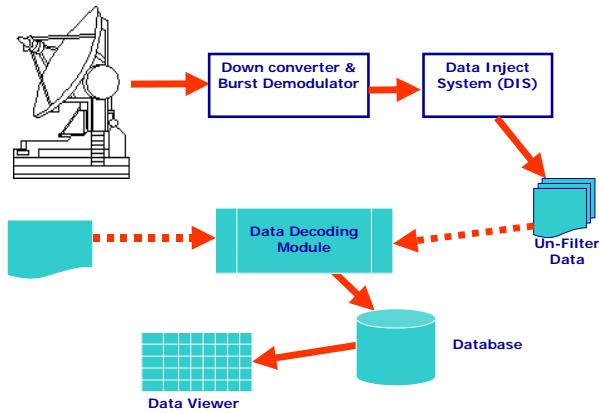


Figure 1. Schematic Diagram of Data Flow after Reception from Satellite

The unique characteristics of ISRO-AMS are as follows:

1. Most of the sensors are indigenously made except radiation sensors
2. Indigenously made datalogger capable of recording and storing data
3. Data uplinking and downlinking facility through INSAT communication transponder
4. Network of automated micrometeorological observations
5. Data to be accessible to researchers, modelers and validation tool for satellite derived products
6. After sale service (calibration etc.) is available in India for assessing long term reliable measurements to add to land surface databases

#### 4. RESULTS AND DISCUSSION

##### 4.1 Evaluation of Surface Fluxes from AMS

The AMS were put in operation at four semi-arid agricultural sites: RRS, Nawagam, Gujarat; JAU, Junagadh, Gujarat; RARS, Bijapur, Karnataka and CRIDA, Hyderabad, Andhra Pradesh. The data were acquired as half-hourly averages during monsoon period between May to September 2008. Three surface flux components such as: net available energy, sensible and latent heat fluxes were

computed from radiation balance components, soil heat flux and vertical gradient of air temperature and relative humidity over different agricultural canopies during this period. The data were analyzed from four different sites situated in semi-arid climate. In all the four sites (Figure 2a-d), distinguished diurnal variation is evident with negative or no zero values in the night, but positive magnitude between sunrise to sunset. Sitewise differences clearly indicated the role of atmospheric transmissivity under clear and cloudy conditions, canopy types and stages and soil moisture distribution on energy partitioning. Presence of clouds could reduce the overall energy input and its partitioning.

Attempts have been made to derive sensible heat flux, the most critical component of surface energy balance, using aerodynamic profile technique using iterative procedure with Monin-Obukhov Similarity Theory (MOST) in addition to Bowen ratio method. The test study has been carried out using AMS data from Hyatnagar farm, CRIDA, Hyderabad and Nawagam farm, Gujarat. Examples of diurnal variability of sensible heat fluxes ( $H$ ) are shown in Figure 3. There was substantial difference in ' $H$ ' at Nawagam and Hyatnagar due to differences in rice types. The lesser ' $H$ ' in Nawagam (-25 to 50  $\text{Wm}^{-2}$ ) is due to transplanted rice with submerged water in contrast to dryland direct seeded rice in Hyatnagar (-10 to 190  $\text{Wm}^{-2}$ ). Moreover, the daily average solar energy input in Hyderabad is generally higher (90 – 320  $\text{Wm}^{-2}$ ) than at Nawagam (10 – 250  $\text{Wm}^{-2}$ ).

