Surface Energy Balance Closure and Its Role in Indian Climate and Agricultural Studies

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***Abstract*—Surface Energy Balance (SEB) explains how solar energy received at the Earth's surface is distributed into different components such as heating the air, evaporating water, and warming the soil. In theory, all incoming energy should be balanced by outgoing energy. However, many scientific studies show that this balance is not fully achieved in real measurements. This problem is known as surface energy balance closure. In India, agriculture is closely linked to climate, monsoon rainfall, and irrigation practices. Therefore, understanding SEB closure is important for accurate estimation of evapotranspiration, water management, and climate studies. This review discusses the concept of surface energy balance closure, the main reasons for non-closure, and its importance in Indian climate and agricultural research.**

***Index Terms*—Surface energy balance, energy balance closure, Indian climate, agriculture, monsoon**

I. INTRODUCTION

Solar energy is the main source of energy for the Earth's climate system and agricultural production. When sunlight reaches the land surface, it is divided into different forms of energy. Some energy heats the air, some is used to evaporate water from soil and plants, and some warms the soil. This exchange of energy between the land surface and the atmosphere is called the surface energy balance. Scientists study surface energy balance to understand weather patterns, climate change, crop water use, and land–atmosphere interaction (Wilson et al., 2002).

Although modern instruments such as the eddy covariance method are widely used to measure energy fluxes, many studies report that the measured energy components do not fully match the available energy (Foken, 2008). This difference is known as the surface energy balance closure problem. In India, where agriculture depends heavily on monsoon rainfall and irrigation, errors in energy balance measurements can affect climate modeling, irrigation planning, and agricultural productivity. Therefore, studying SEB closure is essential for Indian climate and agricultural studies.

II. CONCEPT OF SURFACE ENERGY BALANCE

Surface energy balance is based on the principle that net radiation received at the Earth's surface is used mainly in three processes: sensible heat, latent heat, and soil heat. Sensible heat increases air temperature, latent heat is used for evaporation and transpiration, and soil heat warms the ground. Ideally, the sum of these energy components should be equal to the net radiation received at the surface (Leuning et al., 2012). The surface energy balance equation is written as:

$$R_n = H + LE + G$$

Where:

- R_n= Net radiation
- H= Sensible heat flux (heating of air)
- LE= Latent heat flux (energy used for evaporation)
- G= Soil heat flux

Ideally, all energy coming to the surface should be used in these three processes. But in real measurements, the sum of $H + LE + G$is often less than R_n. This missing energy is called energy balance non-closure.

However, observations from field experiments often show that the sum of sensible heat and latent heat is less than the available energy. This missing energy is referred to as non-closure of the surface energy balance. Studies across different ecosystems have reported energy balance closure ranging between 60%

and 90%, indicating that non-closure is a common issue worldwide (Wilson et al., 2002).

III. CAUSES OF SURFACE ENERGY BALANCE NON-CLOSURE

One major reason for surface energy balance non-closure is measurement uncertainty. Instruments measuring radiation, heat fluxes, and soil heat operate over different surface areas. This mismatch becomes more significant in agricultural fields where land conditions change rapidly due to crop growth and irrigation (Leuning et al., 2012). In many cases, heat stored in vegetation and soil layers is not fully considered, leading to underestimation of total energy use.

Atmospheric turbulence also contributes to non-closure. Energy is transferred by air movements of different scales. Large and slow air motions are often not captured by standard measurement techniques, resulting in missing energy (Foken, 2008). This problem is more pronounced during calm weather conditions and at night.

Land surface heterogeneity is another important factor, especially in India. Agricultural landscapes in India consist of mixed cropping patterns, irrigated and rainfed fields, bare soil,water channels, and nearby settlements. Such diversity causes horizontal movement of heat and moisture, known as advection, which is not measured properly by point-based instruments (Kanda et al., 2004).

Monsoon climate further complicates surface energy balance studies in India. Cloud cover during the monsoon reduces incoming solar radiation, while high humidity and frequent rainfall alter surface conditions quickly. Sudden changes in soil moisture due to rainfall or irrigation increase evaporation, making energy balance closure more difficult during the monsoon season.

IV. ROLE OF SURFACE ENERGY BALANCE CLOSURE IN INDIAN AGRICULTURE

Surface energy balance closure plays an important role in estimating evapotranspiration, which represents water loss from crops and soil. Latent heat flux is directly related to evapotranspiration, and any error in its measurement affects irrigation scheduling and water resource planning (Sellers et al., 1997). In water-scarce regions of India, such errors can lead to inefficient use of irrigation water.

Energy balance also influences local and regional climate. Surface heating affects air temperature, wind movement, and rainfall formation. Inaccurate surface energy data can reduce the reliability of climate models and monsoon prediction systems, which are crucial for agricultural decision-making in India.

V. EVIDENCE FROM INDIAN STUDIES

Limited studies conducted in India show that surface energy balance closure varies with season and land use. Higher closure is generally observed during dry seasons, while lower closure occurs during monsoon periods due to cloud cover and wet soil conditions. Studies over irrigated croplands show greater imbalance compared to rainfed areas because of sudden moisture changes. Research over forests and plantation systems in India indicates better closure when heat stored in vegetation is included, highlighting the importance of biological factors in energy balance studies.

VI. METHODS TO IMPROVE ENERGY BALANCE CLOSURE

Several methods have been suggested to improve surface energy balance closure. These include accounting for heat stored in soil and vegetation, using longer data averaging periods, and applying better data correction techniques (Mauder & Foken, 2015). Combining ground-based observations with satellite data can help improve regional-scale energy balance estimates. Establishing more long-term observation stations across different agro-climatic zones of India is also necessary.

VII. RESEARCH GAPS AND FUTURE SCOPE

There is a lack of long-term surface energy balance studies over major Indian crop systems such as rice wheat and millet-based farming. Rainfed regions and smallholder farms are underrepresented in current research. Future studies should focus on monsoon-driven energy processes and integrate traditional Indian land and water management knowledge with modern scientific approaches.

VIII. CONCLUSION

Surface energy balance closure remains a major challenge in climate and agricultural studies. In India, monsoon variability, irrigation practices, and land surface diversity strongly influence energy balance measurements. Improving surface energy balance closure will enhance the accuracy of evapotranspiration estimates, climate odelling, and agricultural planning. Strengthening observational networks and adopting integrated measurement approaches are essential for sustainable agricultural and climate research in India.

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