Detecting soil moisture drought impacts on ecosystem physiology from earth observation data

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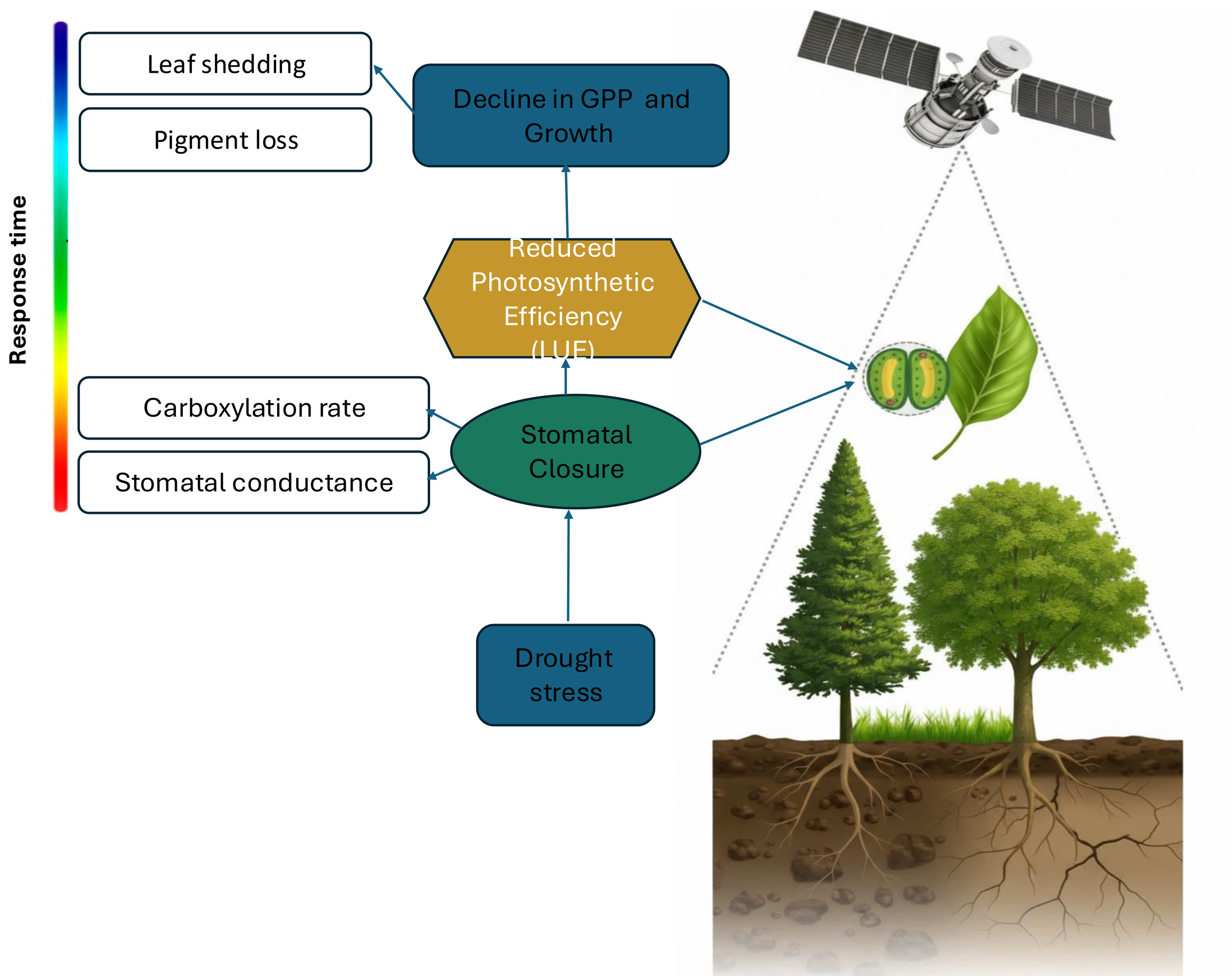
Background

