Can evapotranspiration be estimated from satellite-derived vegetation indices? – investigation in simple and complex vegetation systems

David Helman[1] (davidhelman.biu@gmail.com)
Itamar M. Lensky[1], Yagil Osem[2], Dan Yakir[3] and Eyal Rotenberg[3]
[1]Bar Ilan University, Israel [2]Agricultural Research Organization, Israel [3]Weizman Institute of Science, Israel

Bar-Ilan University אוניברסיטת בר-אילן
Volcani Center - ARO
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE

INTRODUCTION

Estimating evapotranspiration (ET) in space and time is essential for understanding the terrestrial water cycle. Remote sensing can overcome the spatial limitations of scarce ET field measurements. The two main approaches to derive ET from satellite data are: (i) the empirical approach regressing vegetation indices (VIs) against ET from flux towers (Glenn *et al.* 2010), and (ii) the physical-based approach using land surface temperature to solve the energy balance equation (Kalma *et al.* 2008). The advantage of the VI empirical approach is in that it does not require additional micrometeorological information, which is difficult to obtain. However, the degree of success of this approach is controversial (Yebra *et al.* 2013). Moreover, little attention has been given to understand the meaning of the ET – VI empirical relationship.

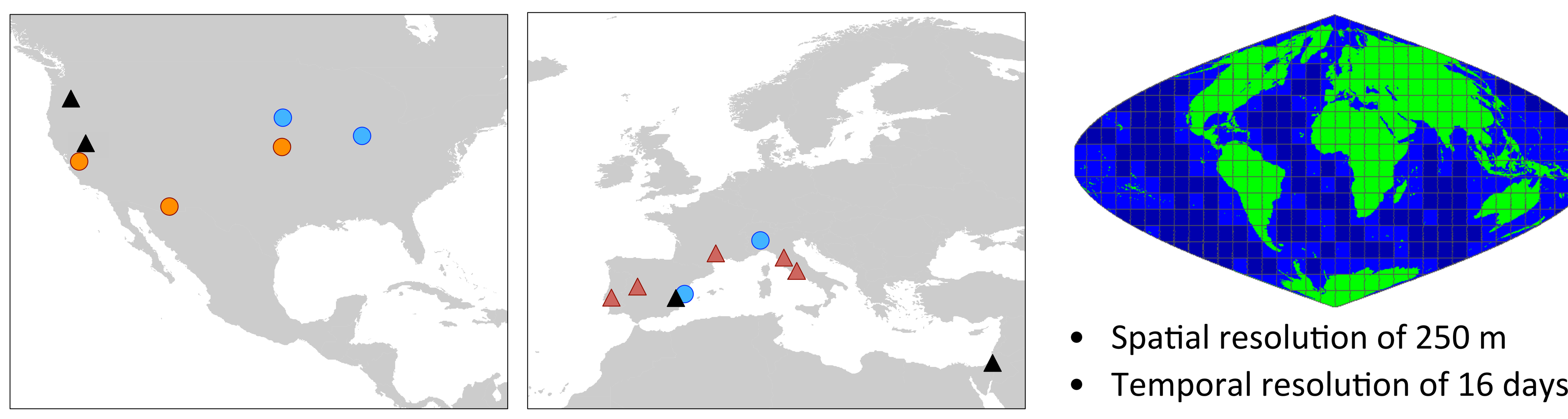
We examine the ET – VI relationship in *Simple* and *Complex* vegetation systems separately to understand (a) its biophysical meaning, and (b) the way it should be used.

Glenn, E. Nagler, P. & Huete, A. 2010. Vegetation Index Methods for Estimating Evapotranspiration by Remote Sensing. *Surveys in Geophysics*, **31**, 531–555.
Kalma, J. McVicar, T. & McCabe, M. 2008. Estimating Land Surface Evaporation: A Review of Methods Using Remotely Sensed Surface Temperature Data. *Surveys in Geophysics*, **29**, 421–469.
Yebra, M. Van Dijk, A. Leuning, R. Huete, A. & Guerschman, J.P. 2013. Evaluation of optical remote sensing to estimate actual evapotranspiration and canopy conductance. *Remote Sensing of Environment*, **129**, 250–261.

