Data assimilation of photosynthetic light-use efficiency using multi-angular satellite data

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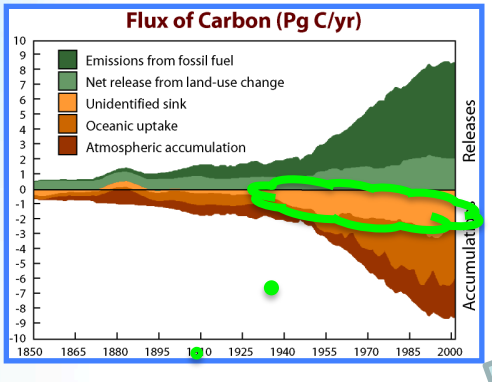
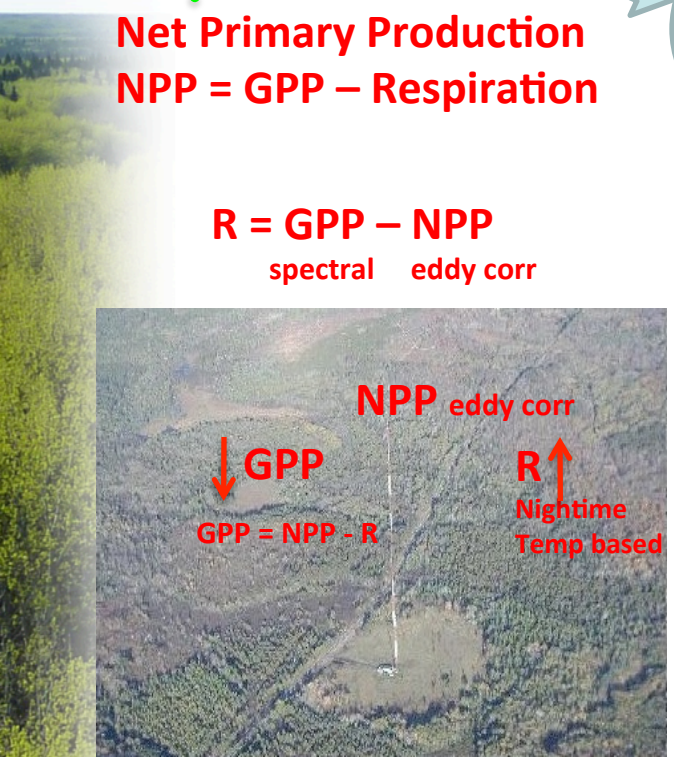
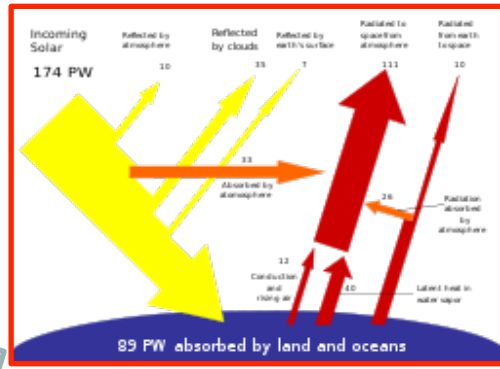
CARBON, WATER & ENERGY CYCLE

