Drought Monitoring with Evapotranspiration and Thermal Infrared

4 December 2024

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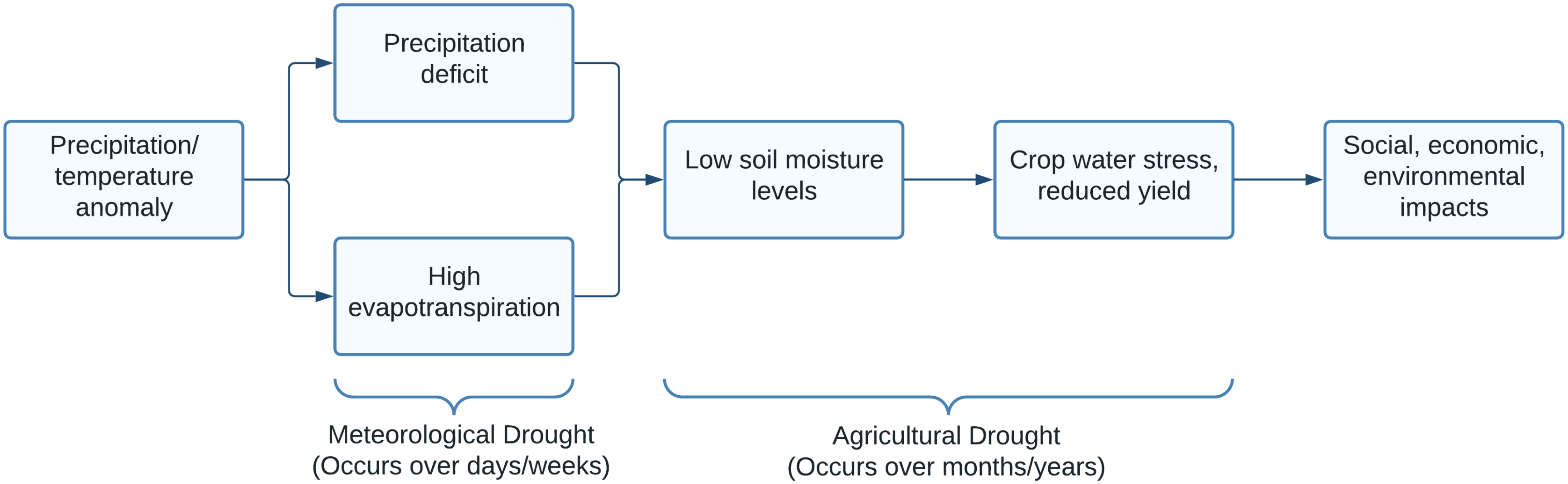
EO AFRICA

ESA HyRelief Project

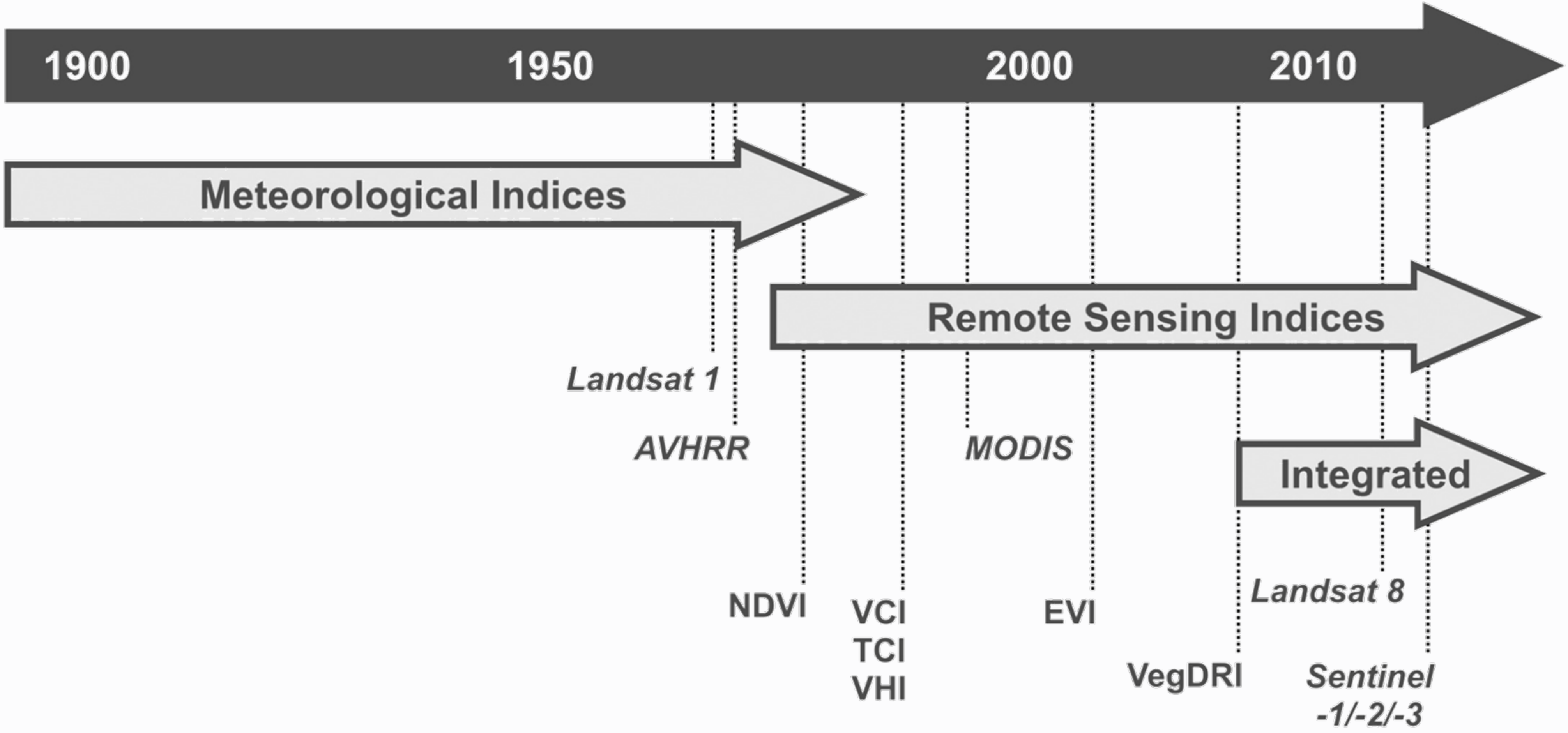
Outline

- Evapotranspiration and drought
- ECOSTRESS
- Surface energy balance
- Land surface temperate (LST)
- Energy balance (LST) approach to ET estimation
- Non-thermal (VI) approach to ET estimation
- Concluding remarks

Definition of Drought

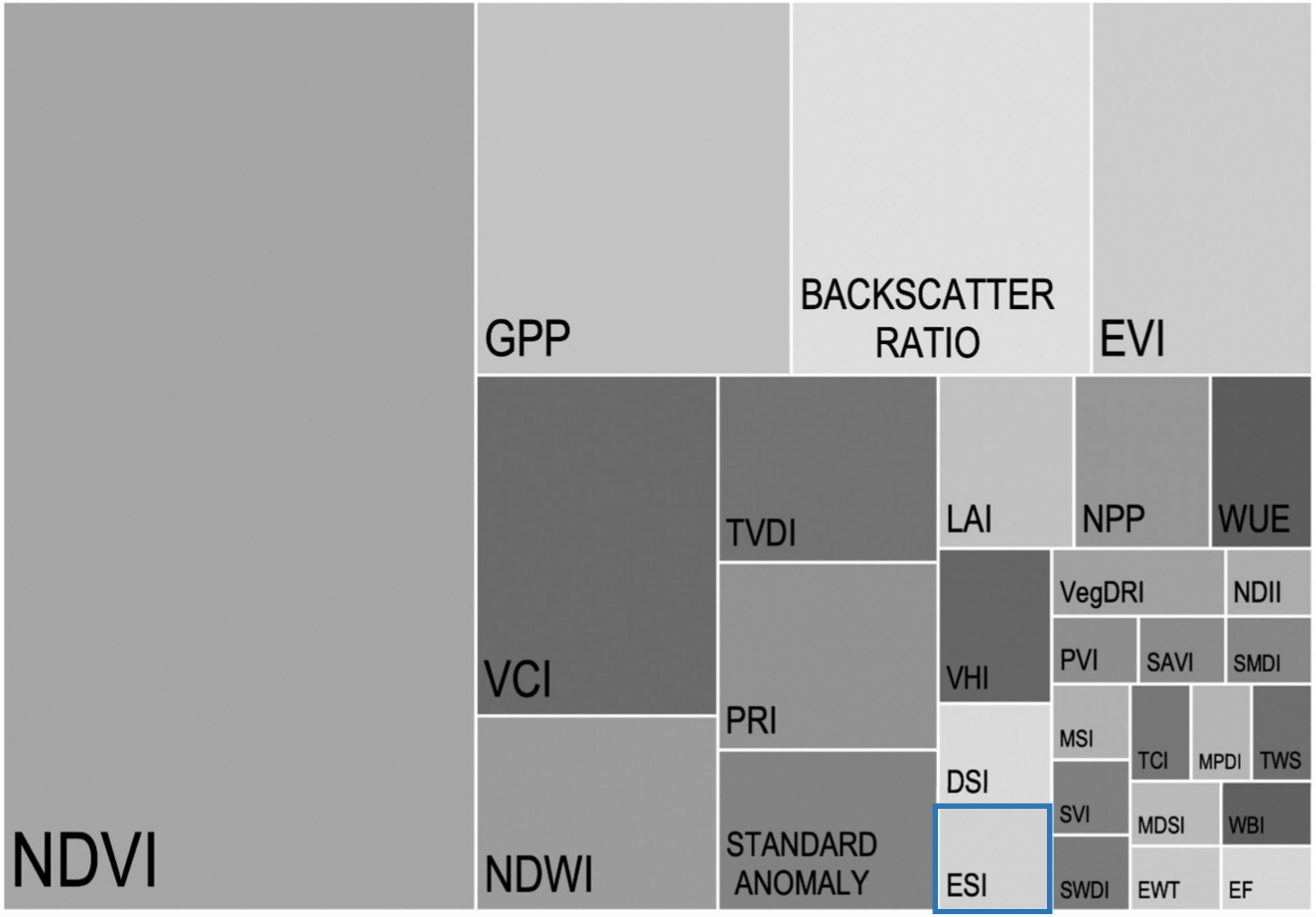


Monitoring Droughts from Weather Stations to Satellites



West, H., Quinn, N., Horswell, M. 2019. Remote sensing for drought monitoring & impact assessment: Progress, past challenges and future opportunities. *Remote Sensing of Environment*, 232: 111291.

