ECOSTRESS Collection 3 Level-3 Evapotranspiration (JET) Algorithm Theoretical Basis Document

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

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Introduction

Purpose

Evapotranspiration (ET) is one of the main science outputs from the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). ET is a Level-3 (L-3) product constructed from a combination of the ECOSTRESS Level-2 (L-2) Land Surface Temperature & Emissivity (LSTE) product and auxiliary data sources.

The ECOSTRESS Collection 3 L3T JET product uses an ensemble of four evapotranspiration models (PT-JPL-SM, STIC-JPL, PM-JPL, and BESS-JPL) to produce robust evapotranspiration estimates. This ensemble approach combines outputs from four distinct models, each with different strengths and theoretical foundations, to reduce uncertainty and improve overall accuracy.

Accurate modelling of ET requires consideration of many environmental and biological controls including: solar radiation, the atmospheric water vapor deficit, soil water availability, vegetation physiology and phenology. LST holds the unique ability to capture when and where plants experience stress, as observed by elevated temperatures which can identify areas that have a reduced capacity to evaporate or transpire water to the atmosphere.

The rate of ET is controlled by many environmental and biological factors, including:

- Incoming radiation
- Atmospheric water vapor deficit
- Soil water availability
- Vegetation physiology and phenology

Scope and Objectives

This document provides:

1. A description of the ET parameter characteristics and requirements.
2. An overview of the general form of the ET algorithms in the JET ensemble.
3. Algorithm-specific adaptations for the ECOSTRESS mission.
4. Required auxiliary data products and their sources.
5. A plan for calibration and validation (Cal/Val) of the ET retrieval.

Parameter Description and Requirements

Attributes of ET Data

- Spatial resolution: 70 m x 70 m
- Temporal resolution: Diurnally varying to match ISS overpass characteristics
- Latency: As required by the ECOSTRESS Science Data System (SDS)

Auxiliary Variables

Auxiliary Variable	Product Layer	Source
Near-surface air temp.	Ta	GEOS-5 FP tavg1_2d_slv_Nx
Relative humidity (RH)	RH	GEOS-5 FP tavg1_2d_slv_Nx
Soil moisture (SM)	SM	GEOS-5 FP tavg1_2d_lnd_Nx
Global radiation	Rg	GEOS-5 FP tavg1_2d_rad_Nx
Net radiation	Rn	BESS-JPL calculation
Cloud mask	cloud	L2 CLOUD product
Water mask	water	NASADEM Surface Water Bodies

Evapotranspiration Retrieval

The ensemble incorporates ET data from four algorithms: Priestley Taylor-Jet Propulsion Laboratory model with soil moisture (PT-JPL-SM), the Penman Monteith-Jet Propulsion Laboratory model (PM-JPL), Surface Temperature Initiated Closure-Jet Propulsion Laboratory model (STIC-JPL), and the Breathing Earth System Simulator-Jet Propulsion Laboratory model (BESS-JPL).

PT-JPL-SM: General Form

The PT-JPL-SM model, developed by Dr. Adam Purdy and Dr. Joshua Fisher, relies on the Priestley-Taylor equation to resolve potential ET (PET), enhanced with soil moisture constraints for improved accuracy in water-limited environments:

$$PT = \alpha \frac{\Delta}{\Delta + \gamma}(R_N - G)$$

Where: - α: Priestley-Taylor coefficient (typically 1.26) - Δ: Slope of the saturation-to-vapor pressure curve (kPa/°C) - γ: Psychrometric constant (kPa/°C) - R_N: Net radiation (W/m²) - G: Ground heat flux (W/m²)

To reduce PET to actual ET (AET), the model applies ecophysiological constraint functions based on: - Plant temperature constraint (f_T): Based on optimal and maximum air temperatures - Plant moisture constraint (f_M): Derived from relative humidity - Plant phenology constraint (f_{APAR}): Based on absorbed photosynthetically active radiation - Soil moisture constraint (f_{SM}): The key innovation, using downscaled soil moisture data

The final ET partitioning includes canopy transpiration, leaf surface evaporation, and soil evaporation components, each modified by appropriate constraint functions.

STIC-JPL: General Form

The Surface Temperature Initiated Closure-Jet Propulsion Laboratory (STIC-JPL) model, contributed by Dr. Kaniska Mallick, was designed as a surface temperature-sensitive ET model, adopted by ECOSTRESS and SBG for improved estimates of ET reflecting mid-day heat stress. The STIC-JPL model integrates LST into the Penman-Monteith Shuttleworth-Wallace system of ET equations and estimates total latent heat flux directly using thermal remote sensing observations.

The general approach involves:

1. Solving state equations to find analytical solutions for aerodynamic temperature (T_0) and conductances (g_a, g_{cs}).

