

climate change initiative

→ LAND SURFACE TEMPERATURE

Water Stress and Diurnal Asymmetry of ET, LST, and Conductance Coupled with GPP-SIF Suppression: Insights from CCI-LST Geostationary Observations

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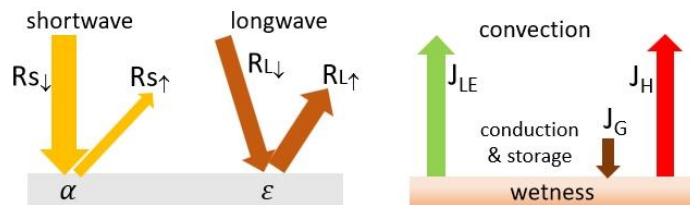
land surface
temperature
cci



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Surface energy balance: LST-ET physical connection



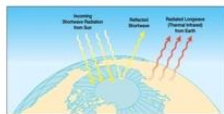
Radiation balance

Energy balance

$$J_N = (R_{S\downarrow} - R_{S\uparrow} + \epsilon_s R_{L\downarrow}) - R_{L\uparrow}$$

$$J_N = J_{\downarrow} - R_{L\uparrow}$$

$$R_{L\uparrow} = f\{T_{LST}^4\}$$



$$J_{LE} = [\text{evaporation}] [J_E] + [\text{transpiration}] [J_T]$$

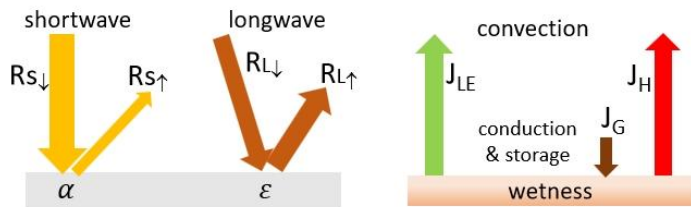
$$J_H = \text{sensible heat flux}$$

$$J_G = \text{Ground heat flux}$$





Surface energy balance: LST-ET physical connection



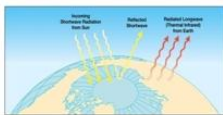
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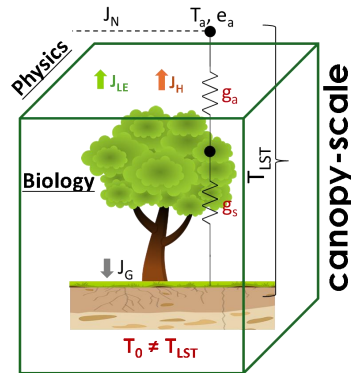
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Covariation

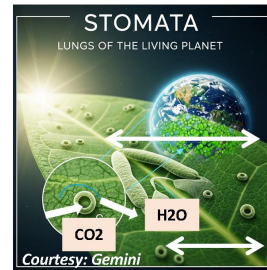
$$f\{T_{LST}^4\} = J_{\downarrow} - \rho c_p k \frac{g_a g_{cs}}{g_a + g_{cs}} (e_0^* - e_a) - J_H - J_G$$

Non-linear feedback



$$J_{LE} = \rho c_p k \frac{g_a g_{cs}}{g_a + g_{cs}} (e_0^* - e_a)$$

leaf-scale



$$J_T = \rho c_p k g_s (\Delta e)$$



$$J_{LE} = [\text{evaporation}] [J_E] + [\text{transpiration}] [J_T]$$

$$J_H = \text{sensible heat flux}$$

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T_0 : aerodynamic temperature, e_0 : aerodynamic vapor pressure, e_0^* : saturation aerodynamic vapor pressure, g_a : aerodynamic conductance, g_s : canopy-surface conductance, ρ : density of air; γ : psychrometric constant; c_p : specific heat of air at constant pressure