CARBON CYCLE





ENERGY CYCLE



PAR

PHOTOSYNTHETIC RATE
Gross Primary Production

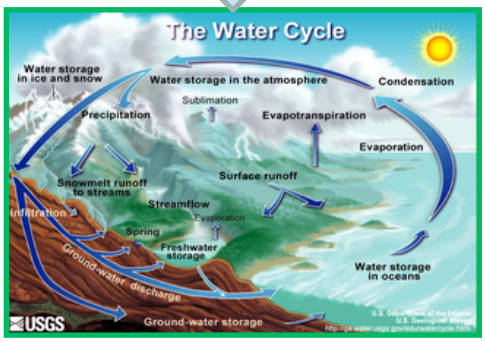
GPP = PAR x Fpar x ε

Net Primary Production
NPP = GPP – Respiration

R = GPP – NPP
spectral eddy corr

NPP eddy corr
↓GPP
R↑
GPP = NPP - R
Nightime
Temp based

Evapotranspiration
ET = Transpiration + Evaporation



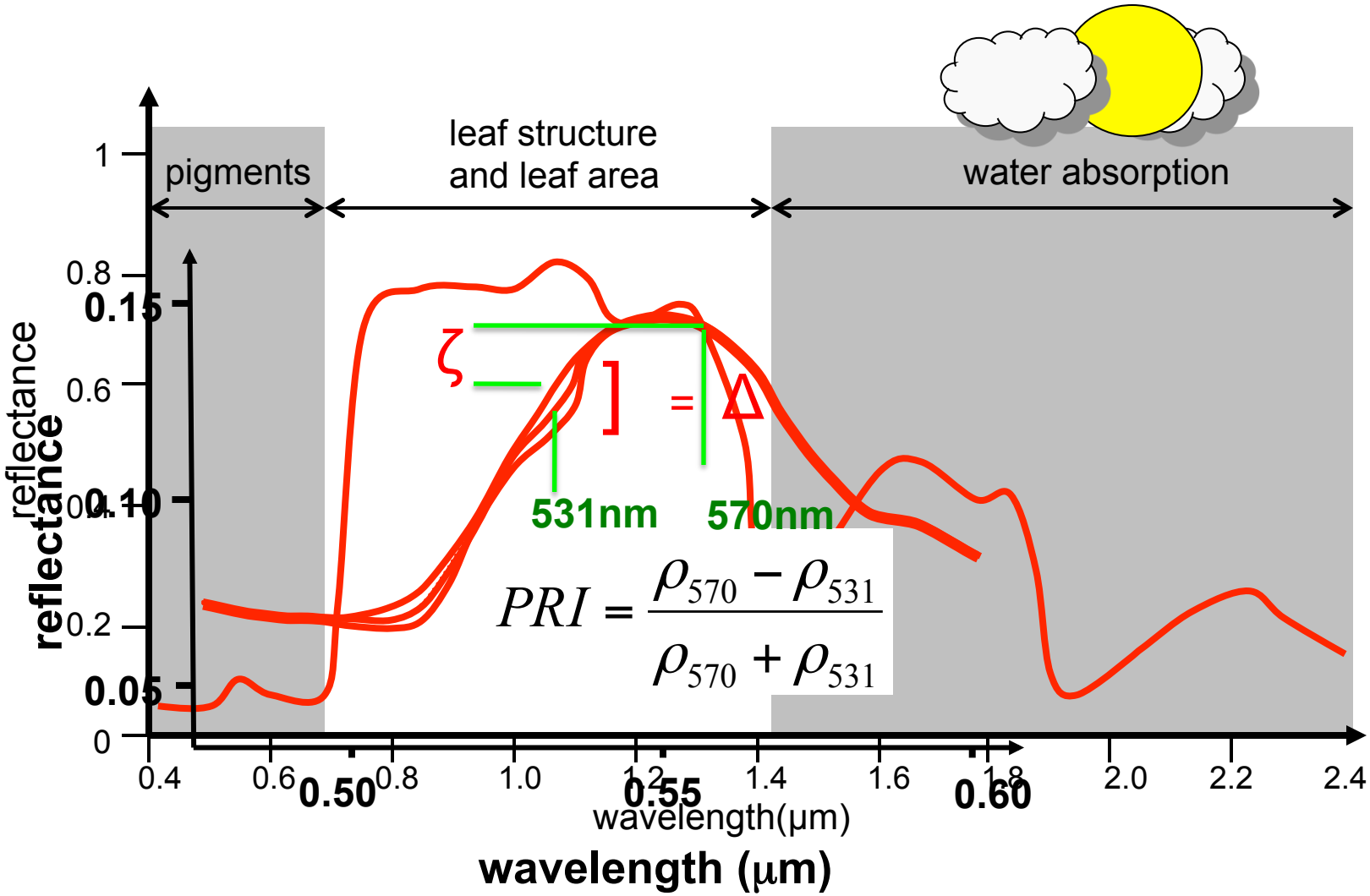
WATER CYCLE

Light Use Efficiency
mol C/ mol photon

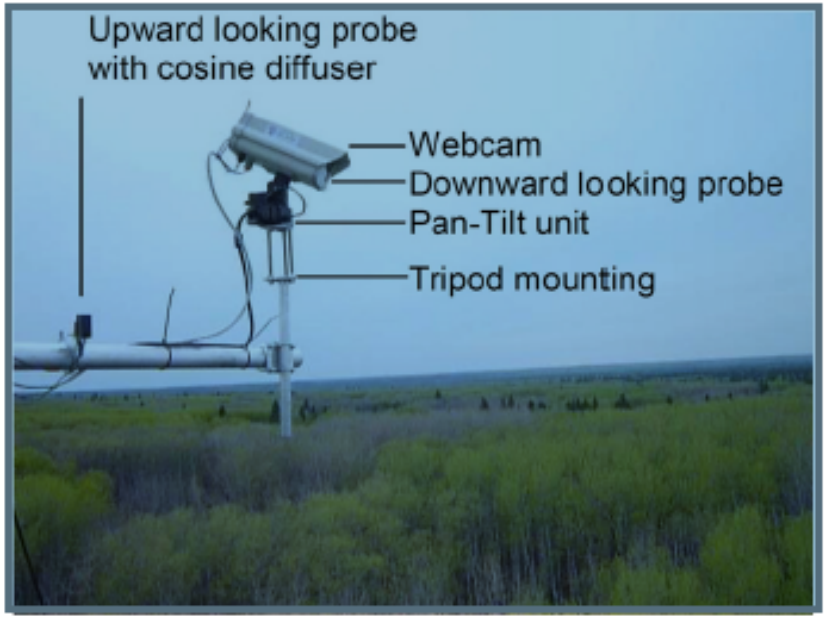
$$T \sim [e^* - e_a] \frac{g_c g_a}{g_c + g_a}$$

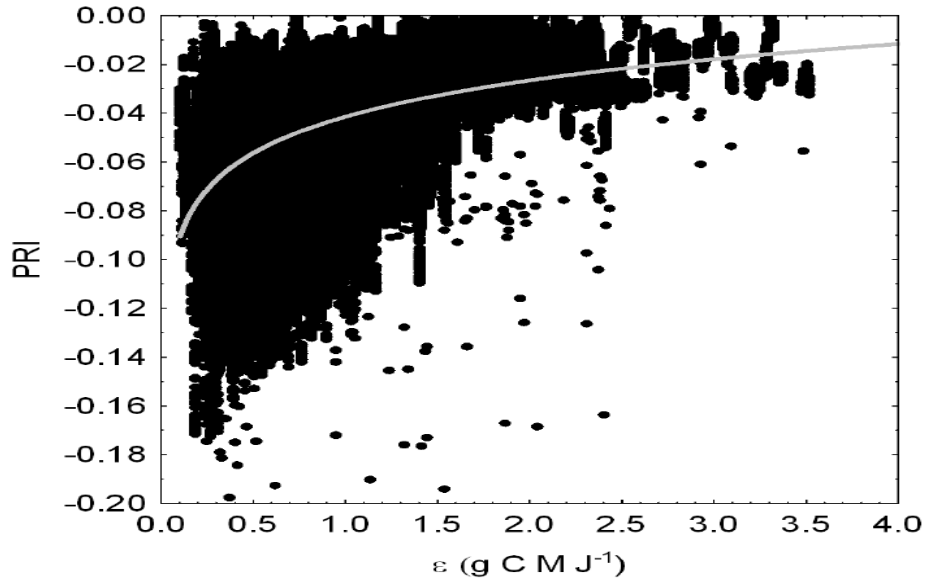
$$g_c = a + b \text{ GPP} \times (h/c)$$