Emergence of Polar-orbiting Satellite Missions



Evaporative Stress Index (ESI)

ET-based drought indices detect declines in ET relative to the atmospheric demand for moisture (PET):

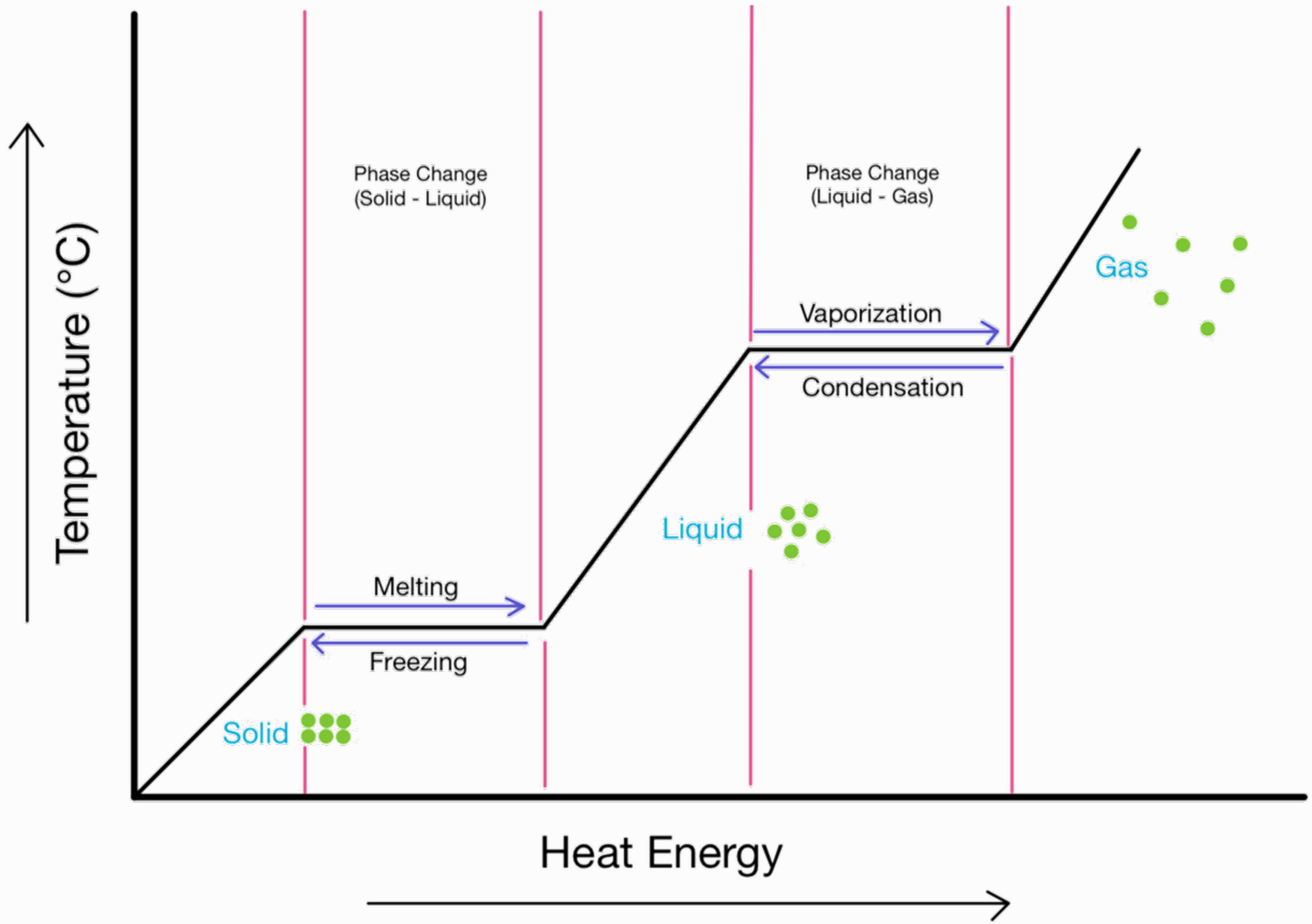
$$\mathrm{ESI} = \frac{\mathrm{ET}}{\mathrm{PET}}$$

The probability of drought increases as ESI→0.

ESI effectively monitors changes in soil moisture levels linked to agricultural drought and provides early detection of “flash” droughts

Anderson, M.C., Hain, C., Wardlow, B., Pimstein, A., Mecikalski, J.R., Kustas, W.P., 2011. Evaluation of Drought Indices Based on Thermal Remote Sensing of Evapotranspiration over the Continental United States. Journal of Climate 24: 2025–2044.

Latent Heat of Vaporization (λLE)



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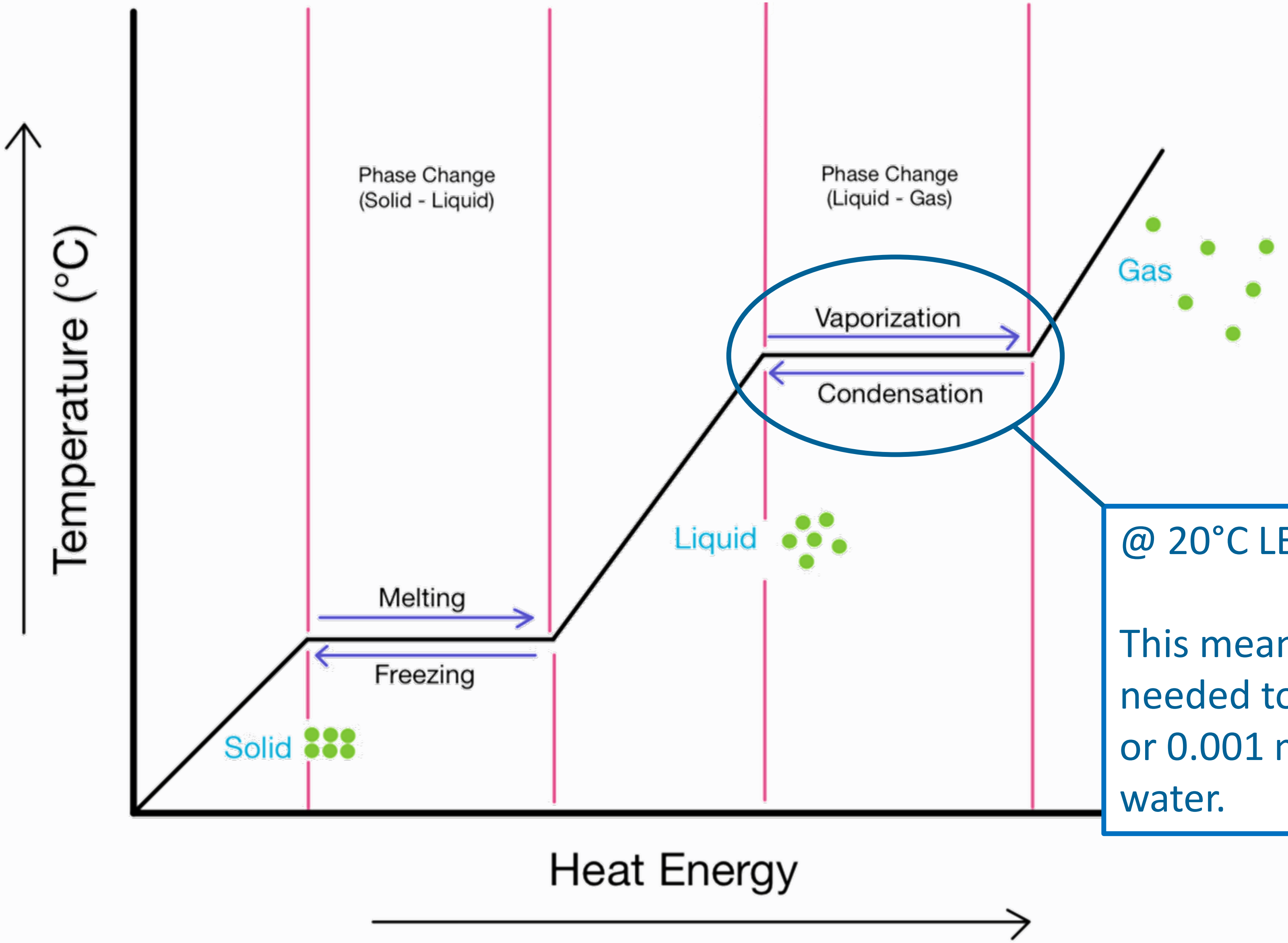
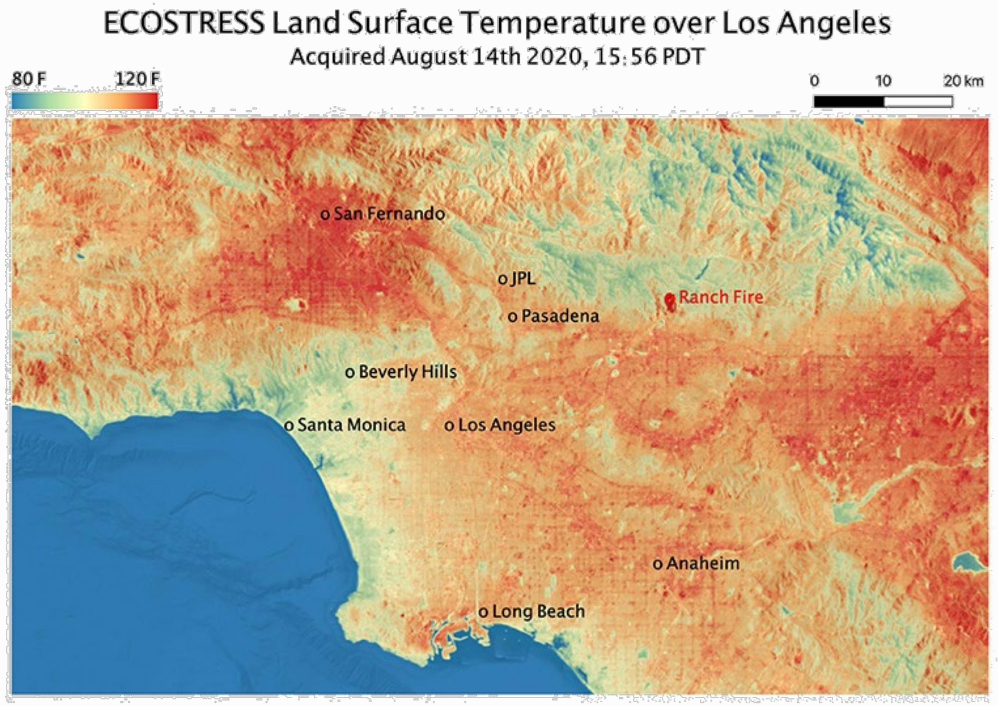


@ 20°C LE ~ 2.45 MJ kg^{-1}.