Diurnal ET asymmetry, role of water stress



Energy-limited

J_N dominant

$$g_s \rightarrow g_a;$$

$$g_s/g_a \rightarrow 1$$



Water-limited

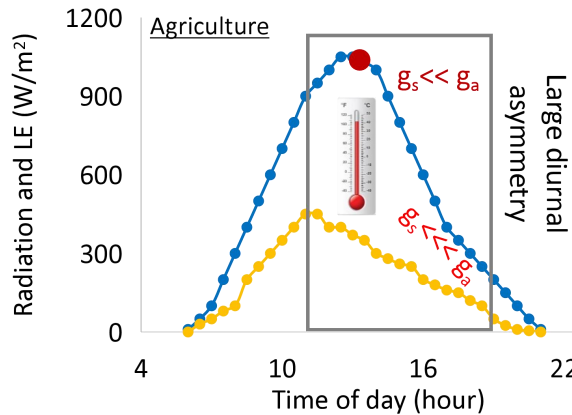
J_N , T_{LST} , & D_a dominant

$$g_s \ll g_a;$$

$$g_s/g_a \rightarrow 0$$



$$ET_{PM} = \frac{s(J_N - J_G)}{s + \gamma \left\{ 1 + \left(\frac{g_a}{g_s} \right) \right\}} + \frac{\rho c_P g_a D_a}{s + \gamma \left\{ 1 + \left(\frac{g_a}{g_s} \right) \right\}}$$





Diurnal ET asymmetry, role of water stress



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J_N dominant

$$\begin{aligned} g_s &\rightarrow g_a; \\ g_s/g_a &\rightarrow 1 \end{aligned}$$



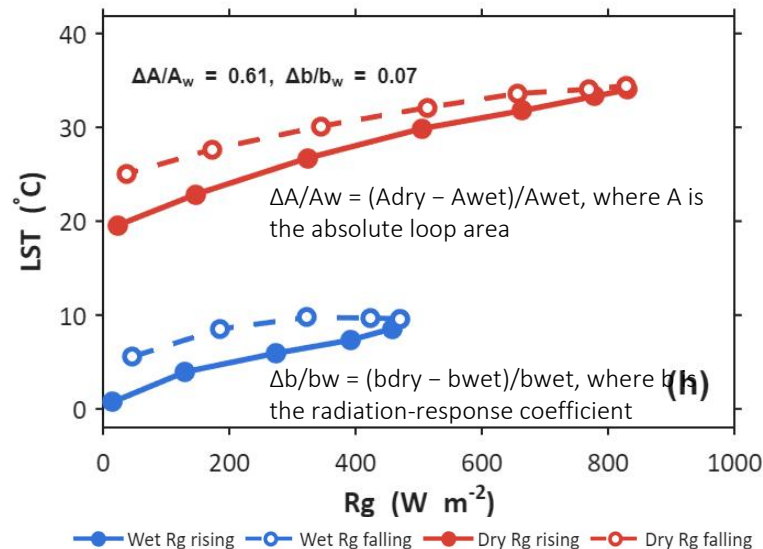
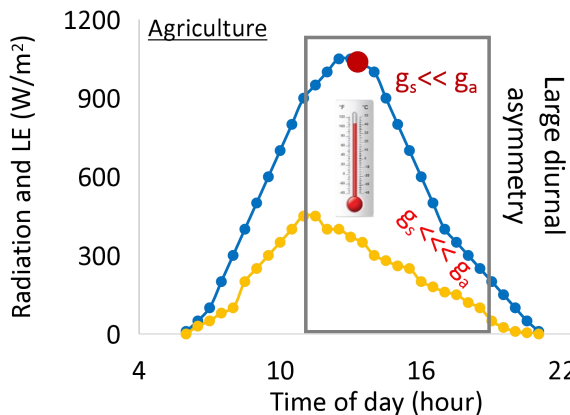
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$$Y(t) = A + B[R_g(t)] + C[dR_g/dt]$$

+ $\Delta A/A_w$: stronger dry-month hysteresis relative to the wet month.

Camuffo–Bernardi (1982)

+ $\Delta b/bw$: enhanced dry-month radiation response of LST





Diurnal ET asymmetry, role of water stress



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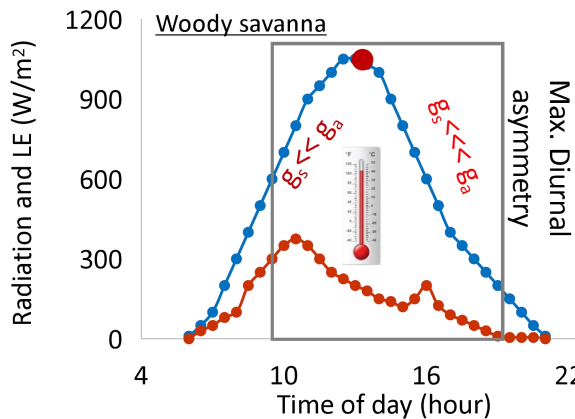
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Diurnal ET asymmetry, role of water stress



