Detecting Early Drought Stress in Plants Using ECOSTRESS:

A Comparison with Field-Measured Water Potentials

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Abstract

Drought stress reduces crop yields, alters ecosystem function, and is expected to intensify with climate change. Early detection of drought stress in plants is critical because management actions are most effective before severe damage occurs. Traditional indicators such as leaf water potential are accurate but rely on intensive field sampling and often detect stress only after plants have already lost turgor. In this study I evaluate whether satellite measurements of evapotranspiration (ET) from the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) can detect plant drought stress and serve as an early warning indicator when compared with field measured leaf water potentials.

I paired ECOSTRESS ET data with predawn and mid day water potential measurements from the PSInet field network across woody plant species distributed globally. After spatially and temporally matching the datasets within a seven day window, I filtered observations to individual species at specific coordinate locations and used linear regression to test for relationships between ET and water potential. For most species, lower ET values were aligned with more negative water potentials, indicating increased drought stress. For mid day measurements, 9 of 26 species showed significant correlations between ET and water potential. For predawn, 7 of 28 species were significant. Representative species included Prunus dulcis ($R = 0.66$), Acer pseudoplatanus ($R = 0.99$), Fagus sylvatica ($R = 0.75$), Picea abies ($R = 0.71$), Pinus uncinata ($R = 0.84$), and Abies alba ($R = 0.78$). These patterns suggest that ECOSTRESS derived ET captures physiological responses to water limitation before damage is visible in the field.

My results demonstrate that ECOSTRESS ET has strong potential as a scalable and non-invasive

indicator of plant drought stress. By linking space based ET with ground based water potentials, this project helps bridge the gap between lab level precision and global monitoring, and it provides a framework for future work that could integrate ECOSTRESS with existing drought indices to support early warning systems for agriculture and ecosystems.

I. Introduction

Drought is one of the most damaging natural hazards for both agriculture and natural ecosystems. It develops when precipitation stays well below normal for an extended period and soil moisture declines, which reduces the water available to plants. Drought is often identified when indices such as the Standardized Precipitation Index or the Standardized Precipitation Evapotranspiration Index fall below about minus one for several months, indicating a statistically significant moisture deficit. At the plant level, water stress appears when the soil and atmosphere can no longer supply enough water to keep leaves hydrated, leading to declines in growth, photosynthesis, and eventually survival.

Plant water status is commonly quantified through leaf water potential, which reflects the energy status of water inside plant tissues. Water potential combines osmotic potential and turgor pressure, and more negative values indicate that plants must work harder to move water from soil to leaves. Direct measurements of water potential using a pressure chamber are accurate but time consuming and labor intensive. They are also limited to small field plots, which makes it difficult to monitor drought stress across entire regions or continents.

Remote sensing offers a way to monitor plant water stress at much larger scales. One key variable is evapotranspiration, the combined flux of water vapor from soil evaporation and plant transpiration. When water is plentiful, evapotranspiration is high because stomata stay open and plants lose water while taking up carbon dioxide. Under drought, plants close stomata to conserve water, which reduces evapotranspiration. Satellites that measure land surface temperature and radiation can estimate evapotranspiration and how it changes through time. If satellite evapotranspiration responds strongly to early physiological changes in plants, it could function as an early warning signal for drought stress.

ECOSTRESS is a NASA Earth Venture Instrument mounted on the International Space Station that measures land surface temperature at high spatial and temporal resolution. From these data, ECOSTRESS also provides estimates of evapotranspiration and the Evaporative Stress Index. Recent work has suggested that ECOSTRESS can detect shifts in plant water use during heatwaves and drought, but there are few direct comparisons with field measured water potentials. My project addresses this gap by asking whether ECOSTRESS derived evapotranspiration can detect early drought stress in plants before critical drops in water potential occur.

The central research question is: To what extent can ECOSTRESS detect early warning signs of drought stress before plant water potential drops critically? By pairing satellite evapotranspiration with ground based water potential across many species and locations, I test whether ECOSTRESS can provide a reliable and scalable indicator of plant drought stress.