1. Sites and satellite data

The FLUXNET sites

NDVI and EVI from MODIS



- Spatial resolution of 250 m
- Temporal resolution of 16 days

***Simple* vegetation systems (grass/crop)** | ***Complex* vegetation systems (grass + trees)**

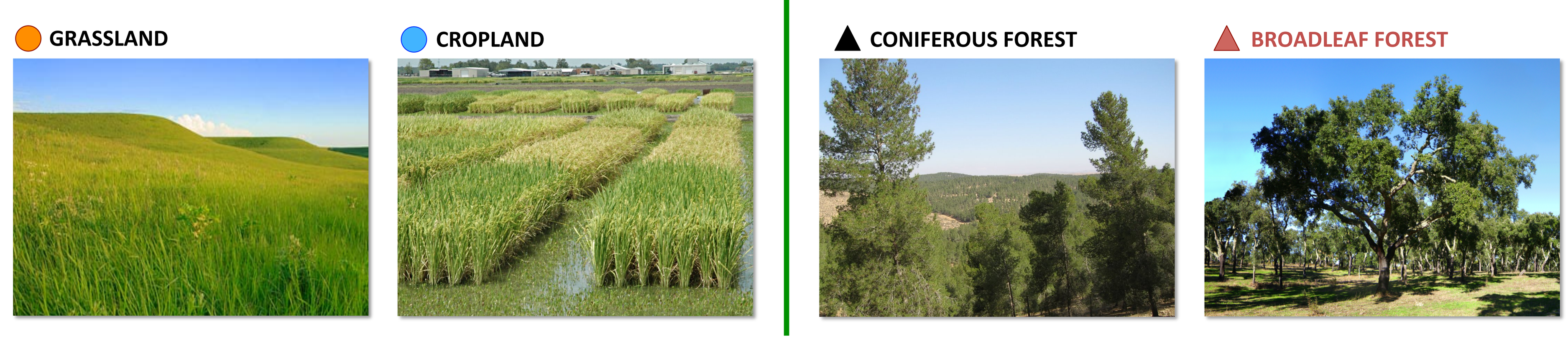


Figure 1. Flux data was collected from 7 ***Simple*** (grasslands and croplands) and 9 ***Complex*** vegetation systems (semiarid and Mediterranean evergreen forests). The **NDVI** and **EVI** were derived from MODIS.