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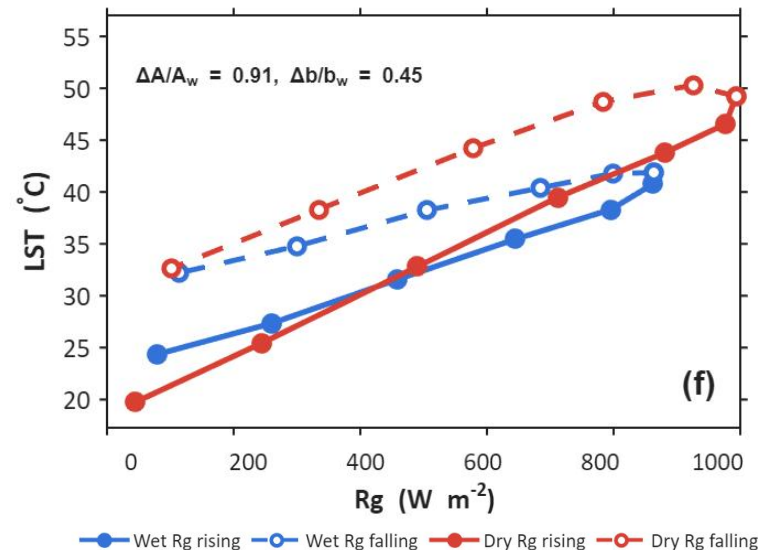
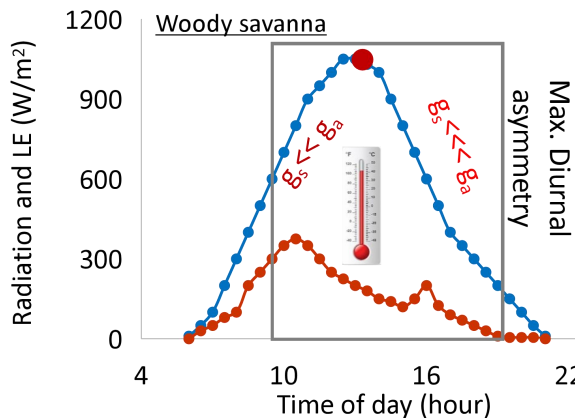
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Research questions



- What is the diurnal response pattern of ET to LST and radiation
- How stomatal mediation impacts diurnal ET response to water stress between biomes?
- Is GPP-SIF suppression coupled with stomatal conductance suppression due to water stress?

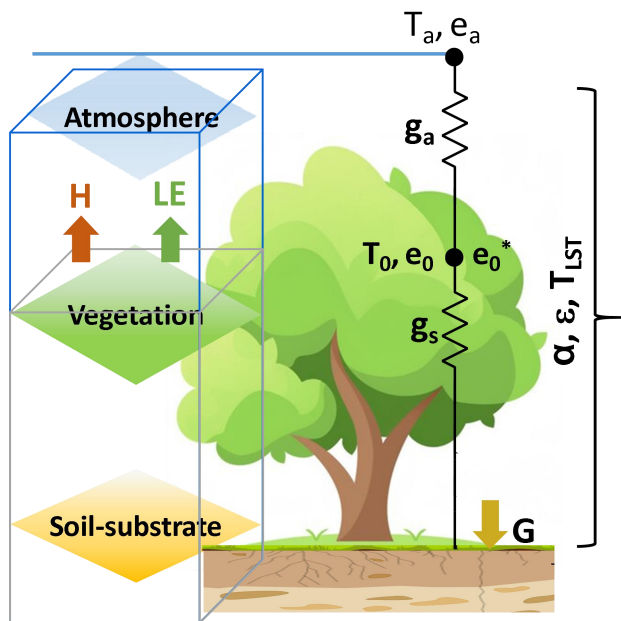




Model: Surface Temperature Initiated Closure (STIC)



$$J_N = R_N - G = LE + H$$



- Fully analytical SEB model; no calibration
- LST integration in the Penman-Monteith equation
- ‘Closed-form’ equations of surface and aerodynamic conductance
- Eliminated need for roughness length characterization as needed in thermal based ET models