II. Background and Research Gap

Many studies have shown that remote sensing can support drought monitoring at regional and global scales. Satellite based indices that combine precipitation, temperature, and vegetation response have been used to track drought onset and recovery in croplands and forests. Recent work has also used hyperspectral imaging and photosystem measurements to detect drought stress in crops before visible wilting, which emphasizes the importance of early physiological signals.

Despite these advances, several gaps remain. Much of the early detection research has been conducted in controlled environments or small experimental plots. Future work has been encouraged to bridge the gap between laboratory precision and field scale monitoring by using portable, high throughput phenotyping tools such as drones and machine learning image analysis. Remote sensing frameworks for drought monitoring often focus on broad indices and yield, but they have not been fully validated across plant growth stages and functional types when compared to standard drought measures.

ECOSTRESS provides a unique opportunity to address both gaps. It measures land surface temperature and evapotranspiration globally at the scale of individual fields, and it overpasses at varying times of day, capturing both midday and early morning conditions. However, few studies have directly compared ECOSTRESS evapotranspiration with in situ plant water potential across species and biomes. Without this link, it is difficult to interpret ECOSTRESS signals in terms of actual plant stress or to evaluate its potential as an early warning tool.

My project builds on previous ECOSTRESS research by explicitly pairing ECOSTRESS derived evapotranspiration with ground based water potential measurements from the PSInet network. By analyzing these paired datasets across multiple species, I test whether reductions in evapotranspiration measured from space align with more negative water potentials in the field and whether these relationships differ between predawn and midday measurements. This direct comparison helps fill the gap between physiological measurements and satellite observations.

III. Materials and Methods

This project is a retrospective observational study that uses existing satellite and field datasets. The analysis focuses on woody plant species for which both ECOSTRESS evapotranspiration and PSInet leaf water potential measurements were available.

ECOSTRESS data. I obtained Level 3 evapotranspiration products from ECOSTRESS for dates and coordinates that matched PSInet field sites. ECOSTRESS is mounted on the International Space Station and uses a thermal radiometer to retrieve land surface temperature, which is then used in an energy balance model to estimate evapotranspiration at approximately 70 meter spatial resolution. Each evapotranspiration product includes quality flags that I used to screen for cloud free, high quality pixels.

PSInet water potential data. PSInet, the Plant Stress Integrative Network, is a global dataset of plant water potential measurements collected by field researchers using pressure chambers. For each measurement, the dataset includes species identity, leaf water potential in megapascals, measurement type (predawn or midday), date, and geographic coordinates. Water potential values near zero megapascals indicate well watered plants, whereas more negative values indicate increasing drought stress.

Data matching and filtering. For each water potential measurement, I searched for ECOSTRESS evapotranspiration observations within a seven day window before or after the field measurement date. I identified the ECOSTRESS pixel that contained the PSInet site coordinates and retained only sites where the surrounding pixel neighborhood corresponded to the same general land cover type reported for the field site. I removed ECOSTRESS observations with low quality flags and excluded water potential measurements that lacked clear predawn or midday labels. I then grouped matched observations by species and by site and retained only species with at least ten matched evapotranspiration and water potential pairs for either predawn or midday.

Variables and definitions. For each matched observation I recorded ECOSTRESS evapotranspiration in millimeters per day, leaf water potential in megapascals, species identity and functional type, and measurement type. In this study, plant drought stress is defined as sub optimal water availability that limits plant growth and function.

Statistical analysis. I conducted all analyses in Python. For each species and measurement time, I plotted scatterplots of evapotranspiration versus water potential and fit simple linear regression models of water potential as a function of evapotranspiration. I calculated Pearson correlation coefficients and associated p values. Relationships with p less than 0.05 were considered significant. Because water potential becomes more negative under drought while evapotranspiration typically declines, a positive correlation between evapotranspiration and water potential was interpreted as consistent with drought stress detection.

IV. Results

Across all sites and species, ECOSTRESS daily evapotranspiration (ET) tended to decrease as leaf water potential became more negative. In other words, plants that were more water stressed (more negative water potentials) usually showed lower ET from space, while plants with better water status had higher ET.