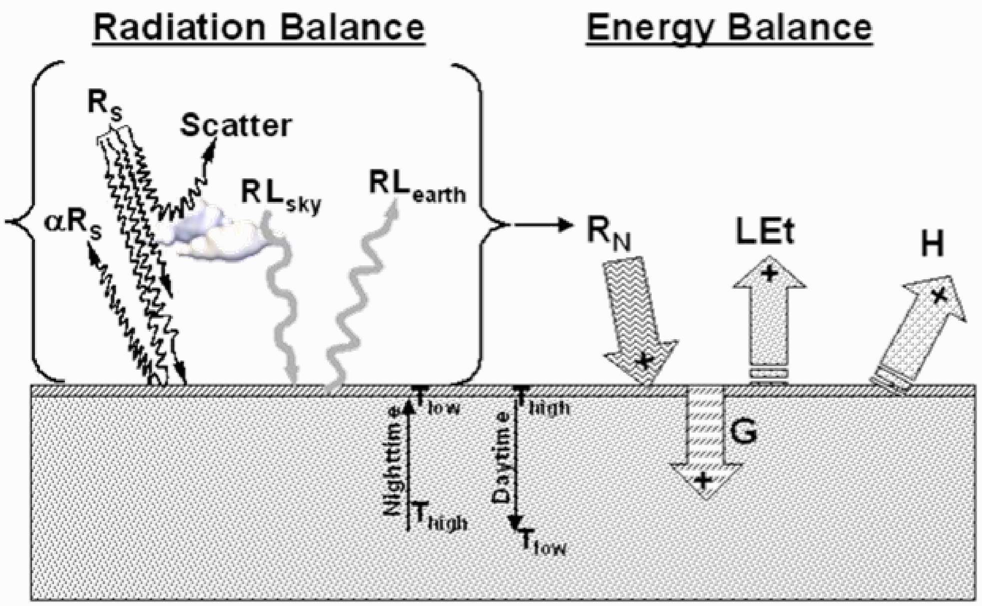
This means, 2.45 MJ are needed to vaporize 1 kg or 0.001 m^3 (1 mm) of water.

ECOSTRESS

- ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
- Multi-spectral thermal infrared imager
- Operated by NASA-JPL
- Launched 2018 29 June
- ISS orbit with irregular returns and overpass times
- Temperature sensitivity ≤0.1 K

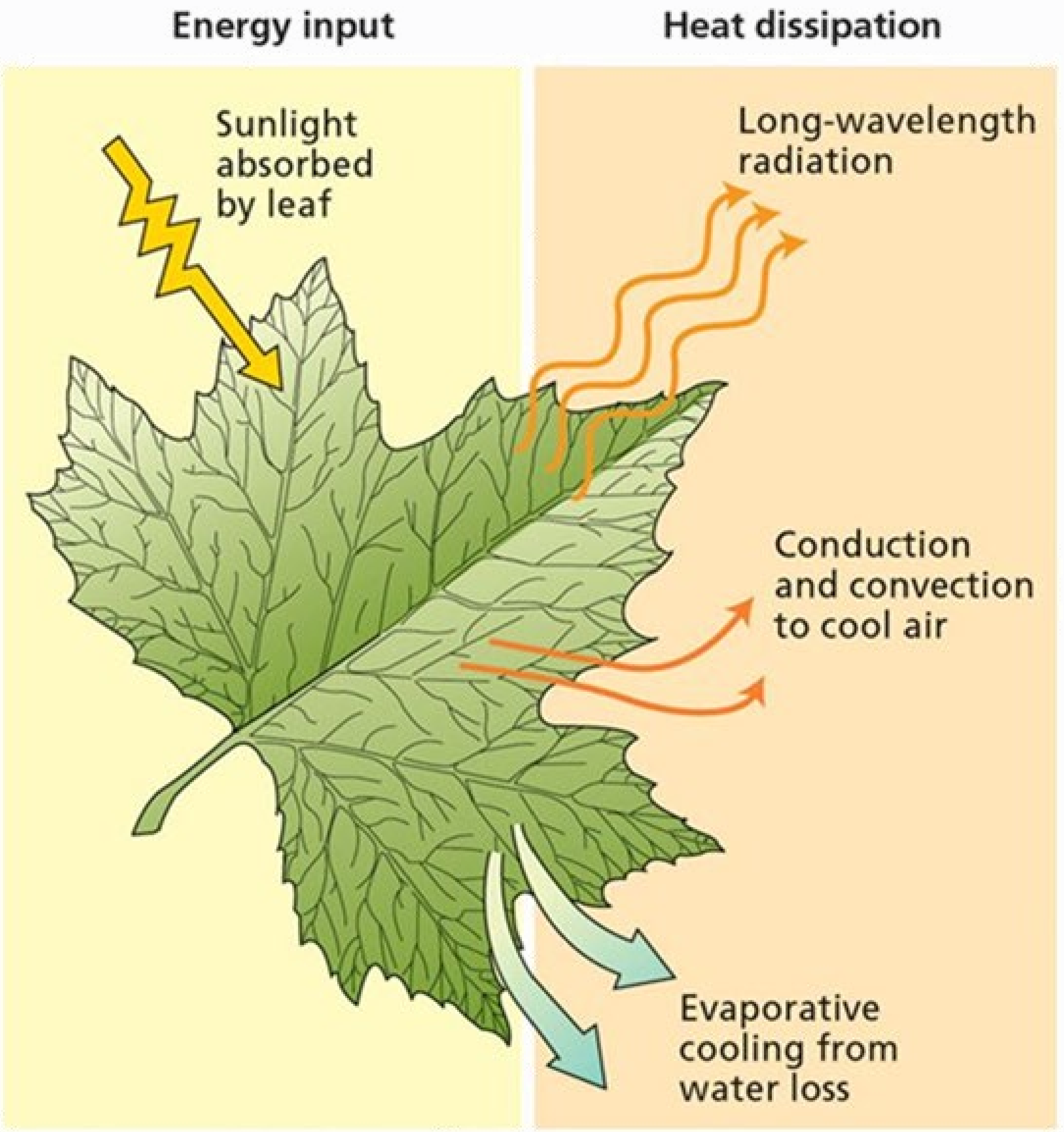


Surface Energy Balance



$$R_N = LE + G + H$$

Net Radiation | Latent Heat | Soil Heat | Sensible Heat



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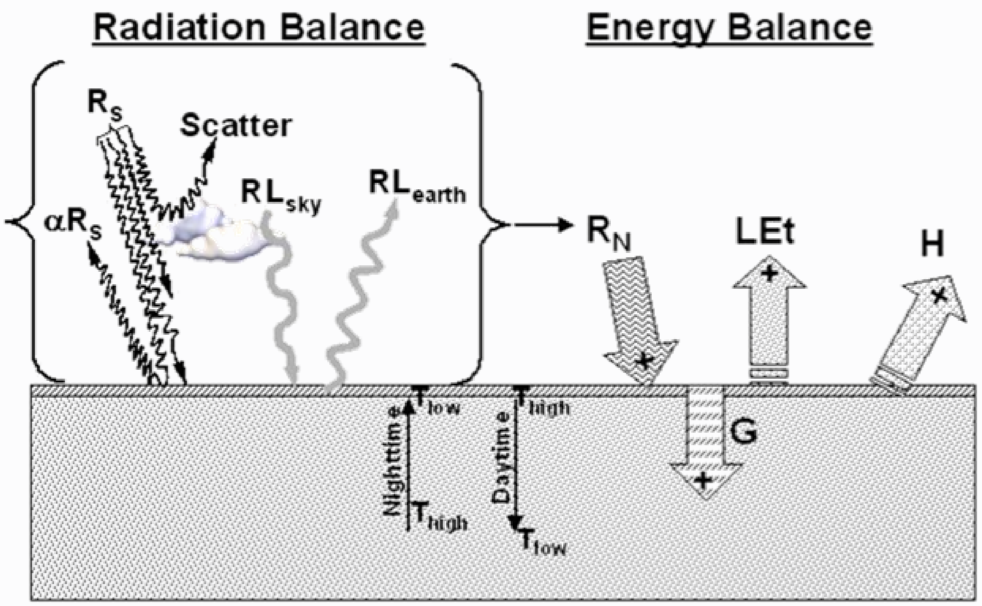
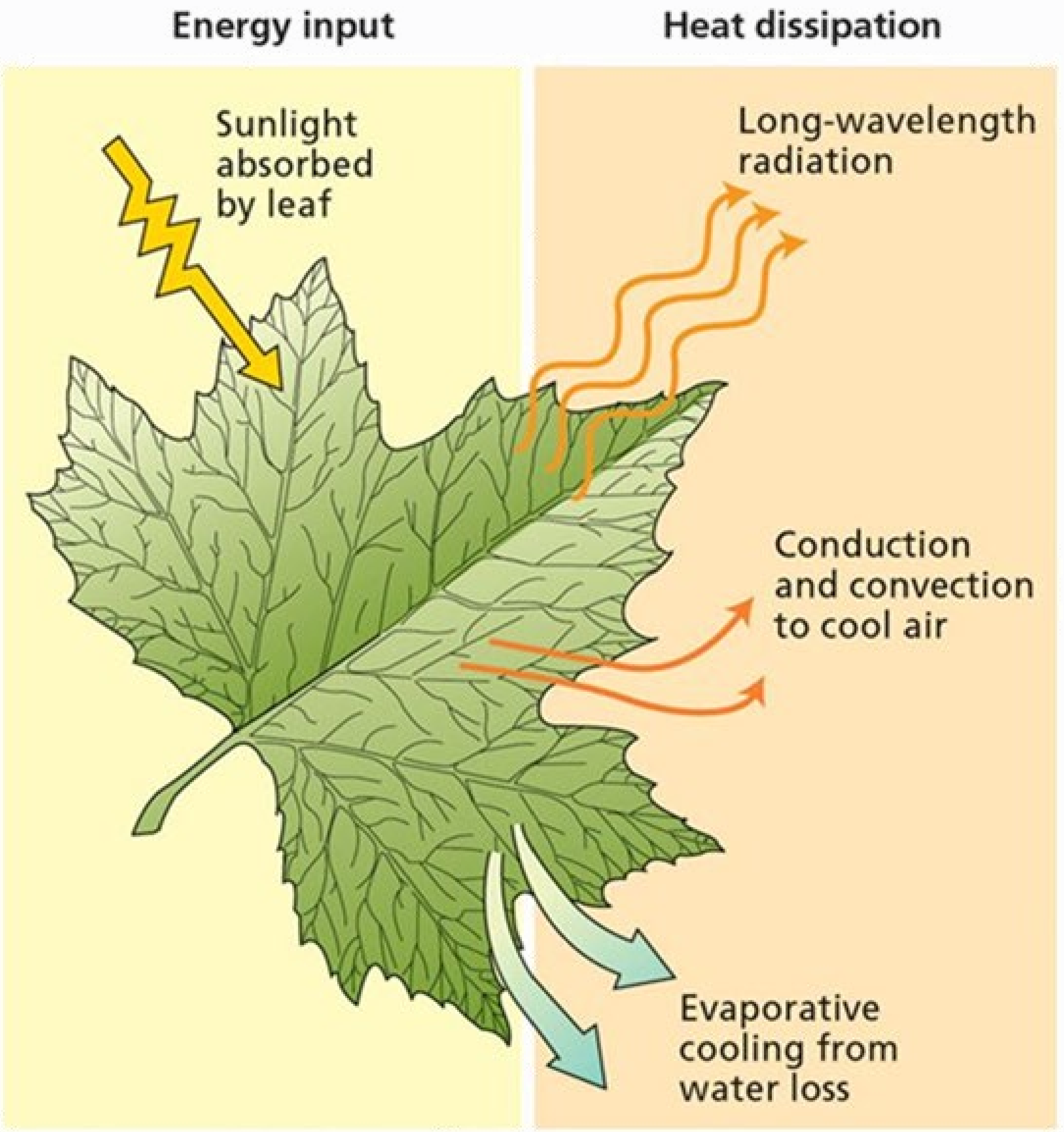