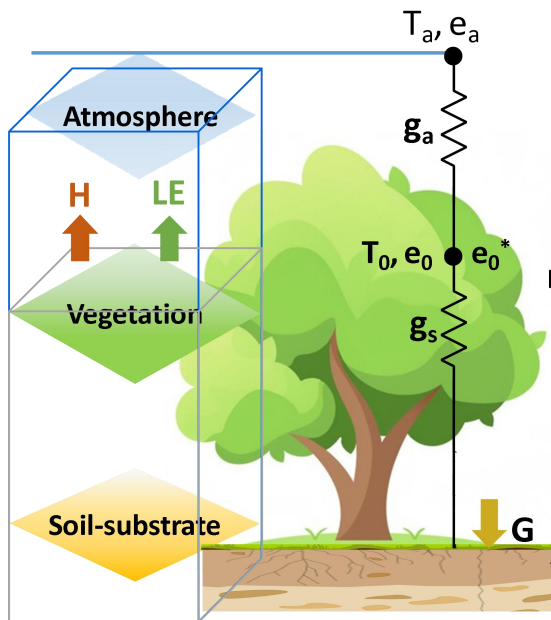
What we can measure?	What we cannot measure/observed?
LST, emissivity, albedo, surface reflectance, LAI, NDVI, veg. cover	conductances (g_x)
Radiation, air temperature, humidity	Aerodynamic temperature and vapor pressures (T_0) (e_0 , e_0^*)



Model: Surface Temperature Initiated Closure (STIC)



$$J_N = R_N - G = LE + H$$



$$H = \rho c_p g_a (T_0 - T_a)$$

$$LE = \frac{\rho c_p}{\gamma} g_a (e_0 - e_a) \\ = \frac{\rho c_p}{\gamma} g_s (e_0^* - e_0)$$

$$\frac{1 - F_E}{F_E} = \frac{\gamma (T_0 - T_a)}{(e_0 - e_a)}$$

Complementary relationship
theory: LE , LE_p^* , LE_{pt}^*

STIC1.4 (TRISHNA version)

$$[g_a, g_s, T_0, F_E] = \\ f\{SW_{\downarrow}, SW_{\uparrow}, LW_{\downarrow}, T_a, D_a, \varepsilon_{LW}, \\ \rho_{RGB/NIR/SWIR}, \\ LAI, f_c, I_{SM}(LST), e_0, e_0^*\}$$

$SW_{\downarrow}$: downwelling shortwave radiation

$SW_{\uparrow}$: reflected shortwave radiation

$LW_{\downarrow}$: downwelling longwave radiation

ε_{LW} : longwave emissivity

$\rho_{RGB/NIR/SWIR}$: surface reflectances

LAI: leaf area index

f_c : fractional veg. cover

I_{SM} : Soil moisture Stress Index

T_a : air temperature

D_a : vapor pressure deficit

F_E : evaporative fraction



Method of diurnal asymmetry analysis



$$\text{Diurnal centroid } (C_F) = \frac{\sum V(t) \cdot t}{\sum V(t)}$$

Time-weighted center (center of mass) of a diurnal cycle.

t = time of observation (hour)

$V(t)$ = magnitude at that time

$$\text{Relative diurnal centroid } (C_F^*) = C_F - C_{ref}$$

timing shift between two processes; compares the timing of one process relative to another reference process

C_F = centroid of target variable

C_{ref} = centroid of reference variable

Under water stress:

- ET often shifts earlier
- afternoon stomatal closure occurs
- centroid moves toward morning

Centroid timing is a strong indicator of stress, hysteresis, ecohydrological regulation.