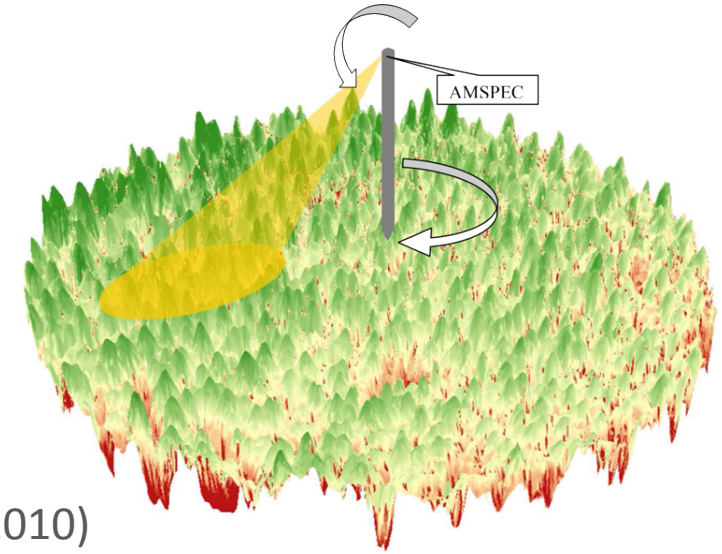
Associated changes in reflectance



Multi-angle Remote Sensing of ε

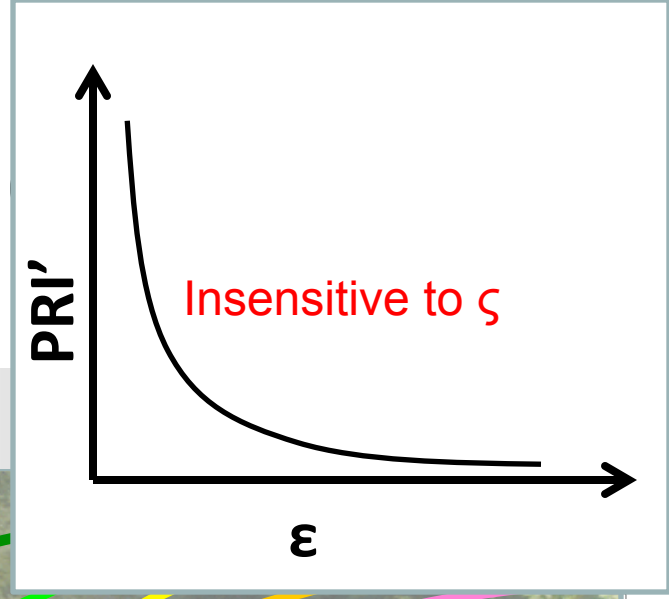