2. MODIS VI vs. observed ET/GPP

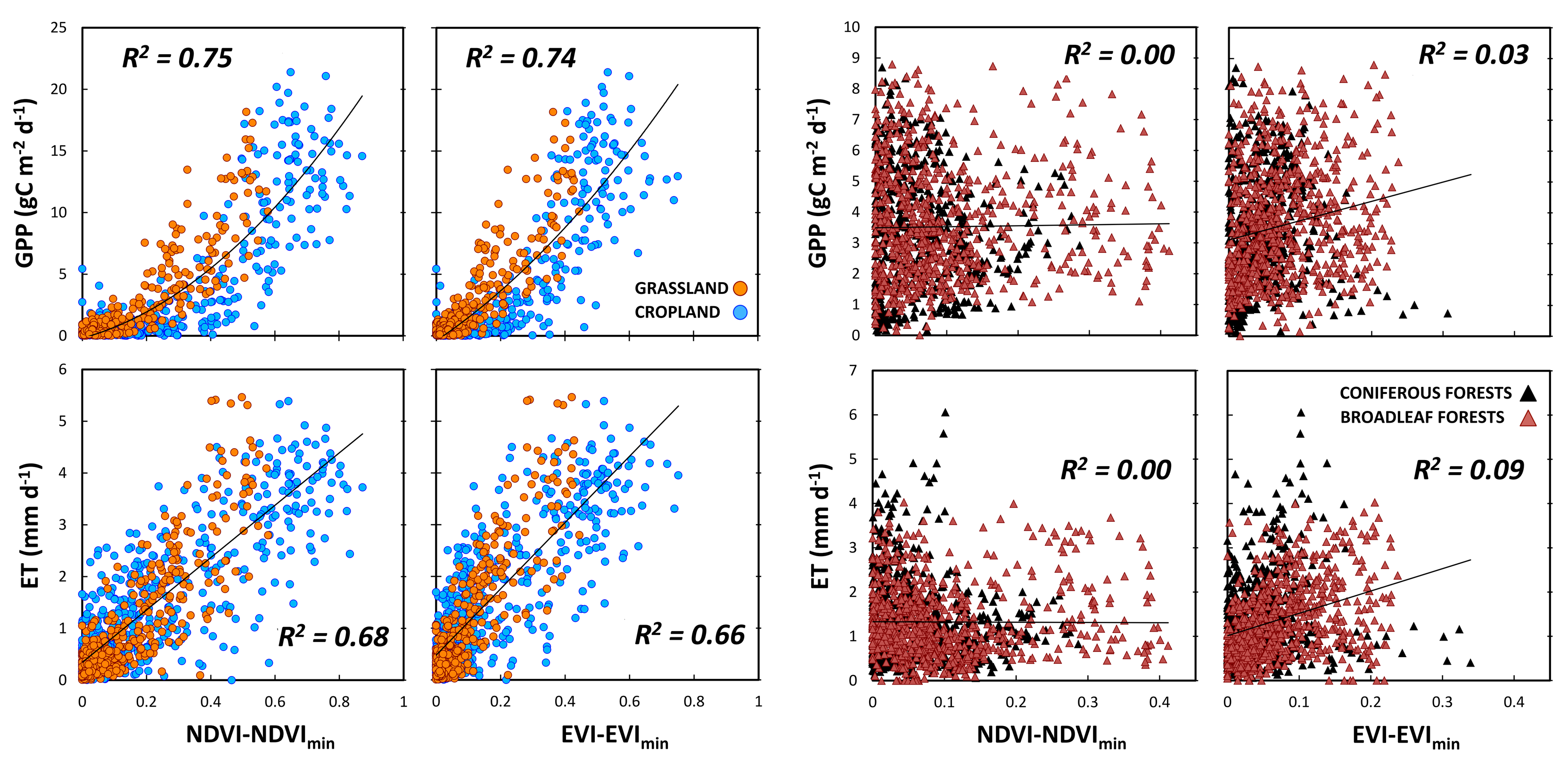


Figure 2. Direct regressions of ET and GPP against NDVI and EVI for 7 ***Simple*** (**grasslands** and **croplands**) and 9 ***Complex*** (evergreen **coniferous** and **broadleaf** forests) vegetation sites. A good VIs–GPP fit in ***Simple*** systems suggest the linkage of VIs to biomass.

