DART-EB: 3D modelling of times series of satellite observations and energy balance of vegetation canopies

Supervisors: Jean-Louis Roujean (jean-louis.roujean@univ-tlse3.fr), Yingjie Wang (yingjiewang@iut-tlse3.fr)
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Subjects:

Remote sensing is essential for studying and managing land surfaces at various spatiotemporal scales. Specifically, high temporal and spatial resolution observations provide insights into the dynamics and functioning of homogeneous landscape units. For instance, in the optical domain, certain types of data such as SPOT, Landsat, Sentinel-2, and Pléiades have been utilized to develop high-resolution digital models and mock-ups. In the thermal domain, the upcoming launch of sensors like TRISHINA (2026), SBG (2028), and LSTM (2029) is expected to bring significant advancements in understanding the life of agro-ecosystems. However, scientific challenges hinder the accurate interpretation of remote sensing observations, particularly concerning directional effects due to variations in illumination and observation angles. These effects, already documented in optics for radiometry, are also significant in the thermal domain by the canopy heating effect and thermal inertia. They are closely related to the 3D architecture and heterogeneity of land surfaces. Therefore, it is essential to develop physical models that are capable to explain phenomena related to surface anisotropy to enhence the utility of remote sensing tools.

The coupling of models, such as the remote sensing model (radiative transfer, sensor configuration, etc.) and the energy balance model (vegetation/soil functioning, energy and mass fluxes, etc.), is promising but challenging to implement. This is because it involves combining models often designed for different spatial and/or temporal scales and based on different levels of simplification. For example, SCOPE (https://scope-model.readthedocs.io), the reference model for simulating the energy balance and evapotranspiration of getation, represents the surface as a one-dimensional medium (1D model). To enhance precision, models, in general, need to consider the three-dimensional architecture (3D model) of land surfaces. This is often modeled in remote sensing models, such as DART (https://dart.omp.eu) and Eradiate (https://www.eradiate.eu/site), which generally do not simulate energy balance. However, observations in the thermal infrared (TIR) strongly depend on the thermodynamic temperature of different components (illuminated and shaded soil and vegetation) with respect to their appearance in the observer's field of view. Indeed, temperature is strongly influenced by surface functioning and energy and mass fluxes. To accurately simulate TIR observations, remote sensing models must also integrate outputs from energy balance models with the same landscape representation.

The objective of the thesis is to develop a comprehensive, accurate, and efficient energy balance model to simulate time series (daily and seasonal cycles) of satellite observations and energy balance consistently across short and long wavelengths. The landscapes studied will be diverse and examined at different spatial resolutions. This model will notably consider the 3D geometry of observed surfaces and the biophysical mechanisms (e.g., thermal conduction, photosynthesis, evapotranspiration) that influence the optical properties and 3D temperature of canopies. This work will simulate and better characterize the dynamics of vegetation in response to abiotic factors, including the effects of water stress, which is a primary objective of the TRISHNA space mission set to launch in 2026. The results of this model will be compared with in-situ measurements (ground-based, airborne).

In this thesis, radiative mechanisms and remote sensing observations (in-situ, airborne, and satellite measurements) of the studied sites will be simulated using the DART model, developed at CESBIO (patented in 2003) since 1992. DART also simulates sun-induced fluorescence and LiDAR observations, complementing the energy balance. It has already been validated based on albedo measurements (precision of 1-2%) and brightness temperature (precision of 1-2 K). The studied sites can include kilometer-scale landscapes-scale with topography and atmospheric effects (water vapor, aerosols). The 3D energy balance model will be developed in parallel, compatible with the DART model: 3D representation of landscapes, 3D distribution of radiation balance, etc., and will adapt biogeophysical processes already implemented in the SCOPE model. The result will be a coupled "DART-EB (Energy Balance)" model.

DART-EB will then be applied to instrumented sites (Auzeville, Auradé, Malegaon) in which CESBIO is involved, particularly in the study of directional effects presented in TIR remote sensing images related to the 3D structure of vegetation canopies and the 3D distribution of temperature. The proposed timeline aligns with the TRISHNA mission roadmap, serving its pre-launch preparation and Cal/Val (post-launch) phases.