For midday measurements, I analyzed 26 species with enough paired ECOSTRESS ET and water potential data. Nine of these species showed statistically significant positive correlations between ET and midday water potential. In these cases, higher ET was linked to less negative water potentials, and lower ET was linked to more negative water potentials. For example, Prunus dulcis had a correlation coefficient of $R = 0.66$ and Acer pseudoplatanus had $R = 0.99$, which means changes in ET lined up very clearly with changes in water potential.

For predawn measurements, I analyzed 28 species. Seven species showed significant positive correlations between ET and predawn water potential. These relationships were usually weaker and more variable than midday, but still showed the same basic pattern. Fagus sylvatica had $R = 0.75$, Picea abies had $R = 0.71$, and Pinus uncinata had $R = 0.84$. In these species, lower ET was linked to more negative predawn water potentials, which means that even overnight water status was connected to the stress signal ECOSTRESS detected.

Relationships also varied by functional type. Some broadleaf species, like Acer pseudoplatanus and Fagus sylvatica, showed very tight patterns where points stayed close to the regression line. Some conifers, like Picea abies, showed more scatter, likely because deeper roots or different canopy structure add noise to the ET signal. Even with this variability, the significant correlations show that ECOSTRESS can still detect drought responses in both broadleaf and conifer species.

Site locations were spread across multiple continents, including North America, Europe, South America, Africa, and Australia. This global distribution means the matched ECOSTRESS and PSInet data covered a wide range of climates and ecosystems. The fact that similar ET–water potential patterns appeared across these regions suggests that the link between ET and plant water status is robust and not limited to a single biome.

To better understand how these patterns look at the site level, I focused on six species that represent different combinations of plant type and measurement time. Figures 1 to 4 show the paired ET and water potential values for each species, along with the regression line and correlation coefficient. In all six cases, higher ET is associated with less negative water potential, and lower ET is associated with more negative water potential, which supports the idea that ECOSTRESS ET can be used as an indicator of plant drought stress.

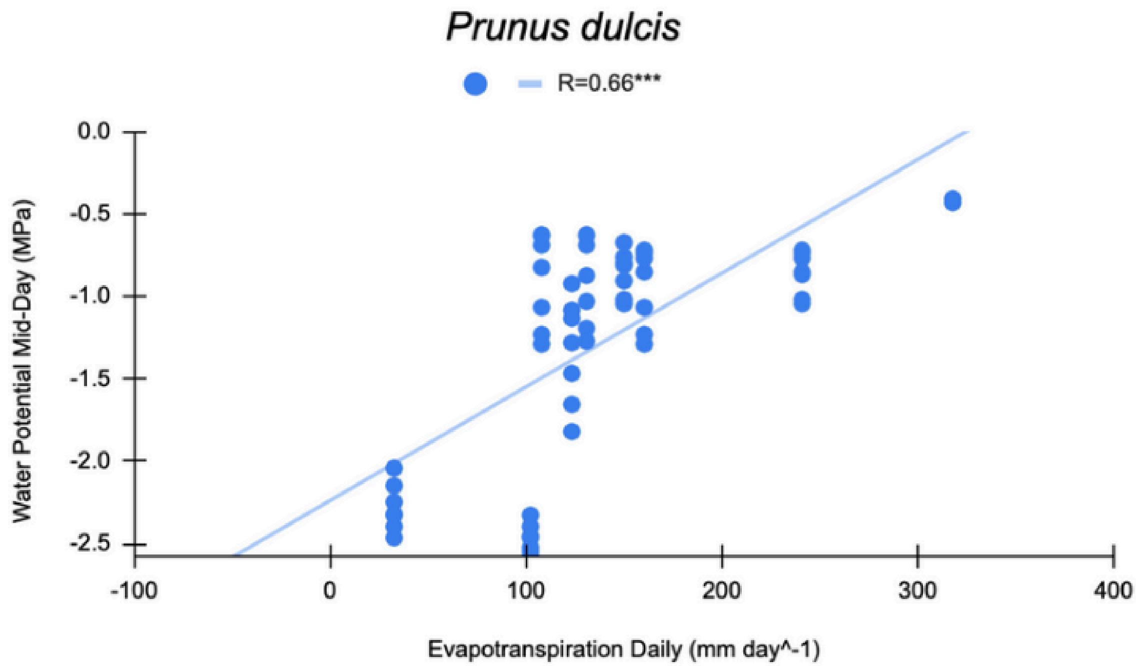

Figure 1. Prunus dulcis (almond)