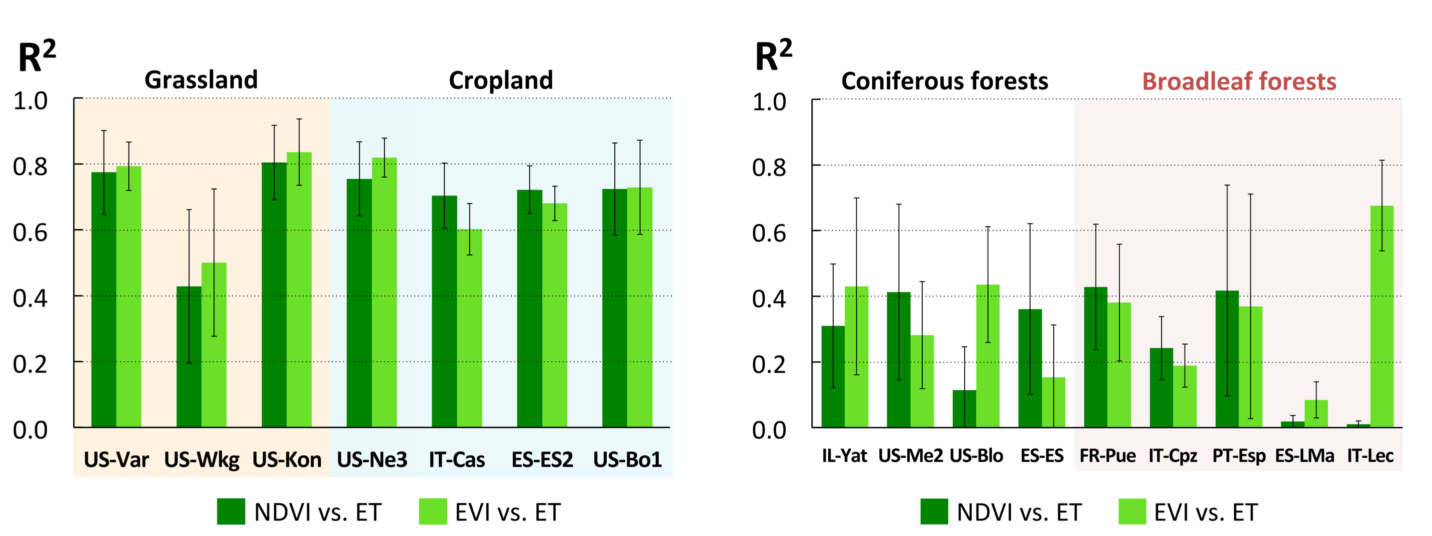


Figure 3. Per-site coefficients of correlation (R^2) from the regression of ET against **NDVI** and **EVI**. The average R^2 after regressing each year separately is presented. Bars denote ±1*σ*.

3. *Simple* vegetation systems

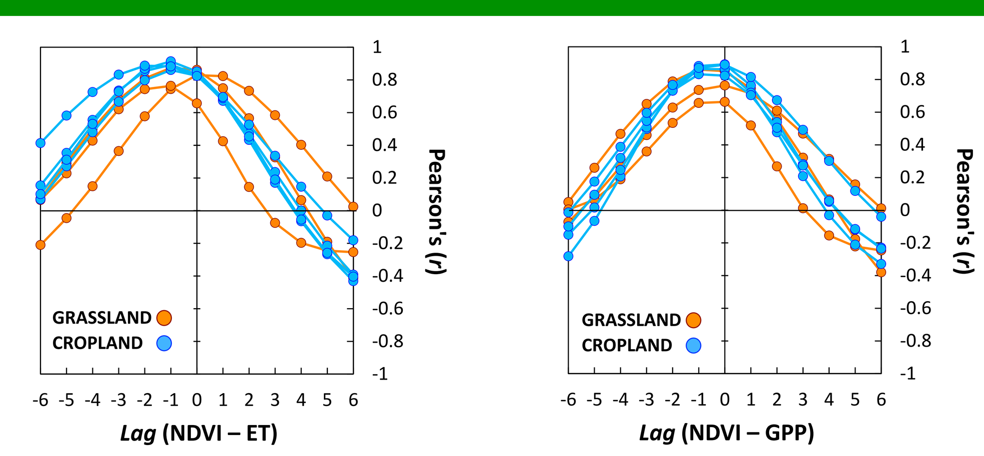


Figure 4. NDVI vs. ET (left) and GPP (right) cross-correlations in **grasslands** and **croplands**. ET is shifted by ca. two weeks (lag = -1) with respect to NDVI except of one grassland site. NDVI and GPP have no shift (lag = 0) suggesting that the NDVI – ET shift is caused by early evaporation (E) not contributed by vegetation.