Data used

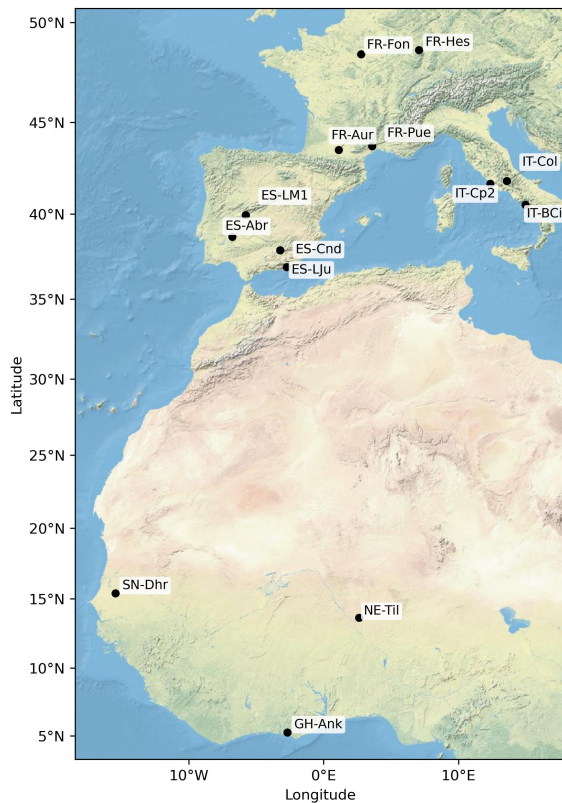


Data	Variable	Spatial Resolution	Temporal Resolution	Usage	References
CCI (MSG-SEVIRI)	LST	0.05 °	Hourly	STIC input	Pérez-Planells et al. (2023)
MCD43A3	Albedo	500 m	Daily	STIC input	Schaaf et al. (2021)
MOD21	Emissivity	1 km	Daily	STIC input	Hulley et al. (2012)
MOD15A2H	LAI	500 m	8-day	STIC input	Myneni et al. (2015)
ERA5-Land	Air temperature	0.1 °	Hourly	STIC input	Muñoz-Sabater et al. (2021)
ERA5-Land	Dewpoint Temp.	0.1 °	Hourly	STIC input	Muñoz-Sabater et al. (2021)
ERA5-Land	Solar radiation	0.1 °	Hourly	STIC input	Muñoz-Sabater et al. (2021)
CGLS	Soil moisture	0.1 °	Daily	Drought analysis	Bauer-Marschallinger et al. (2018)
FLUXCOM	GPP	0.08 °	Monthly	Drought analysis	Jung et al. (2019)
GOSIF	SIF	0.05 °	Monthly	Drought analysis	Li & Xiao (2019)
CSIF	SIF	0.05 °	Monthly	Drought analysis	Zhang et al. (2018)
TCSIF	SIF	0.5 °	Monthly	Drought analysis	Zou et al. (2024)