This figure shows midday leaf water potential versus ECOSTRESS daily evapotranspiration for almonds. Trees with higher evapotranspiration stay around −1.0 MPa, while trees with low evapotranspiration drop below −2.0 MPa. The positive trend and R = 0.66 mean that almonds using more water from the soil keep a better water status.

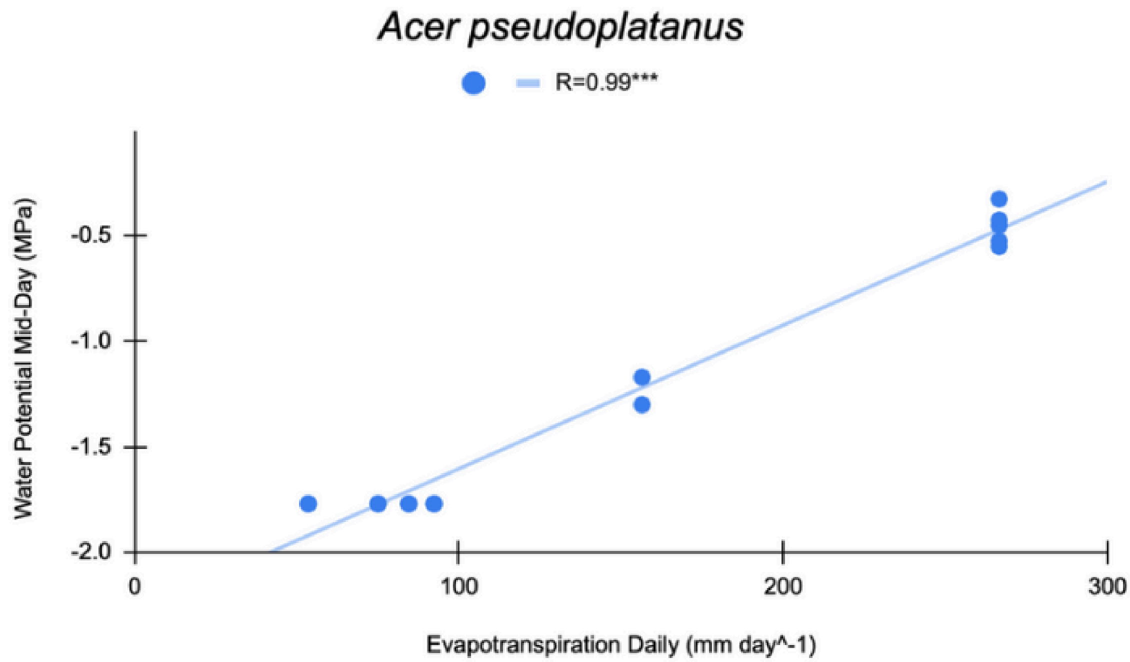

Figure 2. Acer pseudoplatanus (sycamore maple)

This figure shows midday water potential versus daily evapotranspiration for sycamore maple. The points fall close to the line and R = 0.99, which means evapotranspiration almost perfectly tracks water potential in this species. When evapotranspiration decreases, water potential becomes more negative, showing clear drought stress.