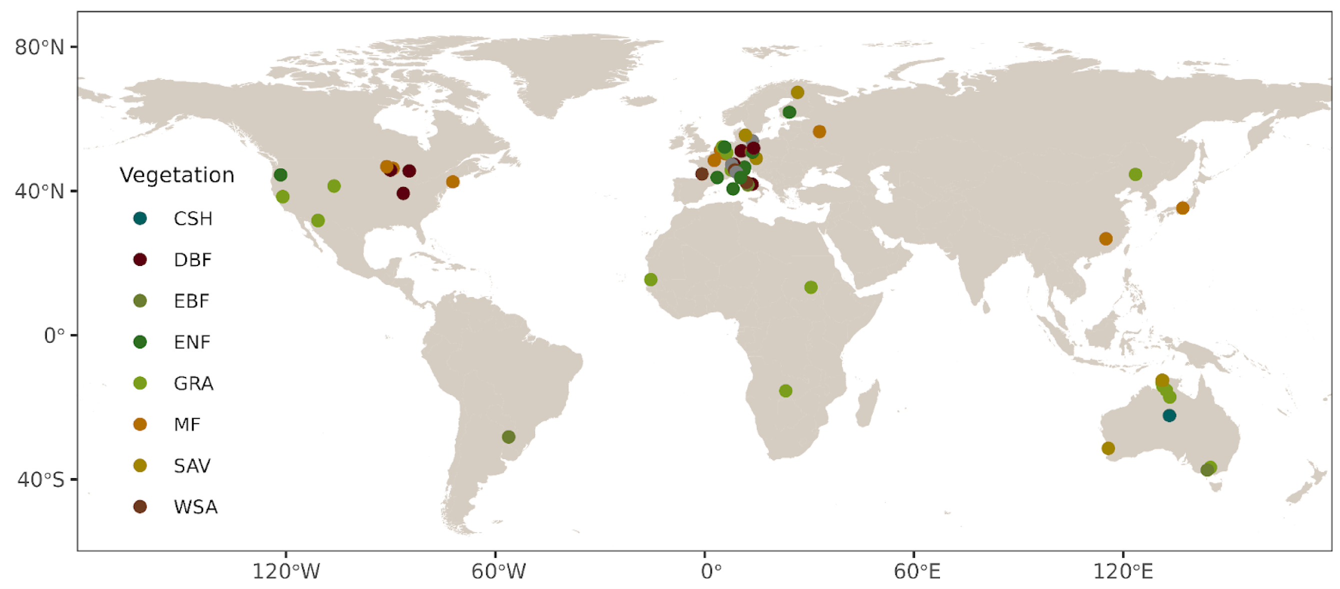
- Key physiological traits (e.g., Vcmax, stomatal conductance) respond more rapidly to environmental stress than structural traits, but are mostly measured at site level and poorly captured at large scales.
- Remote sensing indicators (SIF, PRI, microwave) provide direct insights into vegetation physiological responses, yet are limited by coarse resolution, coverage, and reliance on narrow-band sensors.

☑ Develop an Earth observation approach integrating spectral, thermal, and meteorological data to detect early drought stress before changes in canopy greenness appear.

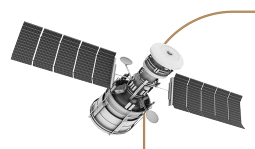


Methods

Dataset : Time series of fractional decline in ecosystem-level LUE caused by soil moisture stress (**fLUE**) for 69 sites and years covered in the FLUXNET2015 dataset . It was estimated by **Stocker et al., (2018)*** using artificial neural networks trained on eddy covariance data, multiple soil moisture datasets, and remotely sensed greenness indices, and it isolates the physiological response from structural canopy changes.



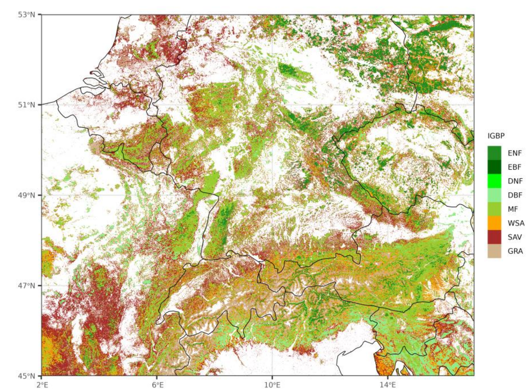
Fractional reduction in LUE due to soil moisture (fLUE)



- **MODIS-derived variables** (nadir reflectance bands and land surface temperature, LST)
- **ERA5-Land climate variables** (2 m air temperature, surface solar radiation) and **derived potential cumulative water deficit (PCWD)**
- **Land cover classification**
- **Normalized difference spectral indices**

Model training Random Forest

Predicted fLUE (fLUE*)



Comparison against normalized difference vegetation index (NDVI) across Central Europe during two summer drought events (the severe drought of 2018 and the mild drought of 2020).