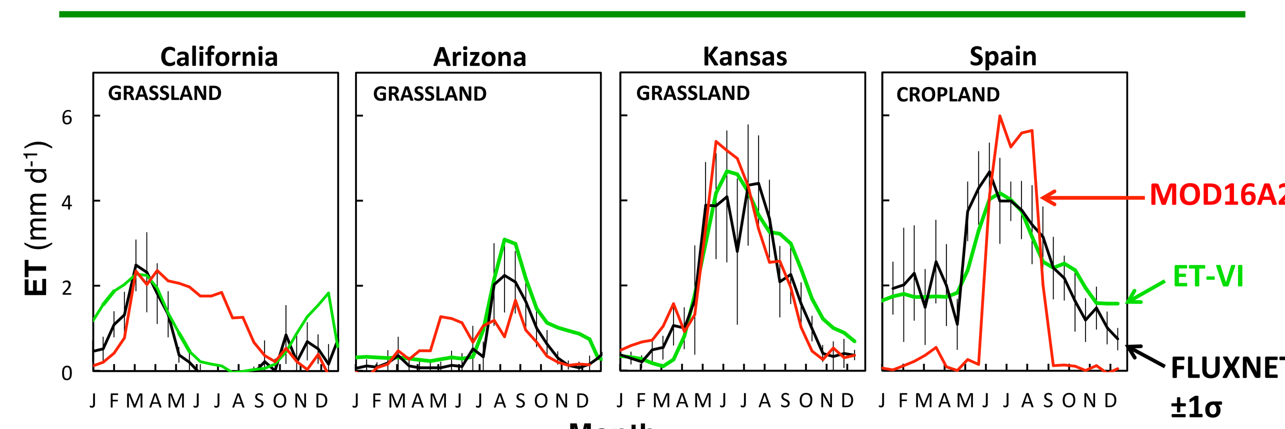


Figure 5. A Jack-Knife cross-validation leaving one year out using the empirical **ET-VI** model after shifting (**Fig. 4**), in four sites. The observed ET from **FLUXNET** and the MODIS's ET product (**MOD16A2**) are presented for comparison.

4. *Complex* vegetation systems

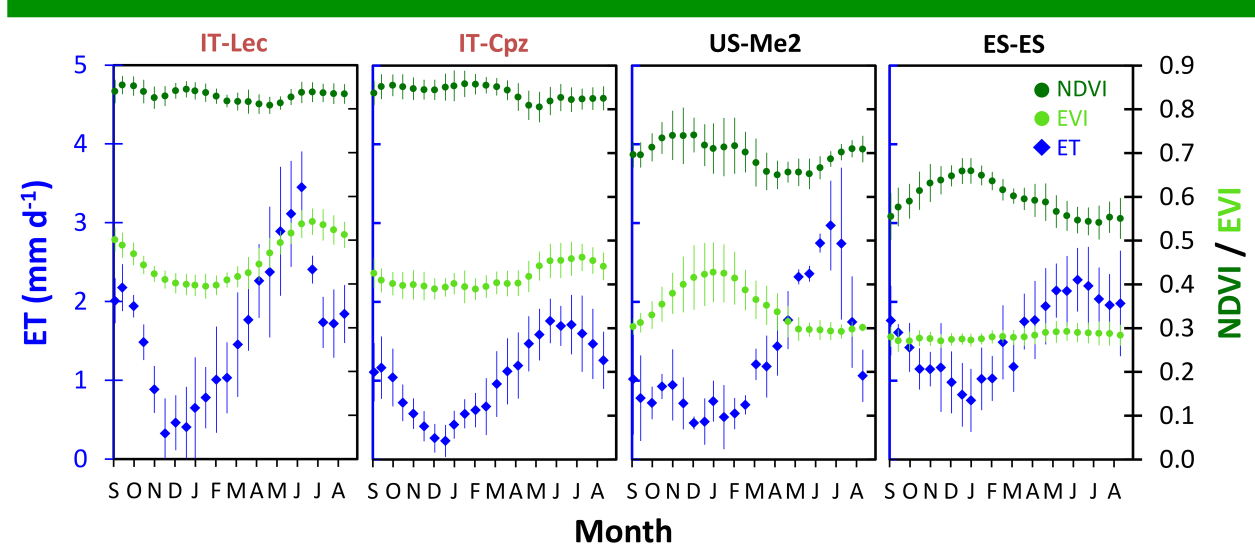


Figure 6. Time series of **NDVI**, **EVI** and observed **ET** at two Mediterranean oak forests (**IT-Lec** and **IT-Cpz**) and two Mediterranean pine forests (**US-Me2** and **ES-ES**) showing different seasonality, which can explain the low VI–ET correlations in the ***Complex*** vegetation systems (in **Fig. 2** and **3**). Error bars are ±1*σ*.

