EGU26-4422, updated on 13 Jun 2026
https://doi.org/10.5194/egusphere-egu26-4422
EGU General Assembly 2026

From ecosystem stress to circulation response: biophysical feedbacks during dry–hot compound extremes

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Dry–hot compound events exert strong and nonlinear impacts on terrestrial ecosystems, with consequences that extend through land–atmosphere feedbacks across scales. This presentation provides an overview of biophysical vegetation–atmosphere feedbacks during dry–hot compound events, highlighting recent research that shows how processes from ecosystem to circulation scales shape the evolution and predictability of these events.

At the ecosystem level, concurrent drought and heat rapidly impair vegetation functioning. Satellite-based indicators of plant physiology show that functional responses to dry–hot stress occur within days, well before structural degradation becomes detectable. This rapid response marks the loss of ecosystem evaporative regulation and sets the conditions for local land–atmosphere feedbacks to emerge. Stomatal closure triggered by rainfall scarcity and high vapour pressure deficit shifts the partitioning of available energy toward sensible heating, while subsequent changes in vegetation structure modify surface albedo and aerodynamic roughness. Together, these processes alter near-surface temperature and humidity, enhance boundary-layer growth, and affect atmospheric stability and cloud formation. These feedbacks operate on diurnal time scales and lead to the self-intensification of dry–hot compound conditions, particularly in regions where vegetation strongly controls surface energy and water fluxes.

As dry–hot conditions persist, these biophysical feedbacks can propagate beyond the local boundary layer and influence atmospheric processes at larger spatial scales. Vegetation-mediated anomalies in sensible and latent heat fluxes modify boundary-layer depth, entrainment, and thermodynamic structure, affecting mesoscale circulation and the advection of heat and moisture. Reduced evaporation lowers atmospheric humidity and precipitation efficiency downwind, allowing dry–hot anomalies to extend beyond their region of origin. These processes favour the spatial organization, persistence, and propagation of dry–hot extremes, especially in transitional and semi-arid regions where land–atmosphere coupling is strong and soil moisture constraints are pronounced. When widespread, coherent surface anomalies can also influence synoptic circulation by modifying diabatic heating patterns and land–sea thermal contrasts, affecting the positioning and persistence of high-pressure systems. Through these cross-scale interactions, ecosystem stress aggravates dry–hot regimes and reinforces coupling between ecosystem dynamics and atmospheric circulation.

Despite growing evidence that vegetation actively modulates dry–hot extremes, major challenges remain. These include disentangling bidirectional causality between ecosystems and the atmosphere, constraining ecosystem influences on atmospheric circulation, and understanding how ecosystem heterogeneity and biodiversity modulate feedback strength. Addressing these challenges is essential to improve vegetation–atmosphere coupling in current forecasting systems and to enhance the predictability of dry–hot compound extremes under ongoing climate change.