Site distribution

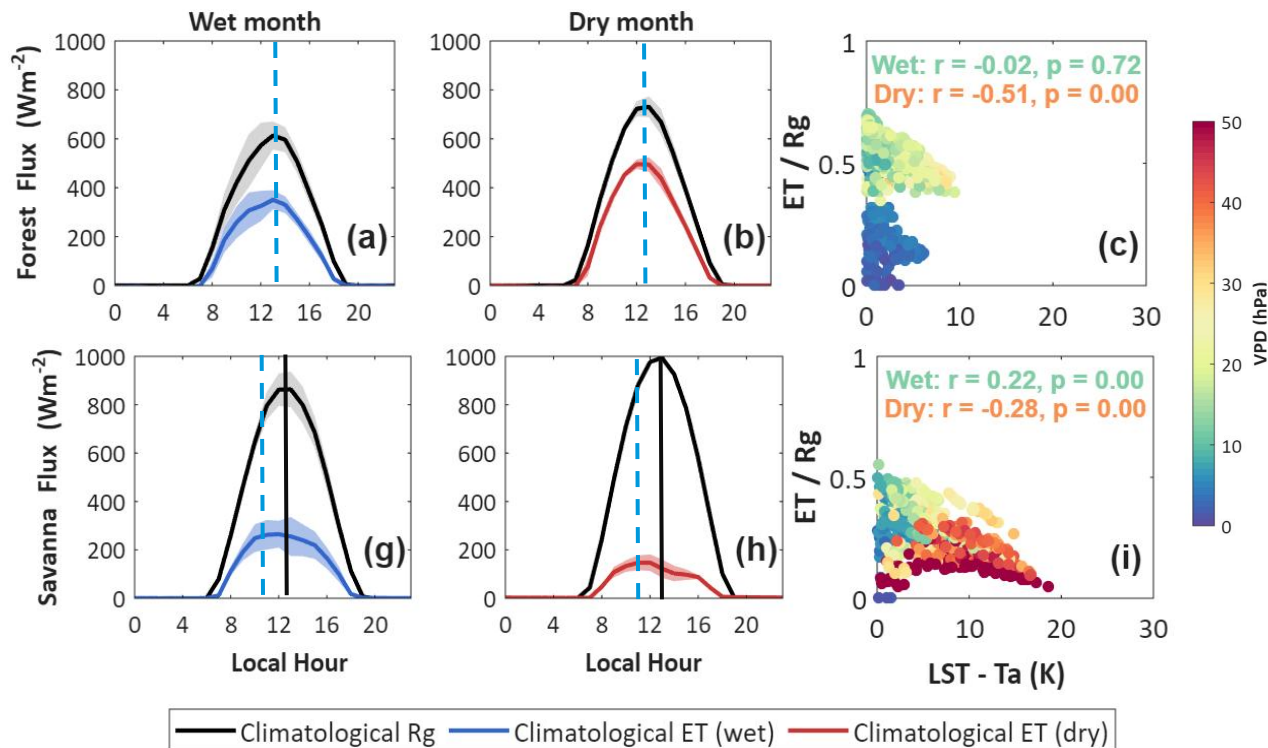


new_id	SITE_ID	LOCATION	LAT	LONG	ELEV	IGBP	MAT	MAP	Start_Year	End_Year
1	GH-Ank	Ghana	5.268500	-2.694200	124	EBF	26.0	1900	2010	2015
2	SN-Dhr	Senegl	15.402800	-15.432200	40	SAV	29.0	404	2010	2015
3	NE-Til	Niger	13.644000	2.629900	300	SAV	NaN	400	2010	2015
4	ES-Lju	Llano de los Juanes	36.926600	-2.752100	1600	OSH	16.0	400	2004	2020
5	ES-Abr	La Albuera	38.701839	-6.785881	279	SAV	15.5	300	2015	2020
6	ES-Cnd	Conde	37.914997	-3.227659	370	WSH	15.8	474	2014	2020
7	ES-LM1	Majadas	39.942690	-5.778683	265	SAV	16.0	700	2014	2020
8	FR-Pue	Puechabon	43.741300	3.595700	270	EBF	13.5	883	2010	2015
9	FR-Fon	Fontainebleau-Barbeau	48.476357	2.780096	103	DBF	10.2	679	2005	2020
10	FR-Aur	Toulouse	43.549650	1.106103	250	CRO	13.1	667	2005	2020
11	FR-Hes	Hesse	48.674100	7.064650	300	DBF	10.0	900	2014	2020
12	IT-BCi	Borgo Cioffi	40.523700	14.957400	20	CRO	18.0	600	2010	2015
13	IT-Col	Collalongo	41.849400	13.588100	1560	DBF	6.3	1180	2010	2015
14	IT-Cp2	Castelporziano	41.704300	12.357300	19	EBF	15.2	805	2010	2015