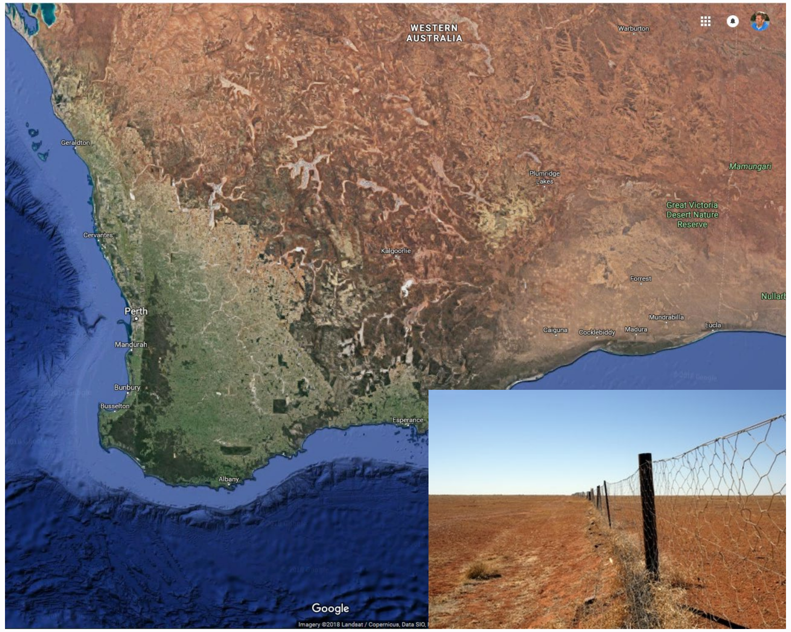
$$R_N = LE + \cancel{G} + H$$

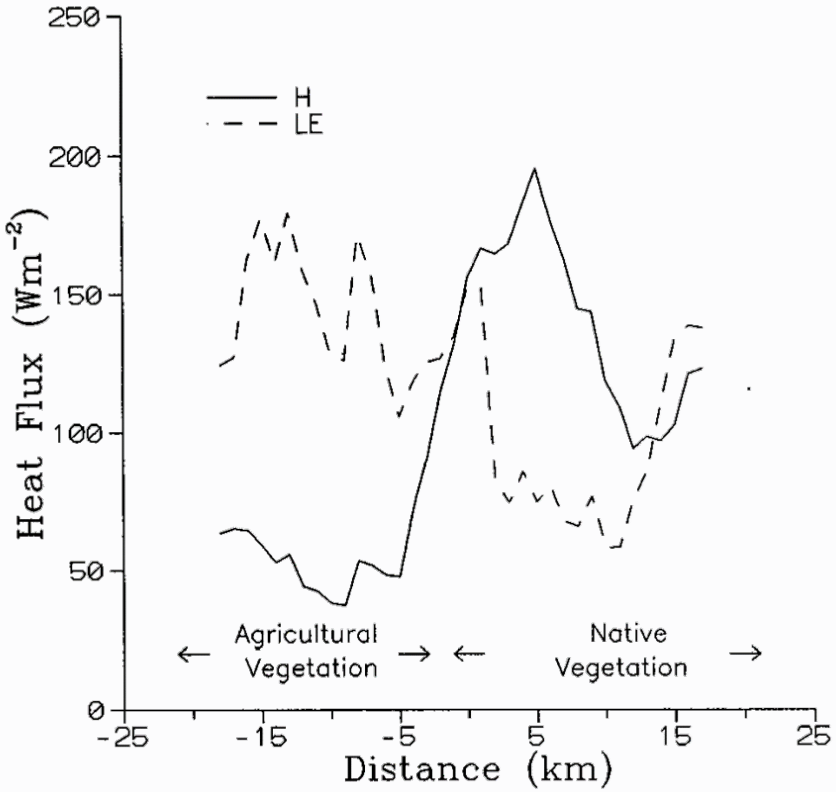
Net Radiation | Latent Heat | Soil Heat | Sensible Heat



Question

The rabbit-proof fence stretches across several areas in western Australia. In southwestern Australia, the fence clearly separates wet irrigated crops near the coast from native vegetation and desert in the interior. In a famous experiment (Lyons et al., 1993), the intensity and frequency of thunderstorm activity was seen to be much higher on the drier side of the fence.



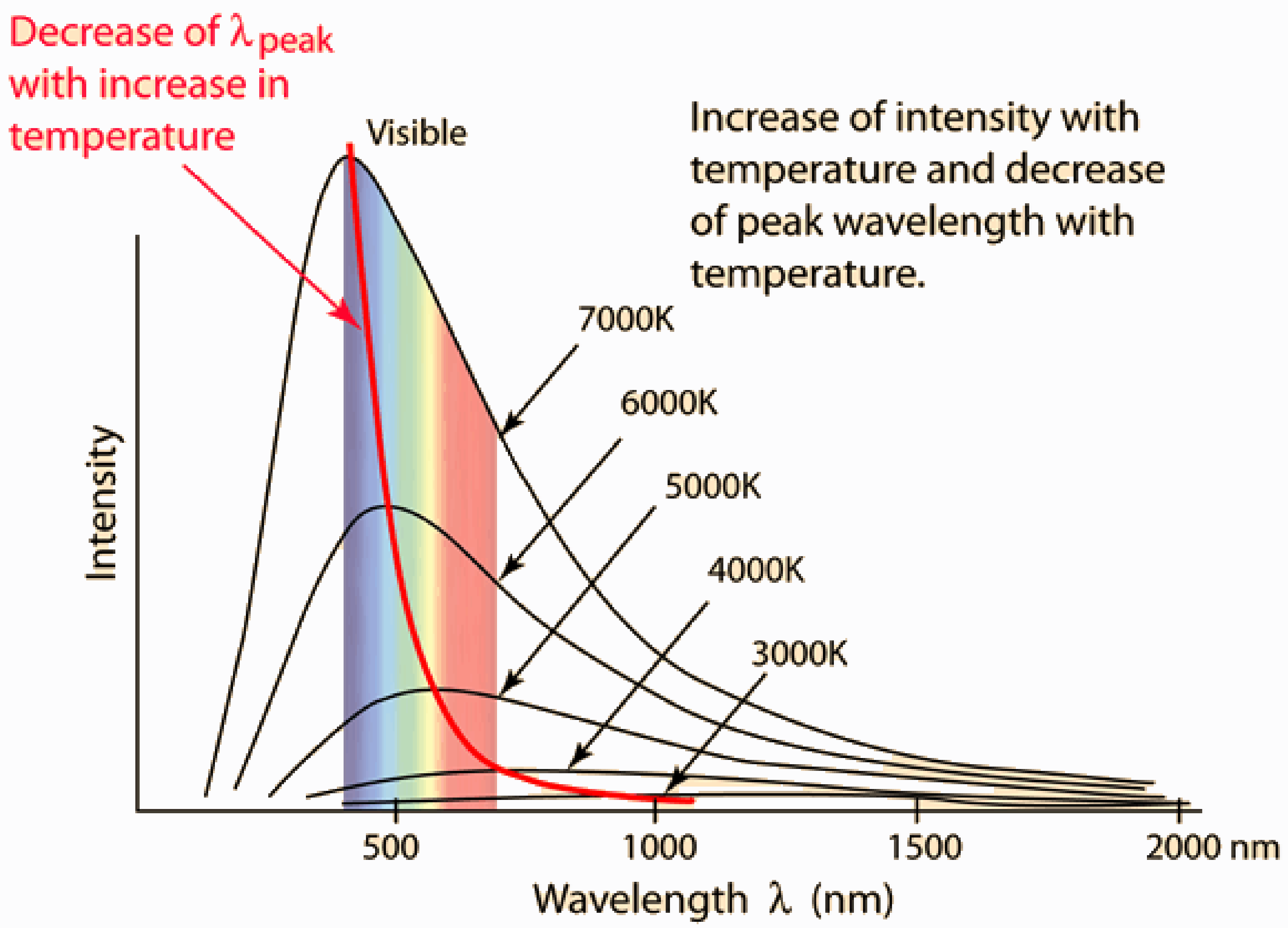


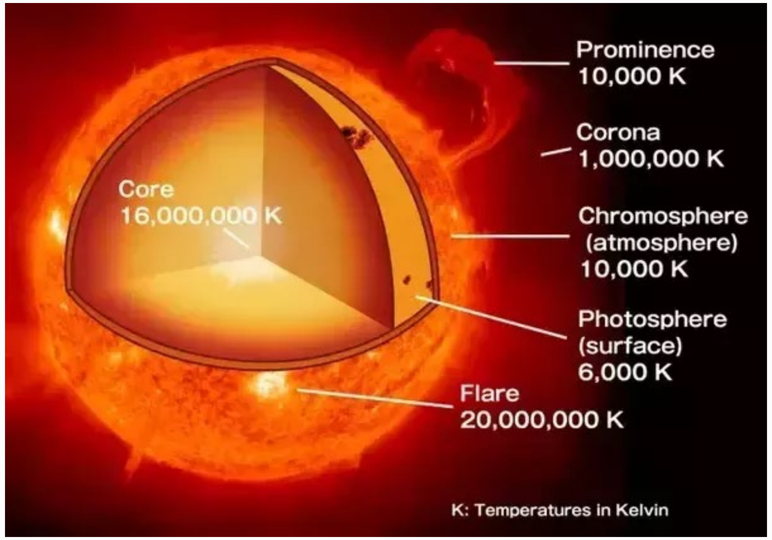
Why is there more thunderstorm activity on the drier side of the fence?