2. Iteratively estimating unknowns using Penman-Monteith and Shuttleworth-Wallace equations.

PM-JPL: General Form

The Penman-Monteith-Jet Propulsion Laboratory (PM-JPL) algorithm is a derivation of the MOD16 algorithm that was originally designed as the ET product for the Moderate Resolution Imaging Spectroradiometer (MODIS) and continued as a Visible Infrared Imaging Radiometer Suite (VIIRS) product. PM-JPL uses a similar approach to PT-JPL and PT-JPL-SM to independently estimate vegetation and soil components of instantaneous ET, but using the Penman-Monteith formula instead of the Priestley-Taylor.

The algorithm is based on the Penman-Monteith equation with environmental constraints from vegetation cover, temperature, and atmospheric moisture deficits. It resolves evaporative fluxes from the soil, canopy, and intercepted water separately. The PM-JPL latent heat flux partitions are summed to total latent heat flux for the ensemble estimate.

BESS-JPL: General Form

The Breathing Earth System Simulator-Jet Propulsion Laboratory (BESS-JPL) model is a coupled surface energy balance and photosynthesis model contributed by Dr. Youngryel Ryu. The model iteratively calculates net radiation, ET, and Gross Primary Production (GPP) estimates. The latent heat flux component of BESS-JPL is included in the ensemble estimate, while the BESS-JPL net radiation is used as input to the other ET models.

The BESS-JPL algorithm couples atmospheric and canopy radiative transfer processes with photosynthesis, stomatal conductance, and transpiration. It uses a quadratic representation of the Penman-Monteith model to estimate transpiration, incorporating both physiological and environmental constraints.

AquaSEBS Water Surface Evaporation

For water surface pixels identified using the NASADEM Surface Water Body extent, the ECOSTRESS Collection 3 processing chain implements the AquaSEBS (Aquatic Surface Energy Balance System) model developed by Abdelrady et al. (2016) and validated by Fisher et al. (2023). Water surface evaporation is calculated using a physics-based approach that combines the equilibrium temperature model for water heat flux with the Priestley-Taylor equation for evaporation estimation.

The AquaSEBS model implements the surface energy balance equation specifically adapted for water bodies:

$$R_n = LE + H + W$$

Where the water heat flux (W) is calculated using the equilibrium temperature model:

$$W = \beta \times (T_e - WST)$$

Latent heat flux is then calculated using the Priestley-Taylor equation with α = 1.26 for water surfaces:

$$LE = \alpha \times \frac{\Delta}{\Delta + \gamma} \times (R_n - W)$$

The AquaSEBS methodology has been extensively validated against 19 in situ open water evaporation sites worldwide spanning multiple climate zones, with daily evaporation estimates showing r^2 = 0.47-0.56 and RMSE = 1.2-1.5 mm/day.

Ensemble Processing

The median of total latent heat flux in watts per square meter from the PT-JPL-SM, STIC-JPL, PM-JPL, and BESS-JPL models is upscaled to a daily ET estimate in millimeters per day and recorded in the L3T JET product as `ETdaily`. The standard deviation between these multiple estimates of ET is considered the uncertainty for the evapotranspiration product, as `ETinstUncertainty`. The ETdaily product represents the integrated ET between sunrise and sunset.

Calibration/Validation

ET Evaluation

Eddy covariance (EC) towers provide year-round observations at frequencies (~30 minutes) and spatial scales (10s-100s m) necessary to evaluate the JET ensemble. This analysis uses EC data from the Ameriflux network.

Error Budget and Performance Targets

The ECOSTRESS ET products target an error value of 1 mm/day, consistent with established literature and user requirements for water resource management applications.

Individual Model Performance: - PT-JPL-SM: RMSE of 6%, $R^2 = 0.88$ (Purdy et al., 2018) - STIC-JPL: RMSE of 0.7-1.2 mm/day across multiple biomes (Mallick et al., 2016) - PM-JPL (MOD16): RMSE of 0.84 mm/day (Mu et al., 2011) - BESS-JPL: RMSE of 0.8-1.1 mm/day (Ryu et al., 2011)

Ensemble Performance: The ensemble approach typically achieves: - Daily estimates: RMSE ≤ 1.5 mm/day - Instantaneous estimates: RMSE ≤ 60 W/m² - Correlation: R^2 > 0.7 across most biomes

Uncertainty Sources: 1. Input data uncertainty: LST accuracy (±0.5°C target), meteorological forcing 2. Model structural uncertainty: Algorithm assumptions and parameterizations 3. Scale mismatch: 70m pixel vs. flux tower footprint 4. Temporal mismatch: Instantaneous satellite vs. daily tower measurements

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Algorithm Repositories

The evapotranspiration algorithms are located in the JPL-Evapotranspiration-Algorithms organization:

- PT-JPL-SM: https://github.com/JPL-Evapotranspiration-Algorithms/PT-JPL-SM
- STIC-JPL: https://github.com/JPL-Evapotranspiration-Algorithms/STIC-JPL
- PM-JPL: https://github.com/JPL-Evapotranspiration-Algorithms/PM-JPL
- BESS-JPL: https://github.com/JPL-Evapotranspiration-Algorithms/BESS-JPL
- AquaSEBS: https://github.com/JPL-Evapotranspiration-Algorithms/AquaSEBS

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