Diurnal response of ET to LST and radiation

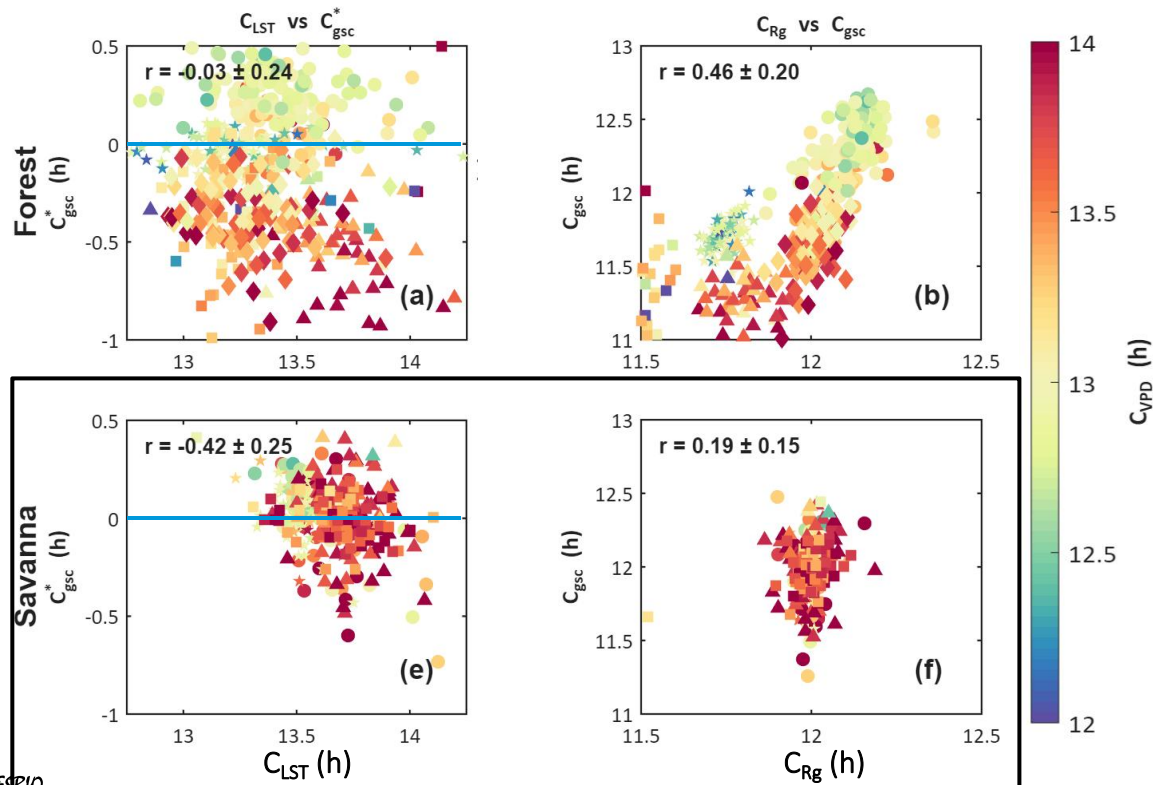


- Symmetrical diurnal pattern between ET and radiation in forest
- Profound diurnal asymmetry between ET and radiation in savanna; **morning skewed ET both seasons**
- $\downarrow \text{ET/Rg}$ with $\uparrow \text{LST-Ta}$ and atmospheric dryness (high VPD) in savanna





Physiological explanation: Why diurnal response of ET differs between biomes?



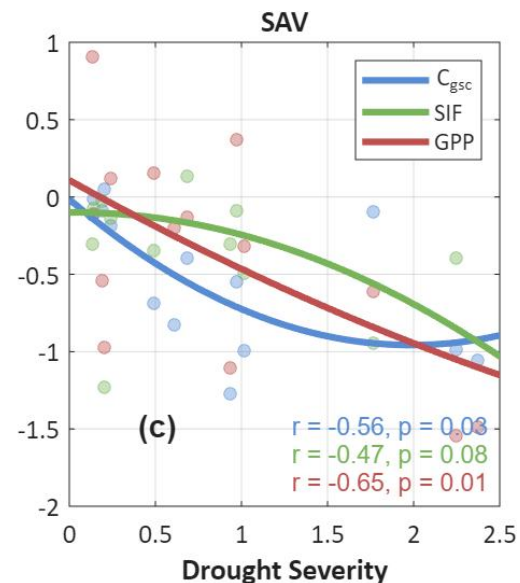
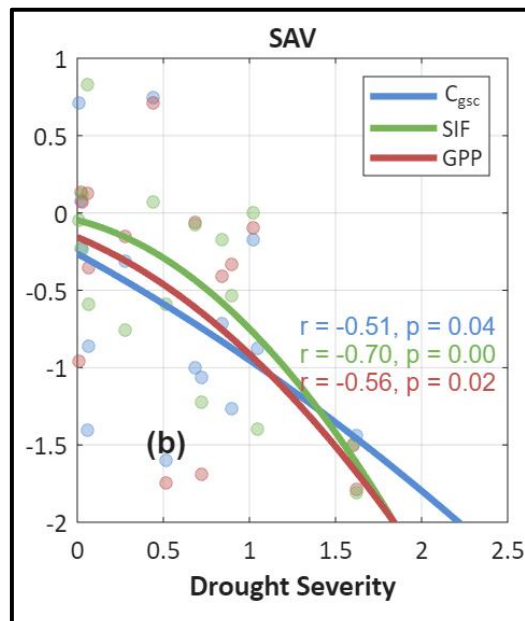
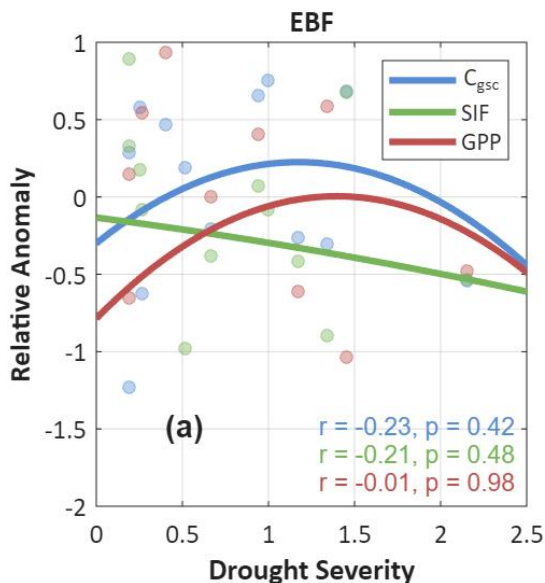
$$C_{gsc}^* = C_{gsc} - C_{LST}$$