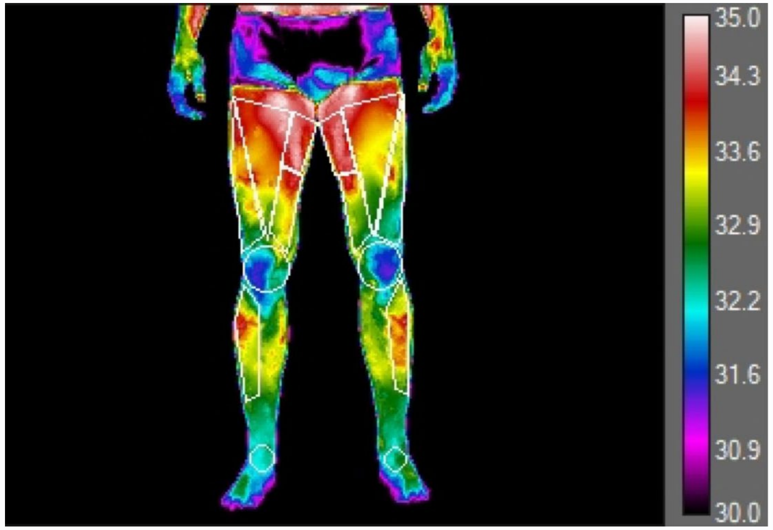
- Latent heat (ET) is much higher on the drier side
- Sensible heat (H) is much higher on the drier side
- Sensible heat is much higher on the wetter side
- Land cover has no impact

Sensible Heat (H) and Radiant Temperature

Wien's Displacement Law for "Black Bodies"







Sensible Heat (H) and Radiant Temperature

Radiance to At-Sensor or TOA Brightness Temperature

$$B_\lambda(T) = \frac{C_1}{\lambda^5(e^{C_2/\lambda T} - 1)}$$

Planck's Radiance Function (PRF)

$$T = \frac{\frac{C_2}{\lambda}}{\ln\left(\frac{C_1}{\lambda}\frac{1}{B_\lambda(T)}+1\right)}$$

Inverted PRF

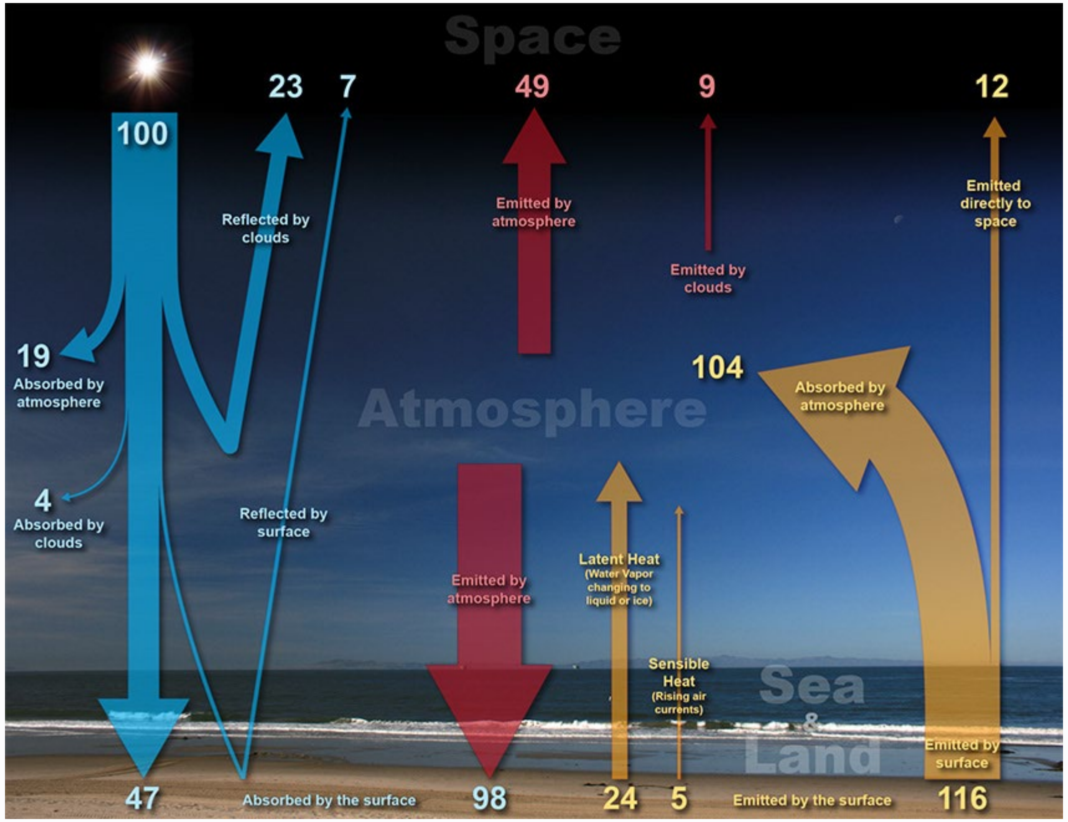
$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)}$$

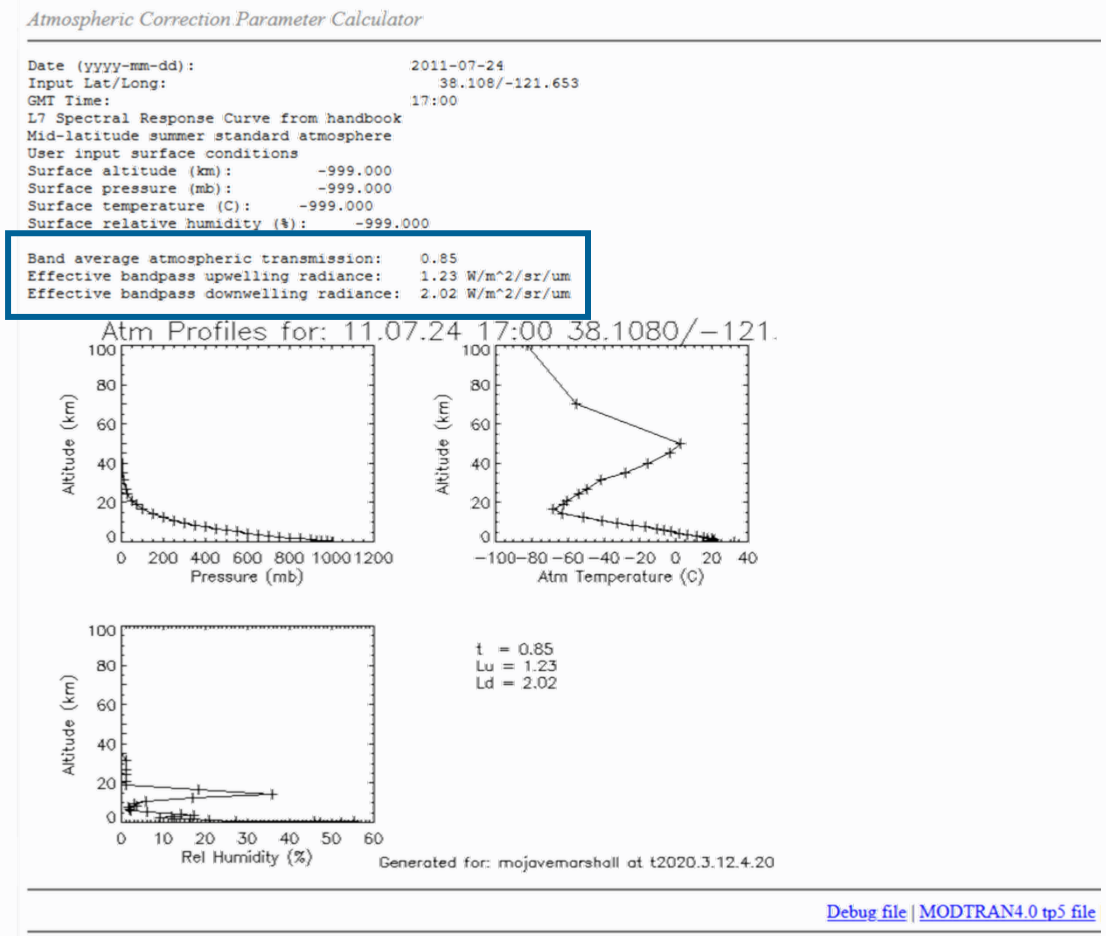
Inverted PRF adapted for remote sensing

T is the TOA brightness temperature, K_1 and K_2 are coefficients corresponding to the effective wavelength (λ) of a sensor, and L_λ is the TOA radiance

Sensible Heat (H) and Radiant Temperature

Radiance to Land Surface Temperature (LST)



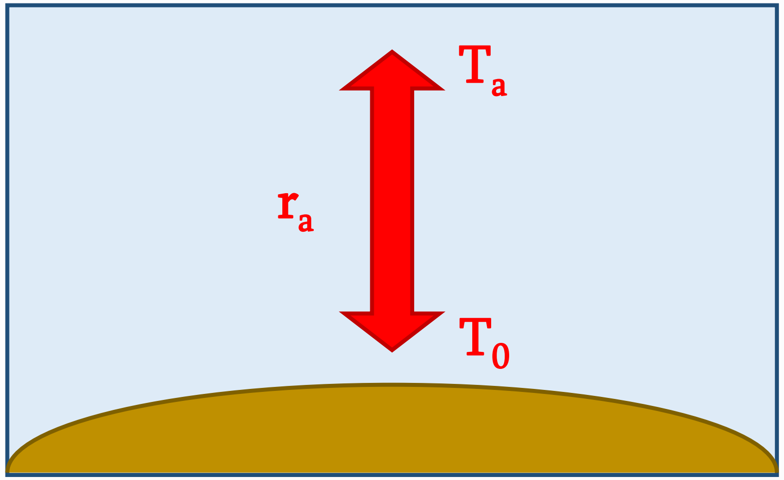


$$L_\lambda = \left[\left(\frac{L_{TOA} - LW^{\uparrow}}{\tau}\right) - (1-\varepsilon)\cdot LW^{\downarrow}\right]\cdot\left(\frac{1}{\varepsilon}\right)$$