Results

fLUE model beyond spectral data

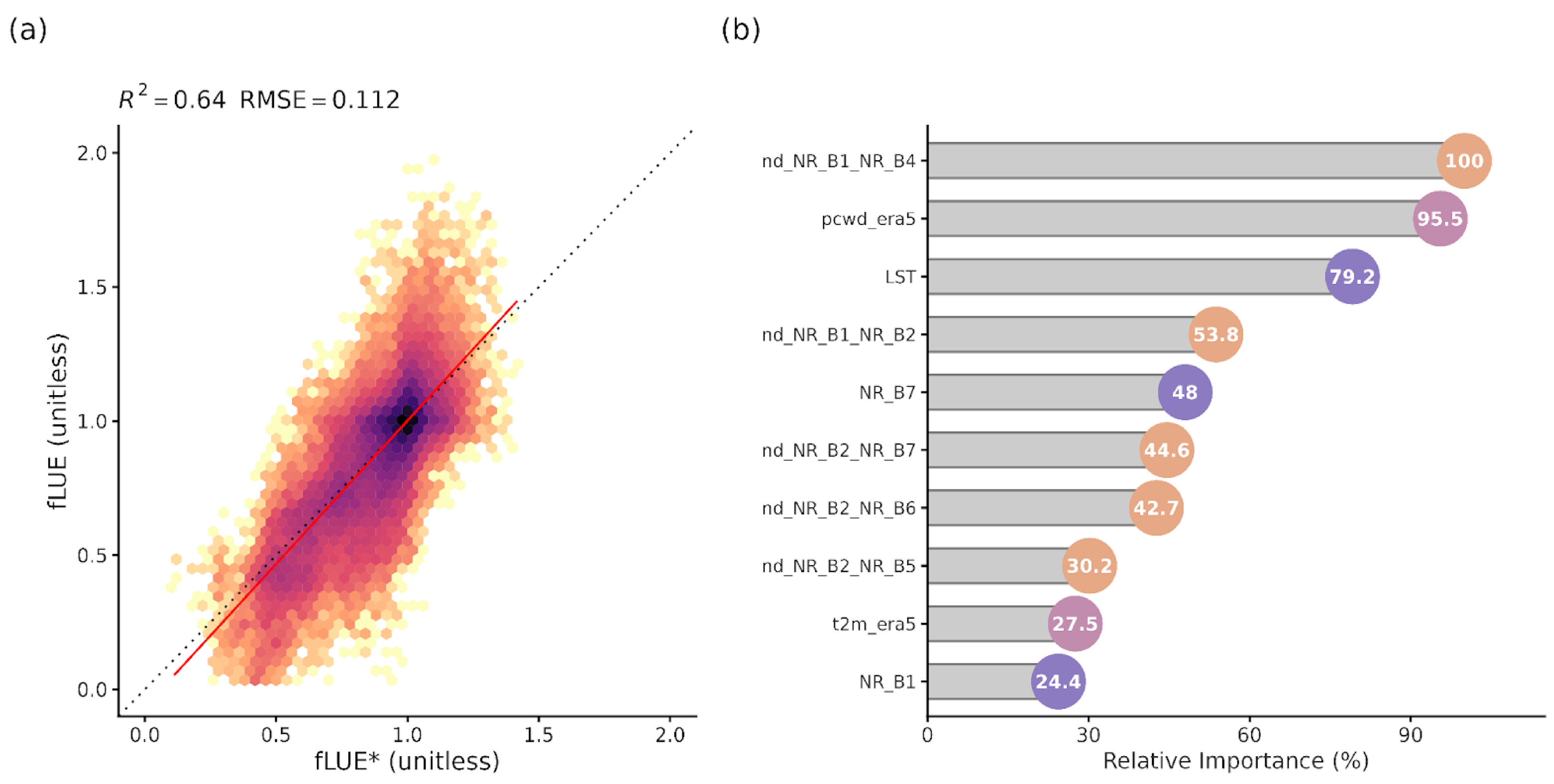


Fig. 1. Regression model (a) and VIP for fLUE prediction using Earth Observation data (b). The prediction performance metrics are quantified on pooled data from predictions for individual held-out sites of each cross-validation folds.