Forest: low LST-Ta magnitude offsets the effects of maximum afternoon VPD on stomatal conductance; **stomatal** responds more to radiation

Savanna: $\uparrow$ LST-Ta & $\uparrow$ VPD; max LST and VPD time nearly coincides; substantial impact on stomatal conductance; **stomata** responds more to LST than radiation



Is GPP-SIF suppression coupled with stomatal conductance suppression in Savanna?

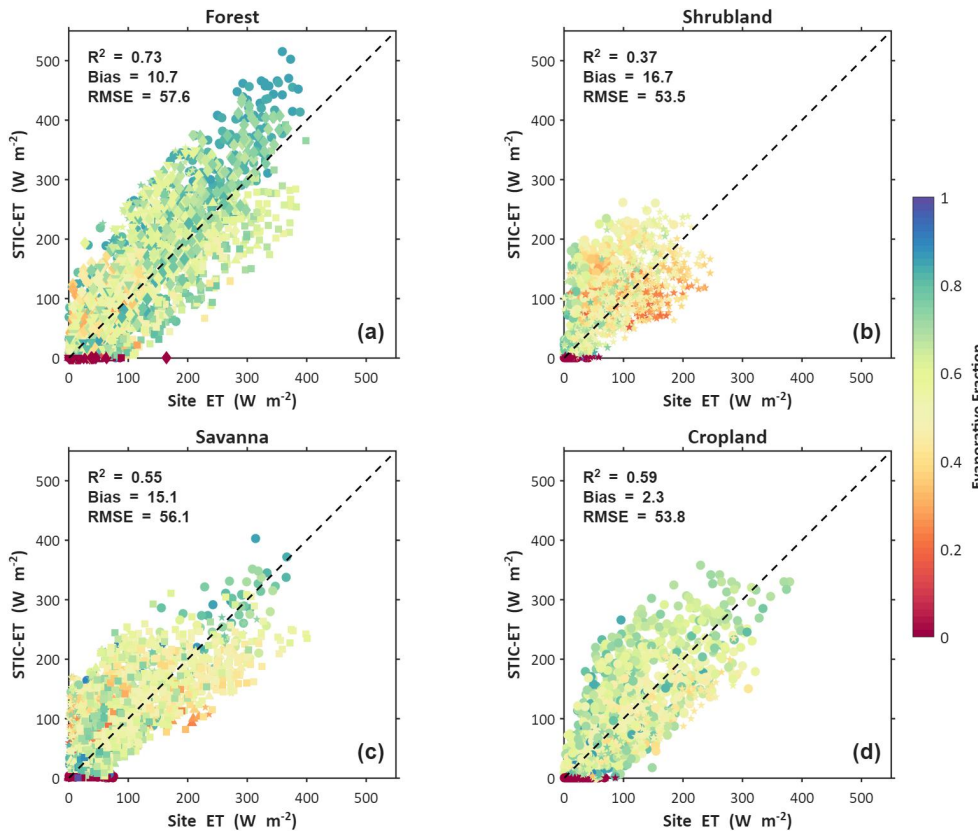


- Savanna: all three factors (C_{gsc} , GPP, and SIF) decline with increasing drought severity; distinct trajectories
- GPP suppression closely followed stomatal anomaly
- decline in photochemical efficiency, increase in non-photochemical quenching (NPQ) and reducing fluorescence yield for SIF drop takes time





To conclude:



- Soil water stress is the strongest driver of the morning skewed ET and gsc in water-scarce environments than atmospheric demand alone.
- Sharper sensitivity of gsc and GPP to soil moisture deficits compared to SIF
- **Thermal remote sensing** estimates of stomatal conductance are a physically grounded and temporally responsive indicator of drought onset.
- **Land surface temperature** and centroid timing metrics reveal **physiological regulation**





Thank you



STIC1.3 version to be decommissioned by summer 2026

Advanced versions of STIC 1.X[STIC1.4; STIC1.5] [TRISHNA version] and STIC2.0 (two-source SES) to be released



European Space Agency