Surface Energy Balance (SEB) Models

The energy used to evaporate water from the soil and vegetation is inversely related to H

$$LE = R_N + G + H$$



$$H = \frac{\rho C_p (T_0 - T_a)}{r_a}$$

ρ is the air density, C_p is the specific heat of air, T_0 is the aerodynamic temperature, and T_a is the near surface air temperature

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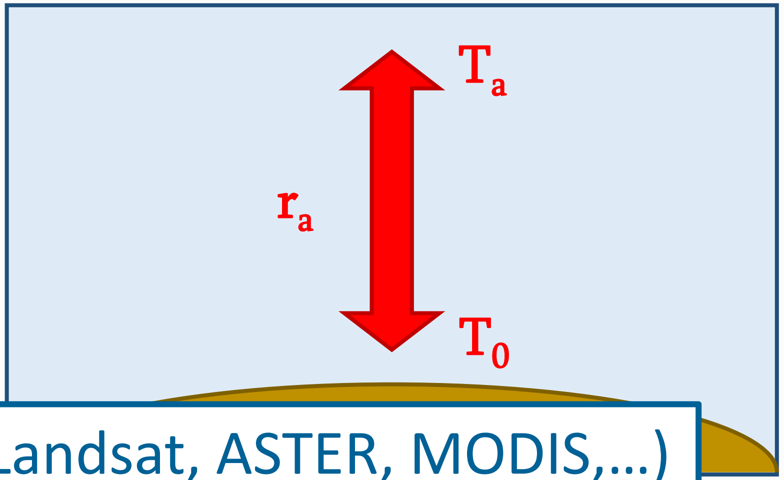
Approximated from LST (Landsat, ASTER, MODIS,…)



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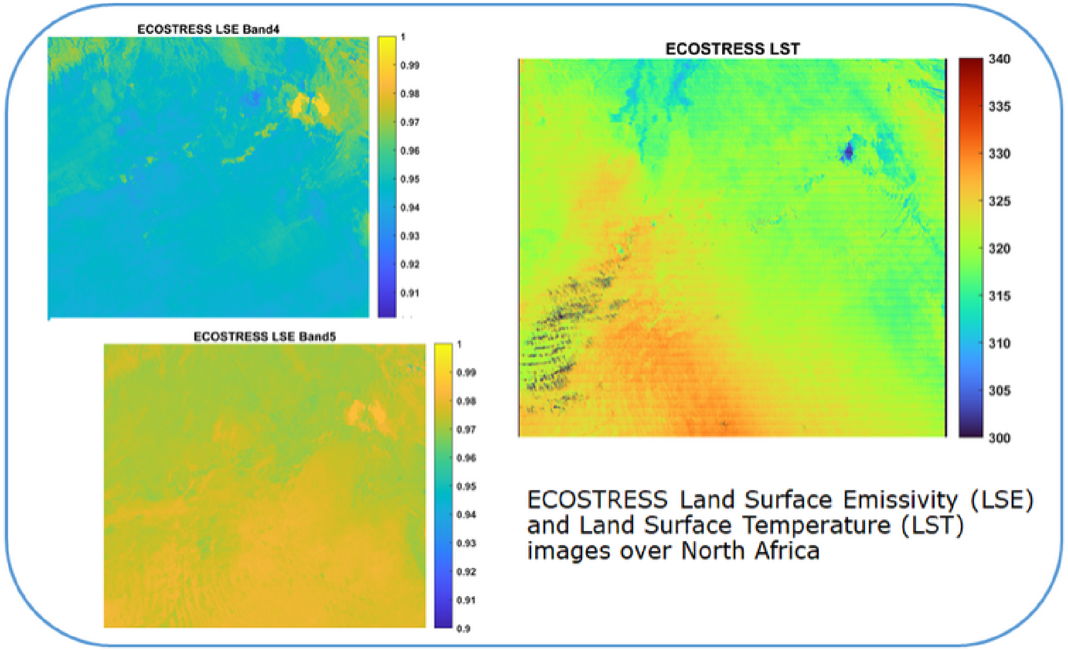
European ECOSTRESS Hub (EEH): Release of fast-track data access catalogue service

Data and products of NASA's ECOSTRESS mission acquired over Europe and Africa are now available for downloading and further processing at the FSTEP. The new data access is part of the European ECOSTRESS HUB (EEH), a project funded by ESA in support of the Copernicus Land Surface Temperature Monitoring (LSTM) High Priority Candidate Mission.

Within EEH, ECOSTRESS data is searchable for user defined area of interest and start/end dates. The current holdings include data spanning approximately one year of acquisition from 08/2018 until 08/2021 and cover eight products, level 1 (RAD, GEO), level 2 (CLOUD, LSTSW, LSTTES), level 3 (ETSTIC, ETSEBS, ETTSEB).



ECOSTRESS Land Surface Emissivity (LSE) and Land Surface Temperature (LST) images over North Africa

The EEH ECOSTRESS data repository was built to test and develop dedicated land surface temperature (LST) and evapotranspiration (ET) retrievals with user exchangeable algorithms and auxiliary data on a cloud platform in preparation of the LSTM mission. Within the EEH project, the Temperature Emissivity Separation (TES) algorithm and the Generalized Split Window (GSW) for LST and three different models (STIC, TSEB and SEBS) for ET will be implemented and made available through the Food Security TEP.

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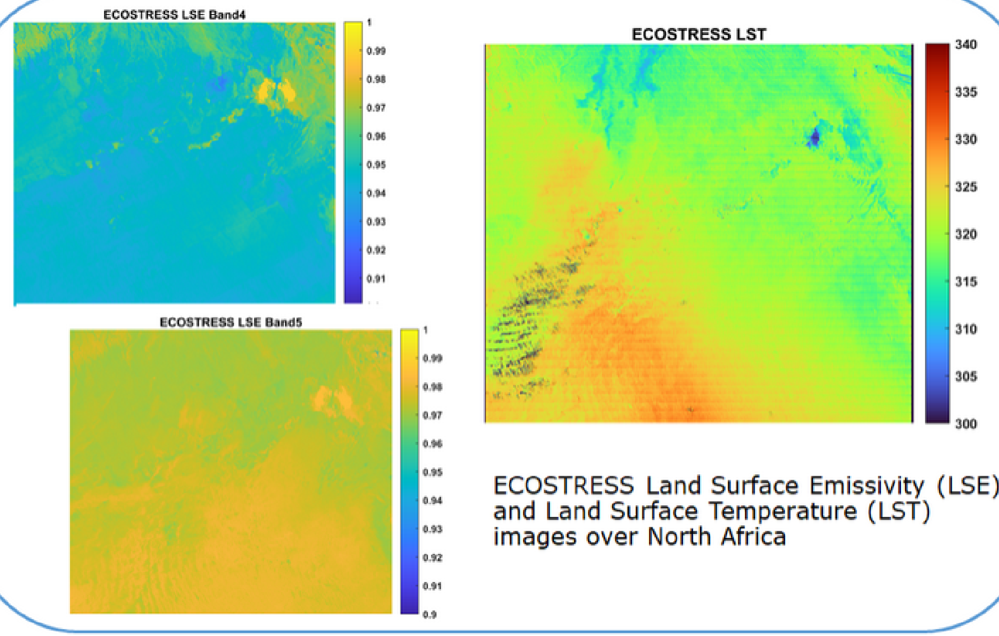

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How do we measure ET from LST?

- Empirical methods
- Single source models (SEBAL, METRIC and SEBS)
- Scatterplot-based methods (triangle and trapezoid)
- Two-source models (TSEB/ALEXI)

SEB Model Uncertainties

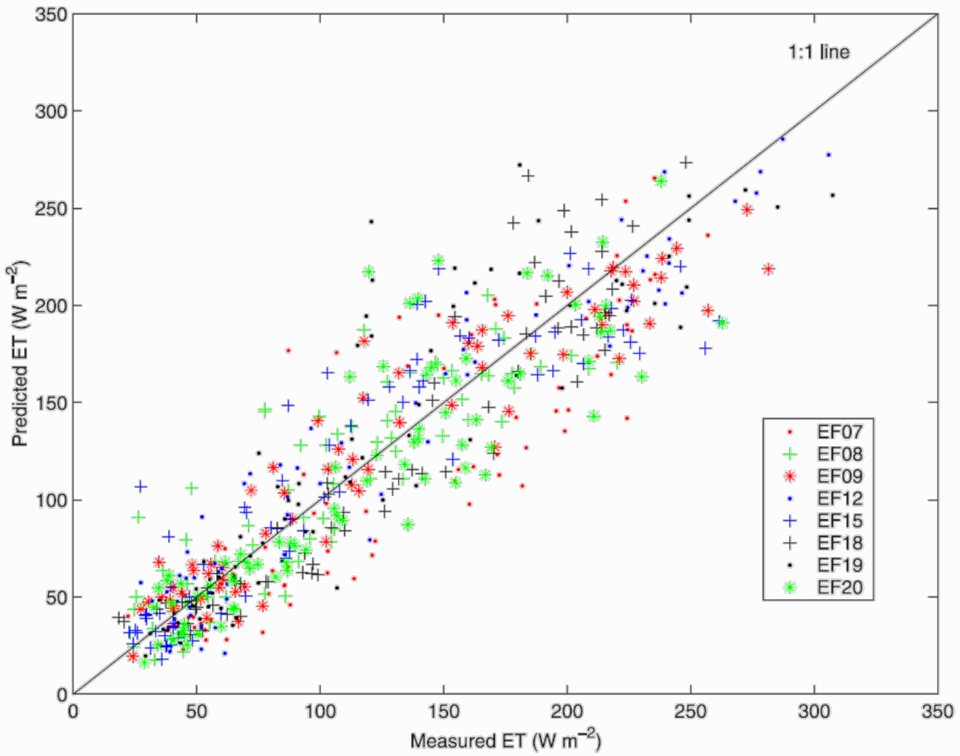
- Difficulties estimating $T_0 - T_a$
  - LST sensitive to water vapor
  - Surface is not a perfect black body
  - Atmospheric correction
  - Spatial heterogeneity
- Transport Coefficient (r_a)
  - Highly sensitive to canopy conditions and the canopy itself
- One-time satellite overpass
  - Evaporative fraction

Empirical Methods

Early methods used linear relationships between ET and $T_0 - T_a$. R_N was used to normalize the relationship. Later methods incorporated VIs such as NDVI and EVI:

$$LE = R_N \cdot (a_0 + a_1 \cdot VI + a_2 \cdot LST)$$

a_0 = intercept and $a_{1,2}$ = slope coefficients



Wang, K., Wang P., Li Z., Cribb M., and Sparrow M. 2007. A simple method to estimate actual evapotranspiration from a combination of net radiation, vegetation index, and temperature. Journal of Geophysical Research 112: D15107, doi:10.1029/2006JD008351.