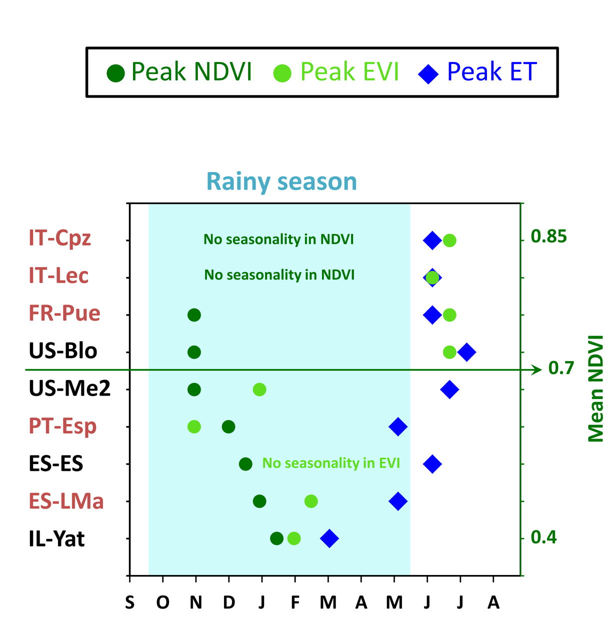


Figure 7. The timing of the peak in **NDVI**, **EVI** and observed **ET** for the 9 Mediterranean evergreen forests (**Coniferous** and **Broadleaf**). The sites are arranged according to their mean NDVI (right axis) in ascending order. The sky blue background denotes the period of the **rainy season**.

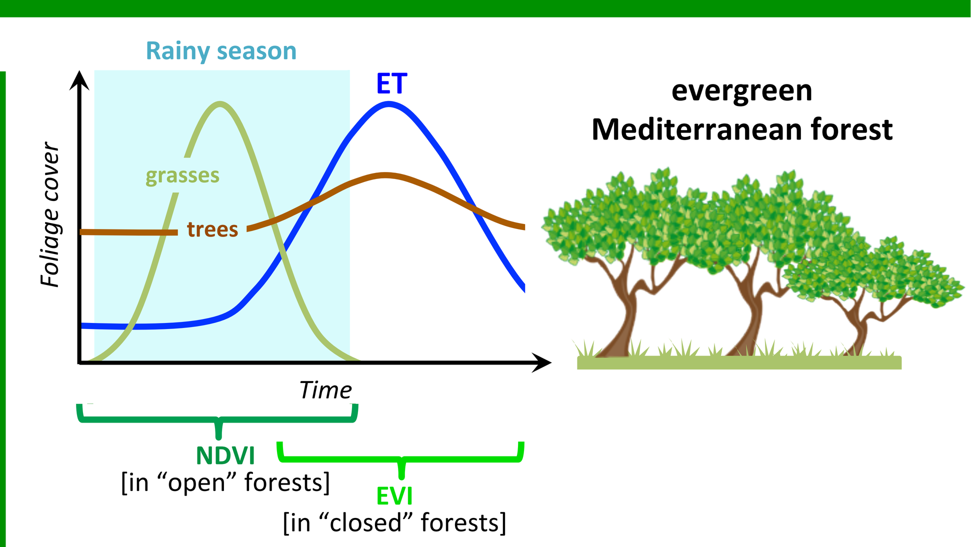


Figure 8. A schematic representation of the annual change in foliage cover of **grasses** and **trees** in an evergreen Mediterranean forest and the corresponding sensitivities of **NDVI** and **EVI** to detect these changes following **Fig. 7**. The **ET** in forests is mostly transpiration (T) from trees (**Fig. 6**).