Clearest advantage of fLUE* in evergreen forests

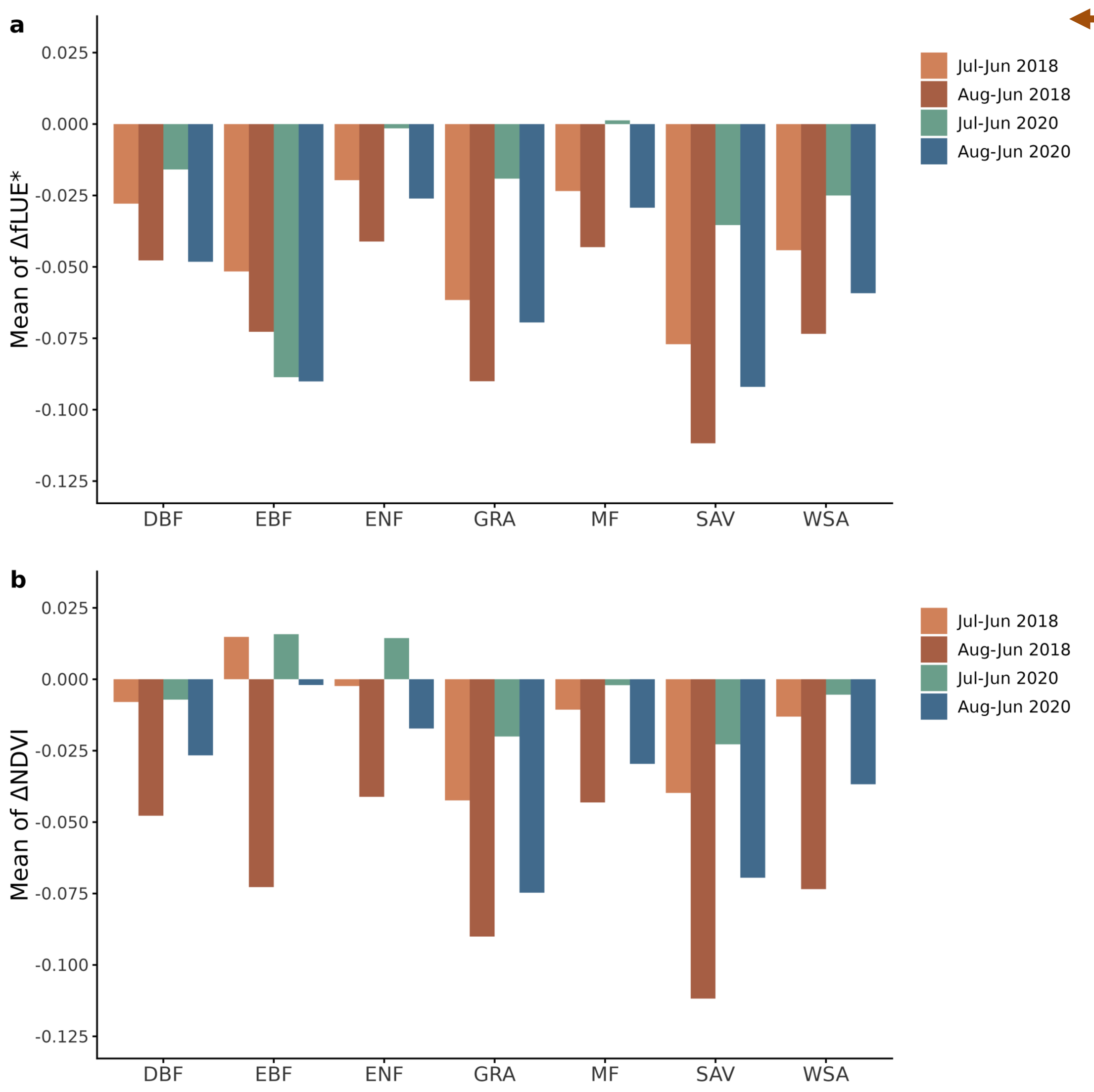


Fig. 3. Changes in fLUE* (a), NDVI (b) for each vegetation type during the summers of 2018 and 2020, comparing July vs. June values and August vs. June values. Values are averages over areas covered by each type.

Spatial aggregation by vegetation type

__Fig. 1 :__ Our model does not rely solely on spectral or thermal information but integrates meteorological drivers of drought, capturing the causal link between atmospheric forcing and physiological response.

__Fig. 2:__ fLUE* exhibits a stronger decline over summer months than NDVI. This is most clearly expressed during the **early drought phase (July)**, where fLUE* records widespread and pronounced reductions (by >0.2 units) across northeastern France, central Germany, and the Netherlands (Panel a).

__Fig. 3:__ Spatial aggregation by vegetation type demonstrates that fLUE* is **more sensitive to drought than NDVI, particularly in evergreen ecosystems (ENF & EBF)** where structural signals are dampened (Panels b–d). This contrast in sensitivity is most pronounced under the relatively moist summer conditions of 2020.