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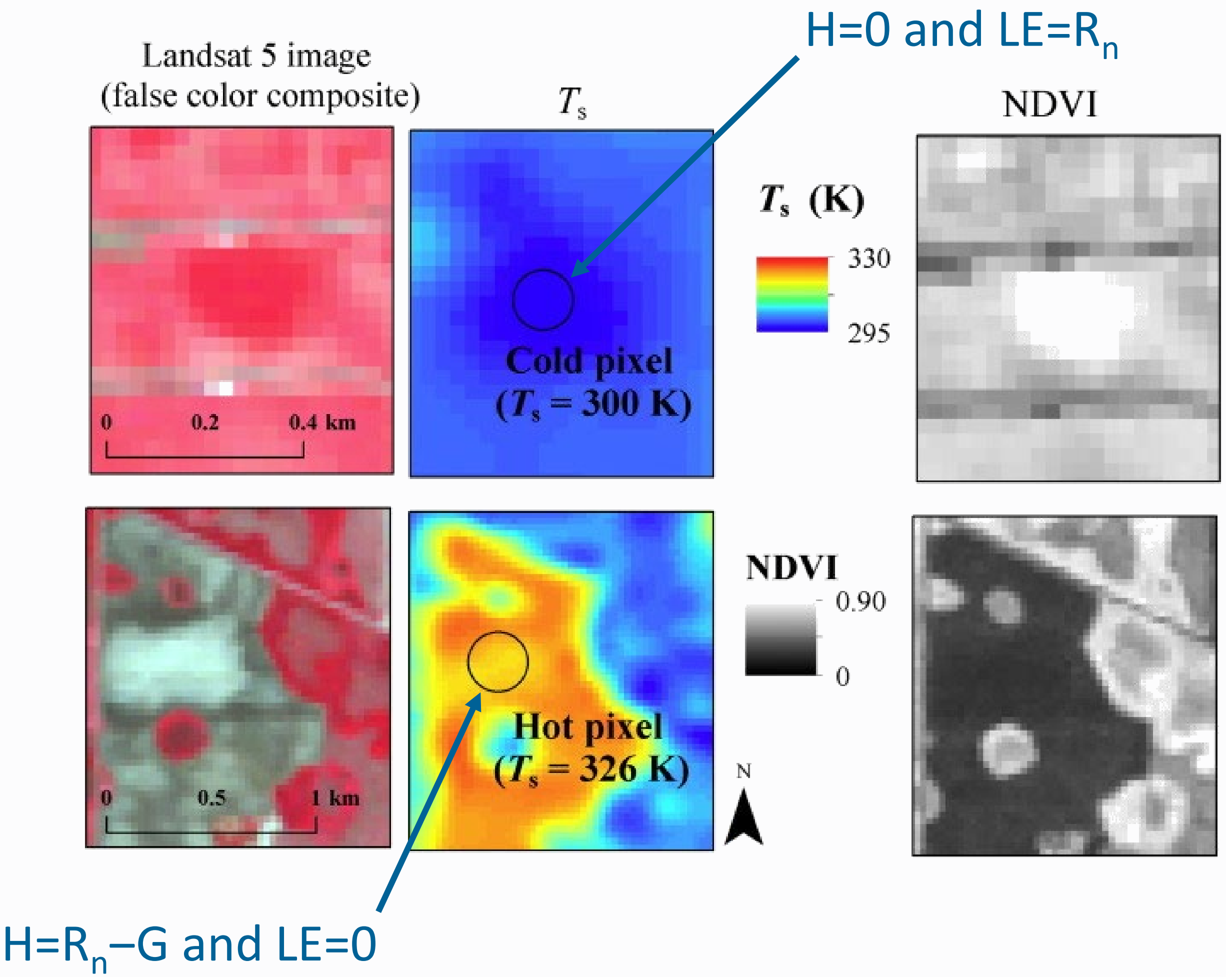
Each address SEB approach limitations

Single Source Models

- Appropriate for high resolution (~30m) imagery
- Assumes soil and vegetation are one source
- Self calibrate for T_0 and T_a
- Still requires r_a
- Evaporative fraction still a problem

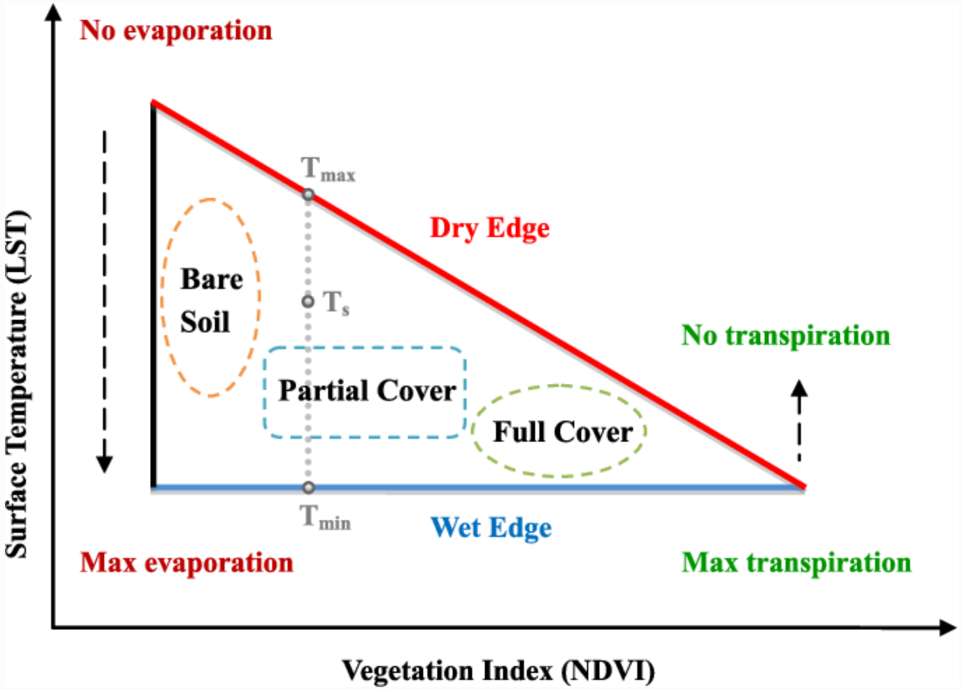


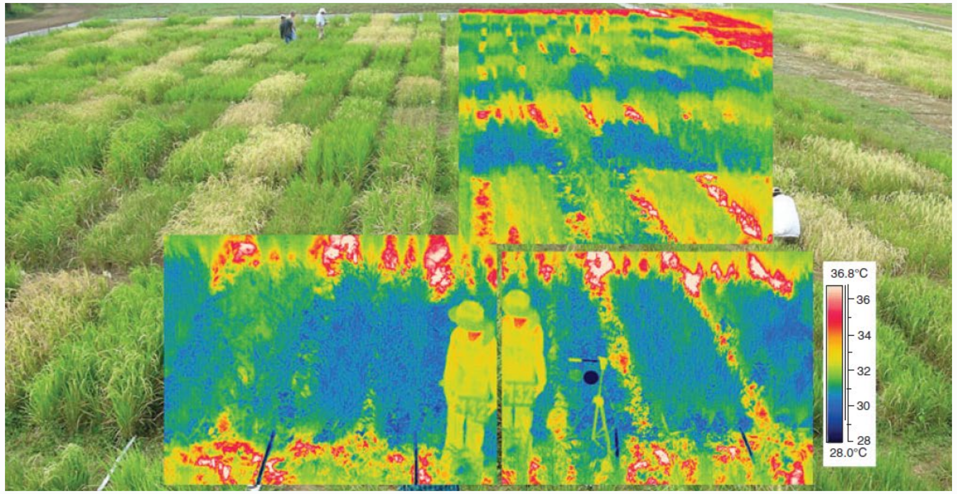
Bastiaanssen, W. 2000. SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. Journal of Hydrology 229: 87-100.

Scatterplot-Based Methods

NDVI-LST Feature Space

- Triangle (LST)
- Trapezoid (LST & T_a)
- Position in feature space determines evaporative fraction
- Soil moisture a limiting factor?
- Cloud contamination
- Edges determined from image
  - Spatial heterogeneity

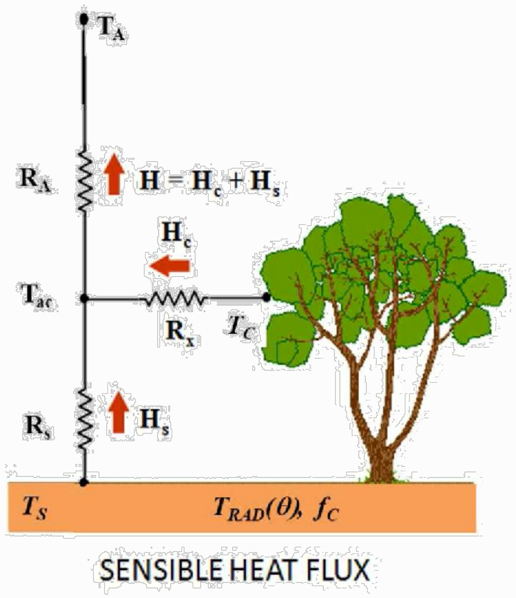




Moran, M., Clarke,T., Inoue, U., and Vidal, A. 1994. Estimating crop water deficit using the relation between surface-air temperature and spectral vegetation index. Remote Sensing of Environment 49: 246–263.