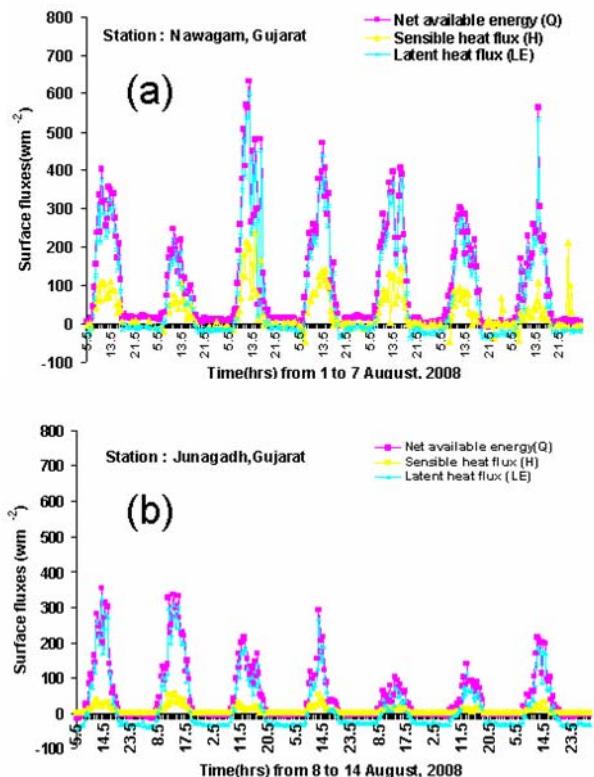


Figure 2a & b. Diurnal Fluxes Over Nawagam and Junagadh

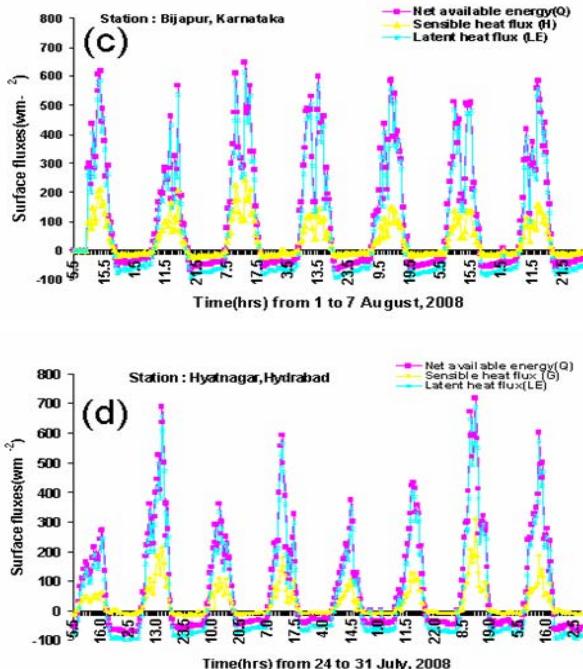
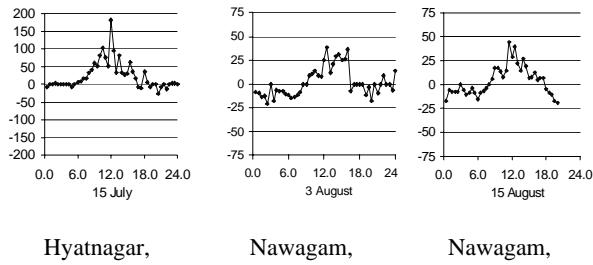


Figure 2c&amp;d. Diurnal Fluxes over Hyderabad and Bijapur

Figure 3. Examples of Diurnal Variation of Sensible Heat Fluxes (in  $\text{Wm}^{-2}$ ) on Y-axis at Different IST Hours (X-axis) from AMS Data Using MOST in Semi-arid Agricultural landscapes

#### 4.2 Transmissivity vs. Evaporative Fraction on Clear and Cloudy Days

Transmissivity and evaporative fraction computed from AMS surface flux components at peak vegetative growth of *kharif* rice at Nawagam and *kharif* groundnut at Junagadh are plotted. In clear skies, evaporative fraction was found to vary between 0.7 to 0.9 at all transmissivity levels between 0.4 to 0.8. The higher evaporative fraction corresponds to near potential rate of evapotranspiration from unstressed rice and groundnut growth. It was found that there was very good correlation between transmissivity and evaporative fraction for transmissivity  $< 0.4$  coincident to cloudy conditions for different fractional vegetation cover conditions (Figure 4).

In cloudy skies, the gradient of water vapour potential between surface to atmosphere becomes low or sometimes just opposite to

that in clear skies. The vapour pressure difference between canopy to atmosphere may become less than canopy-air temperature. Moreover, canopy resistance to diffusion vapour transfer gets substantially increased as compared to resistances to heat exchange. Both the factors might have led to significant drop in latent heat fluxes as compared to sensible heat fluxes. This could decrease evaporative fraction due to presence of clouds. The validity of these findings is still to be ascertained though simulations and independent H and LE data. The empirical relations in cloudy skies for different vegetation types would help derive evaporative fraction as a function of transmissivity.

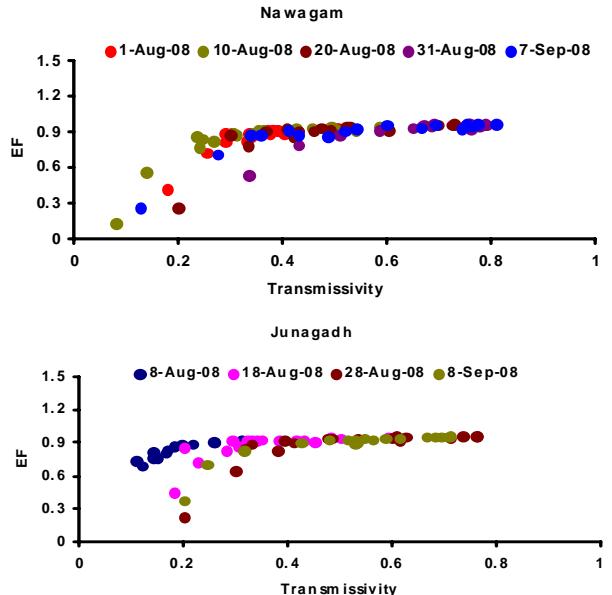


Figure 4. Plot of Atmospheric Transmissivity and Evaporative Fraction

#### CONCLUSION

The study demonstrates the functioning of prototype network measurements of radiation and energy balance components or micrometeorological studies for the first time using communication link of Indian geostationary satellite. Preliminary site specific evaluation was made to check the data quality and to study the differences of radiative, convective fluxes and evaporative fraction both in clear and cloudy skies over different agricultural regimes in semi-arid climate. This measurement system will be able to provide new insight to characterize flux behaviour over different vegetative systems and their modelling.

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