Sensing early drought responses across Central Europe

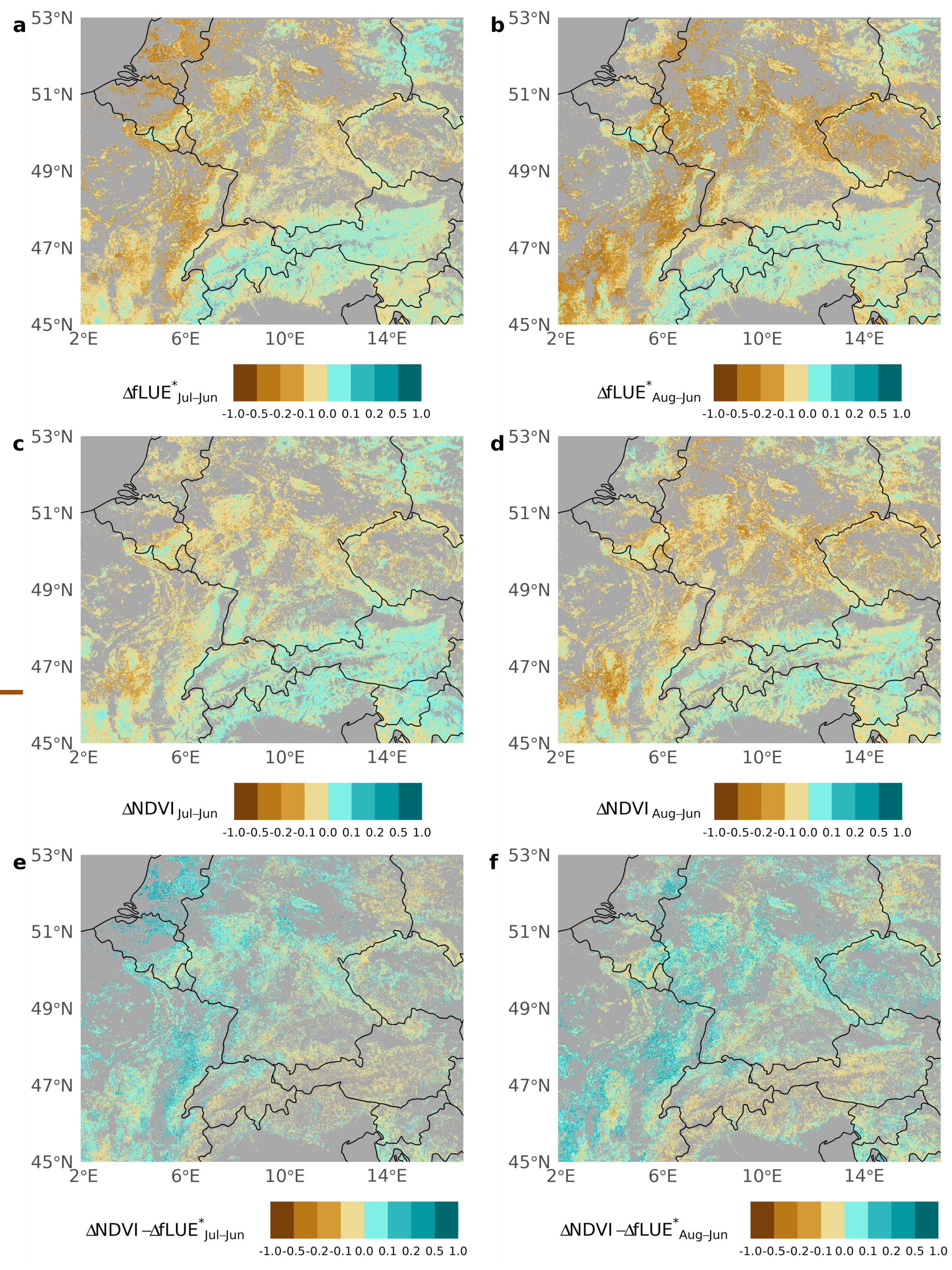


Fig. 2. Spatial patterns of changes in fLUE* and NDVI from June to July (a) and from June to August (b) of 2018. Changes in NDVI for the same periods are shown in (c) and (d), respectively. The difference between temporal changes recorded by NDVI vs. fLUE* for the periods June to July and June to August are shown in (e) and (f), respectively.

*Stocker, B D.,et al., 2019. Nature Geoscience 12 (4): 264–70. https://doi.org/10.1038/s41561-019-0318-6.