Two-source Models

- Coarse resolution
  - DisALEXI
- Soil and vegetation are considered separately
  - Vegetation determined from potential evapotranspiration
  - Soil determined from T_0 and T_a
- Still requires r_a
- Geostationary weather satellites



System, soil, canopy budgets

$R_n = H + \lambda E + G$

$R_{n,s} = H_S + \lambda E_S + G$

$R_{n,c} = H_C + \lambda E_C$

Two-source approximation

$T_{RAD}(\theta)^4 \sim f_C(\theta)\, T_C^4 + [1-f_C(\theta)]\, T_S^4$

Temperature constraint

$H_C, H_S, R_{n,c}, R_{n,s}, G$

PT, PM or LUE R_C model

λE_C

Residual

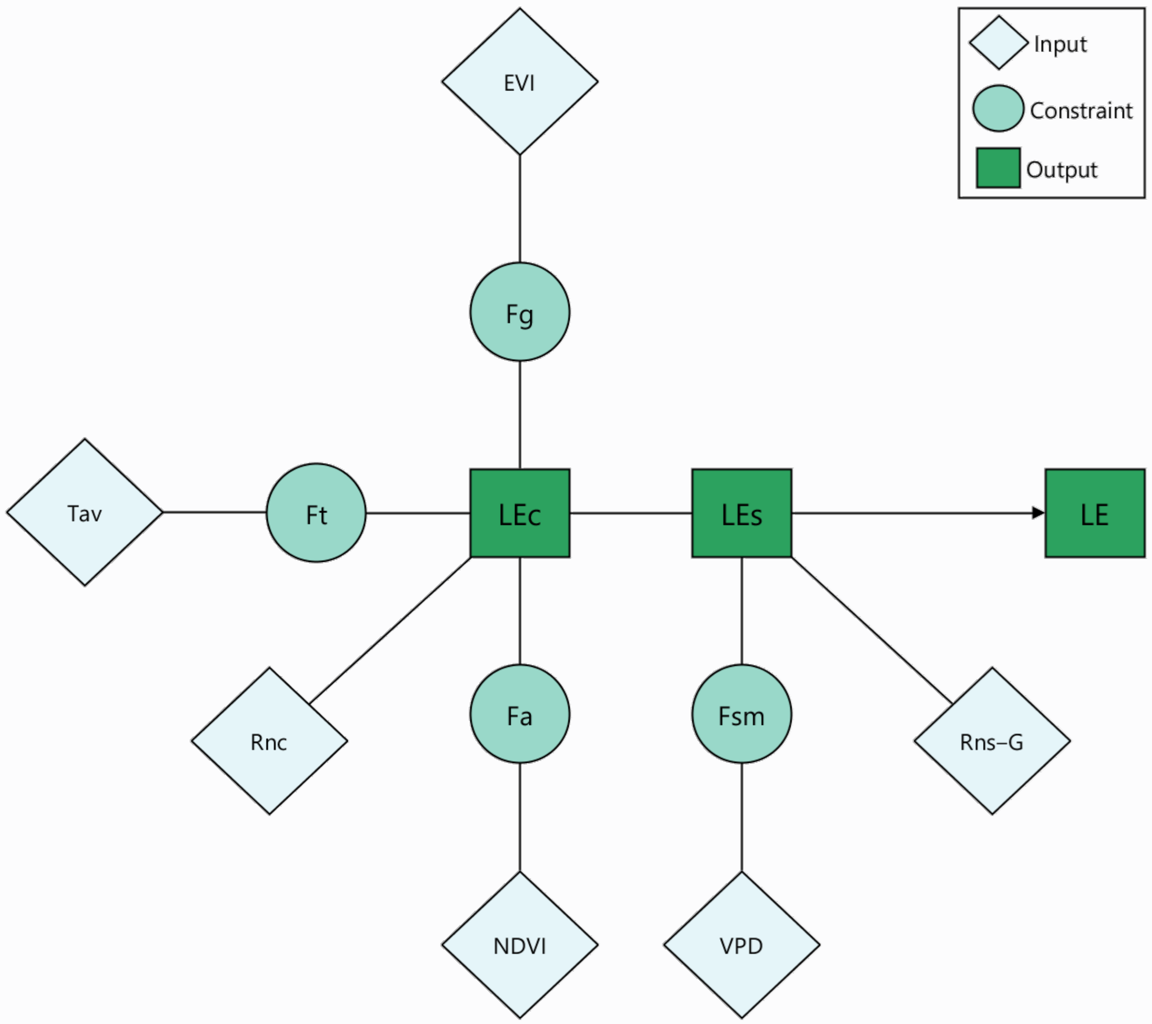
$\lambda E_S = R_n - H - G - \lambda E_C$

Norman, J.,Kustas,W., and Humes, K. 1995. A two-source approach for estimating soil and vegetation energy fluxes in observations of directional radiometric surface temperature. Agriculture and Forest Meteorology 77: 263–293.

Other Methods to Measure ET

- Empirical crop coefficient (FAO-56)
- Direct ET (PT-JPL, MOD16)
- Water-balance (hydrologic or SVAT models)

Non-Thermal Approach (PT-JPL)



Fisher, J.B., Tu, K.P., and Baldocchi, D., 2008. Global estimates of the land–atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites. Remote Sensing of Environment 112: 901-919.

ECOSTRESS

« May 2024 »

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News

NASA Climate Change Research
Apr 23, 2024

26. NASA Maps Key Heat Wave Differences in Southern California
Aug 22, 2023

Dr. Helen Poulos uses

Welcome to ECOSTRESS

Get ECOSTRESS Data Now

Announcement, Save the Date: **ECOSTRESS Science and Applications Team Meeting** that will be held at Jet Propulsion Laboratory, Pasadena, California, October 2 - 3. which will be hybrid. An optional pre-meeting workshop on Tuesday, October 1st (in person only) pending interest. Please fill out this form to indicate if you are interested in the workshop.

News Flash: ECOSTRESS has received approval for operations through FY2026 with potential continued operations until FY2029, subject to a successful 2026 Senior Review!

News Flash: ECOSTRESS has now acquired over 440,000 scenes (after In Orbit Checkout)

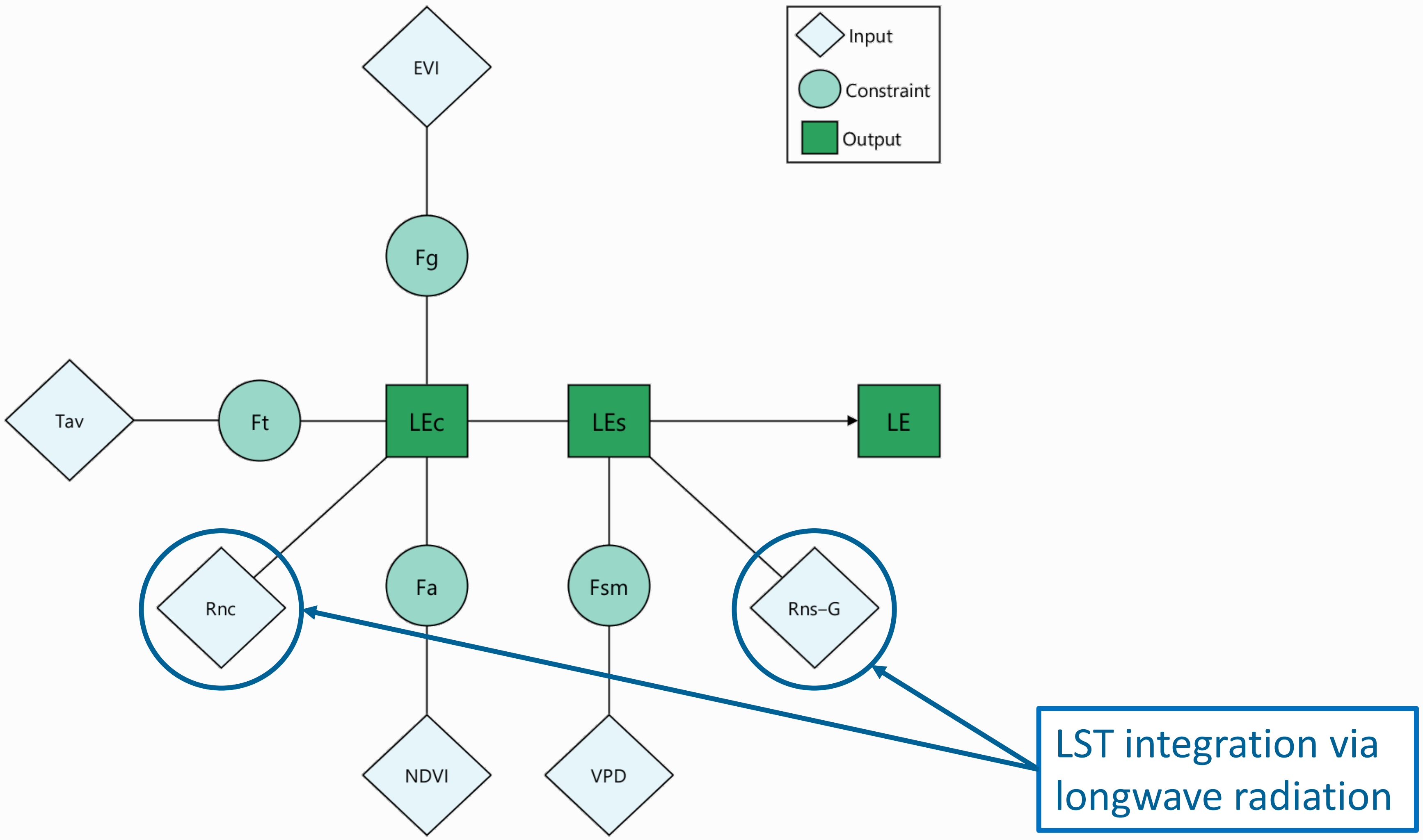
Announcement, Save the Date: "2024 IEEE International Geoscience and Remote Sensing Symposium" - IGARSS 2024 in Athens, Greece on July 7 - 12

ECOSTRESS is addressing three overarching science questions:

- How is the terrestrial biosphere responding to changes in water availability?
- How do changes in diurnal vegetation water stress impact the global carbon cycle?
- Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation?

The ECOSTRESS mission is answering these questions by accurately measuring the temperature of plants. Plants regulate their temperature by releasing water through tiny pores on their leaves called stomata. If they have sufficient water they can maintain their temperature, but if there is insufficient water, their

ECOSTRESS Approach (PT-JPL)



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Concluding Remarks

- Thermal infrared imagery is widely used for evapotranspiration
  - Drought monitoring
  - Irrigated agriculture
- Evapotranspiration links the surface to the atmosphere
- SEB models all loosely based on LST-NDVI
- "Warmer" drier surfaces (bare) tend to radiate more sensible heat
- "Cooler" wetter surfaces (vegetated) tend to emit more latent heat
- Opportunity for non-thermal approach: hyperspectral remote sensing

Questions