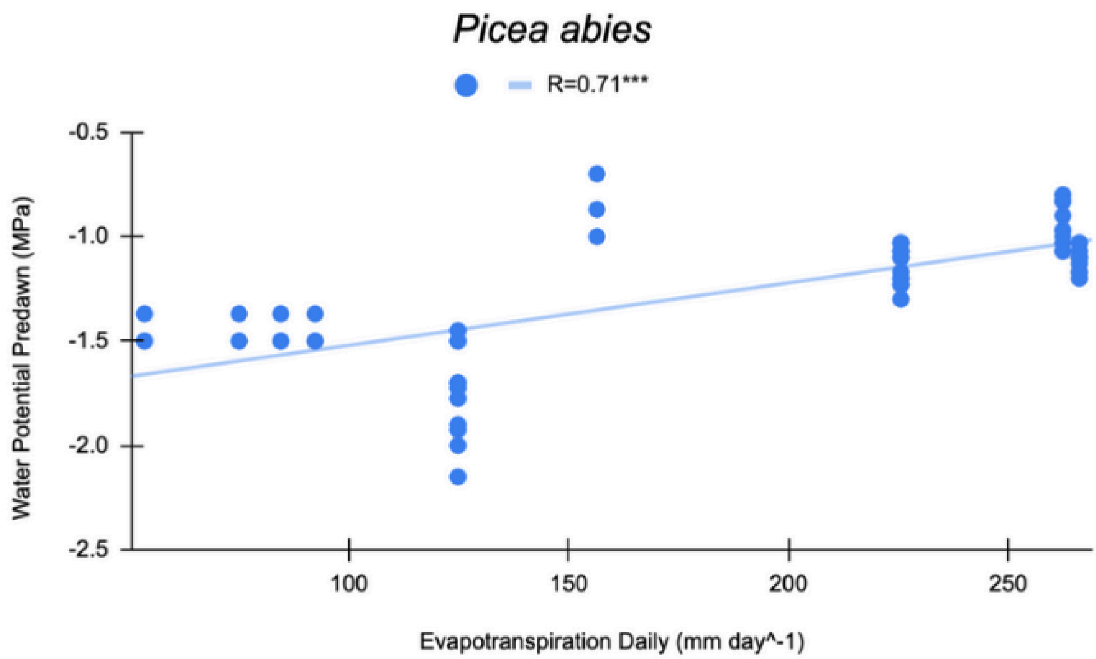

Figure 3. Picea abies (Norway spruce)

This figure shows predawn water potential versus daily evapotranspiration for Norway spruce. The relationship is more scattered, but stands with higher evapotranspiration still tend to have less negative water potentials. The significant correlation (R = 0.71) suggests that ECOSTRESS can detect drought responses in spruce even with more natural variability.