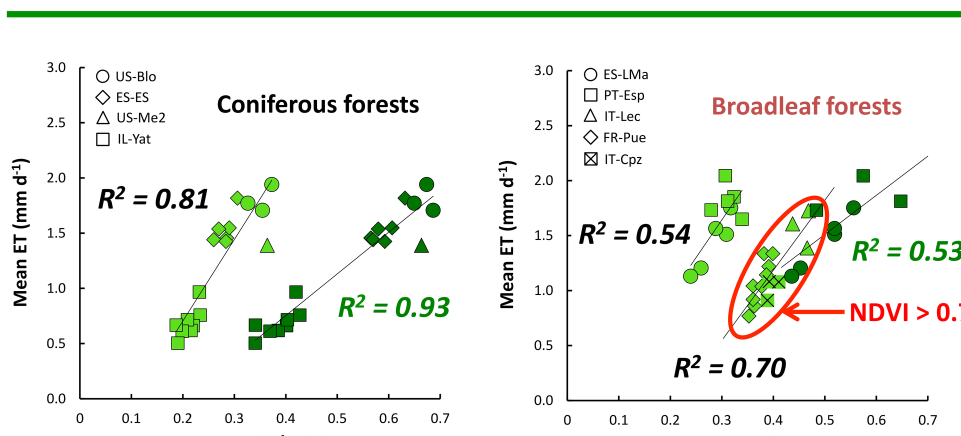


Figure 9. The mean annual **EVI**/**NDVI** versus the mean annual ET in **coniferous** (left plot) and **broadleaf** (right plot) forests. Following **Fig. 7** only years with **NDVI** < 0.7 are plotted except for the **EVI** in **broadleaf** forests. Note the shift in the **EVI**-ET linear relationship in broadleaf forests with **NDVI** > 0.7 (red circle).

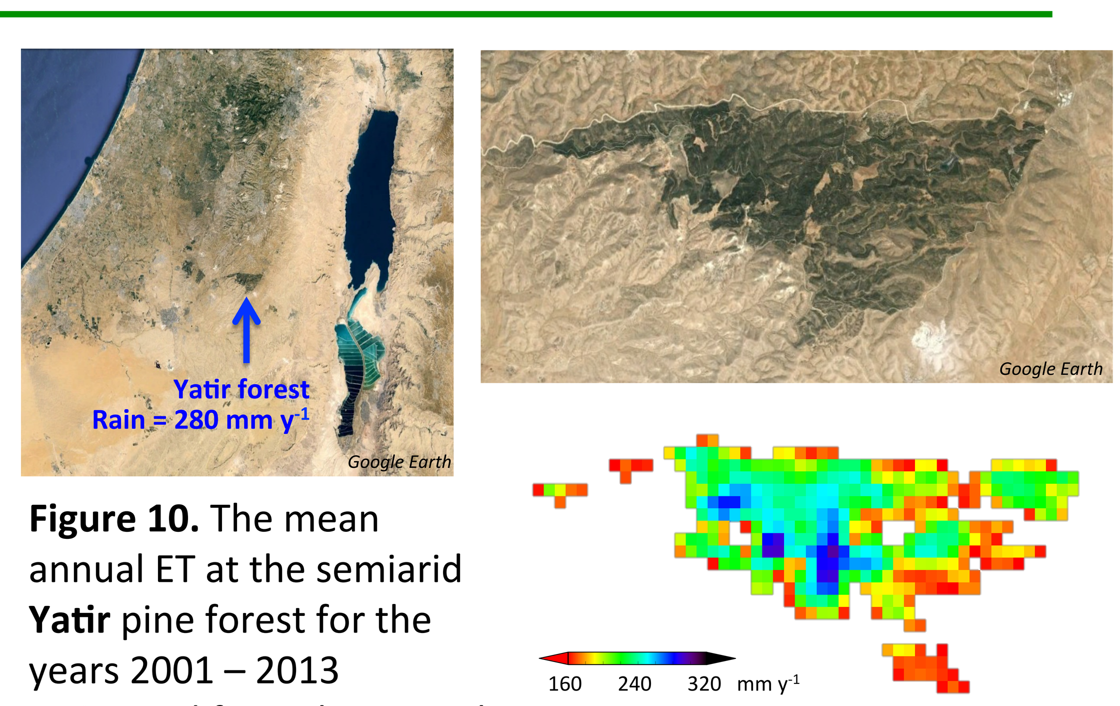


Figure 10. The mean annual ET at the semiarid **Yatir** pine forest for the years 2001 – 2013 estimated from the annual average of NDVI (**Fig. 9**).

CONCLUSIONS

- **ET– VI correlations are shifted by ca. 2 weeks in *Simple* vegetation systems (grasslands and croplands) due to early evaporation not contributed by vegetation**
- **NDVI and EVI mostly reflect the seasonal growth of grasses in "open" forests while in "closed" forests when NDVI saturates (NDVI > 0.7) EVI becomes more sensitive to the tree phenology**
- **The mean annual NDVI/EVI and annual ET in evergreen Mediterranean forests show high correlations**

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