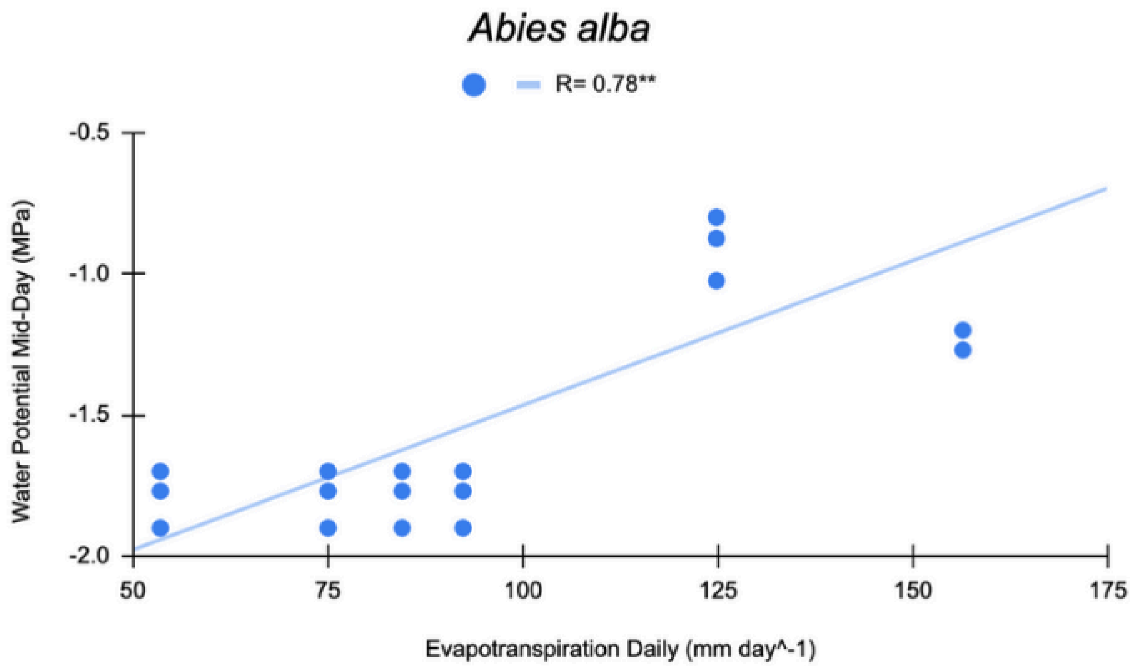

Figure 4. Abies alba (silver fir)

This figure shows midday water potential versus daily evapotranspiration for silver fir. Stands with high evapotranspiration stay near −1.0 MPa, but stands with low evapotranspiration move toward −2.0 MPa, which signals stronger drought stress. The correlation of R = 0.78 shows that ECOSTRESS evapotranspiration captures midday stress responses in this conifer.

V. Discussion

The significant positive correlations between ECOSTRESS evapotranspiration and leaf water potential in many species show that satellite derived evapotranspiration can track plant water status. When evapotranspiration was high, leaves tended to have less negative water potentials, which indicates adequate water supply and open stomata. When evapotranspiration declined, water potentials became more negative, signaling increased drought stress.

These results support the idea that ECOSTRESS can function as an early warning indicator of plant drought stress. In several species, evapotranspiration began to decrease while water potentials were still in the moderate stress range where leaves might not yet show visible wilting. This suggests that ECOSTRESS can detect changes in water use before severe physiological damage occurs. Because ECOSTRESS observes the land surface at high spatial resolution and at different times of day, it is well suited to capture rapid changes in plant activity during hot and dry periods.

The strength of evapotranspiration and water potential relationships varied across species. Some deciduous broadleaf trees showed strong and coherent relationships, while some conifers showed weaker patterns. Differences in rooting depth, stomatal sensitivity, and canopy structure likely contribute to this variation. These species specific patterns suggest that ECOSTRESS based drought indicators may need to be calibrated by functional type or biome.

Traditional drought indices such as the Standardized Precipitation Index and the Standardized Precipitation Evapotranspiration Index rely on meteorological variables and do not directly measure plant physiological response. My findings show that ECOSTRESS evapotranspiration adds complementary information by capturing how plants adjust water use under stress. In the future, ECOSTRESS data could be combined with meteorological indices to create hybrid drought metrics that reflect both climate forcing and plant response.

There are several limitations to this study. The seven day window between ECOSTRESS and PSInet measurements may introduce temporal mismatch, especially in rapidly changing conditions. Some species had relatively few matched observations, which reduces statistical power. In addition, evapotranspiration estimates from ECOSTRESS rely on model assumptions and can be affected by errors in land surface temperature or atmospheric correction. Despite these limitations, the consistent patterns across many species indicate that ECOSTRESS is capturing real physiological signals related to drought stress.

VI. Conclusion and Future Directions

This project demonstrates that ECOSTRESS derived evapotranspiration is positively correlated with field measured leaf water potentials across many woody plant species and regions. Lower evapotranspiration from space generally aligns with more negative water potentials in the field, which indicates increased drought stress. Midday measurements show particularly strong relationships, highlighting the importance of diurnal stomatal behavior.

By directly linking ECOSTRESS evapotranspiration with PSInet water potential data, this project helps bridge the gap between detailed physiological measurements and scalable remote sensing tools. The results support the idea that ECOSTRESS can serve as an early warning indicator of plant drought stress and can provide valuable input for drought monitoring and management in both natural and agricultural systems.

Future research should extend this work by analyzing continuous time series of ECOSTRESS data and repeated water potential measurements, incorporating additional ECOSTRESS products such as the Evaporative Stress Index, and examining how relationships differ among plant functional types. Integrating ECOSTRESS with meteorological drought indices could improve early warning systems and help farmers, foresters, and resource managers respond to drought before plant damage becomes irreversible.

VIII. References

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