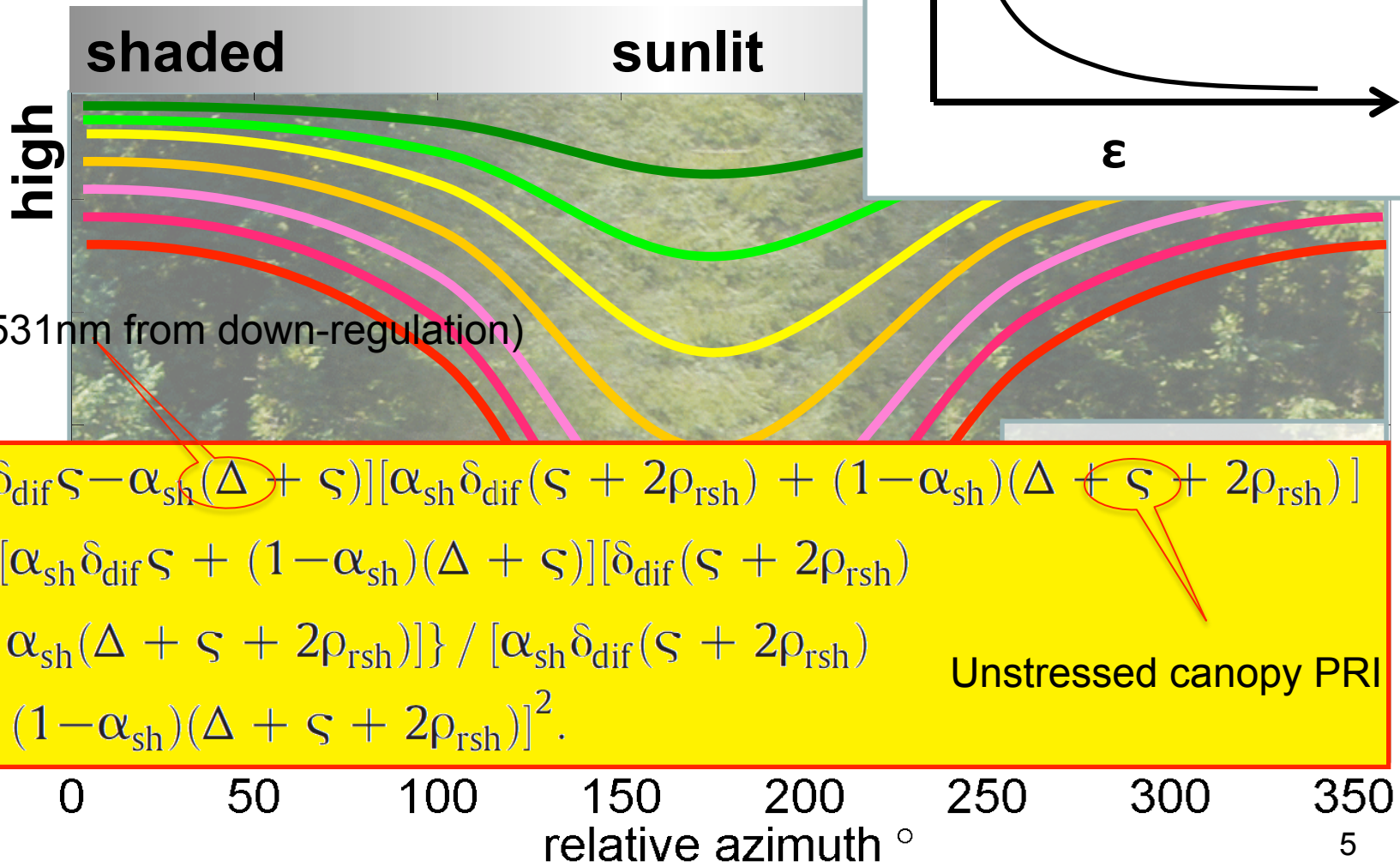




Hilker et al., Remote Sensing of Environment (2010)

Effects of Function on





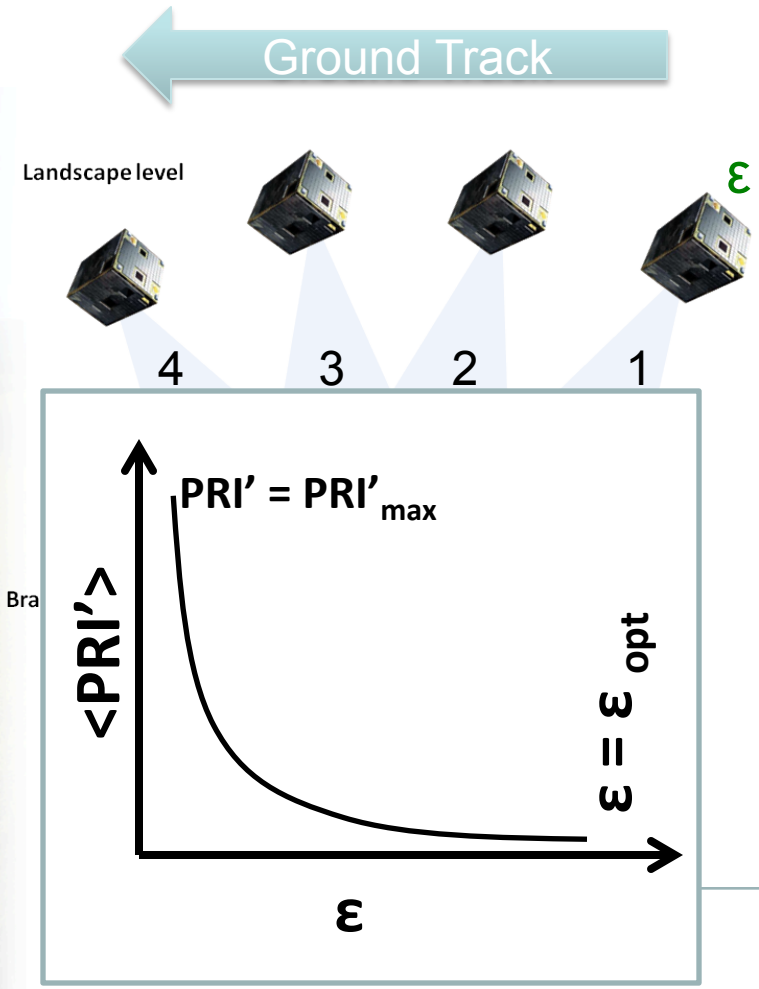
Δρ@531nm from down-regulation)

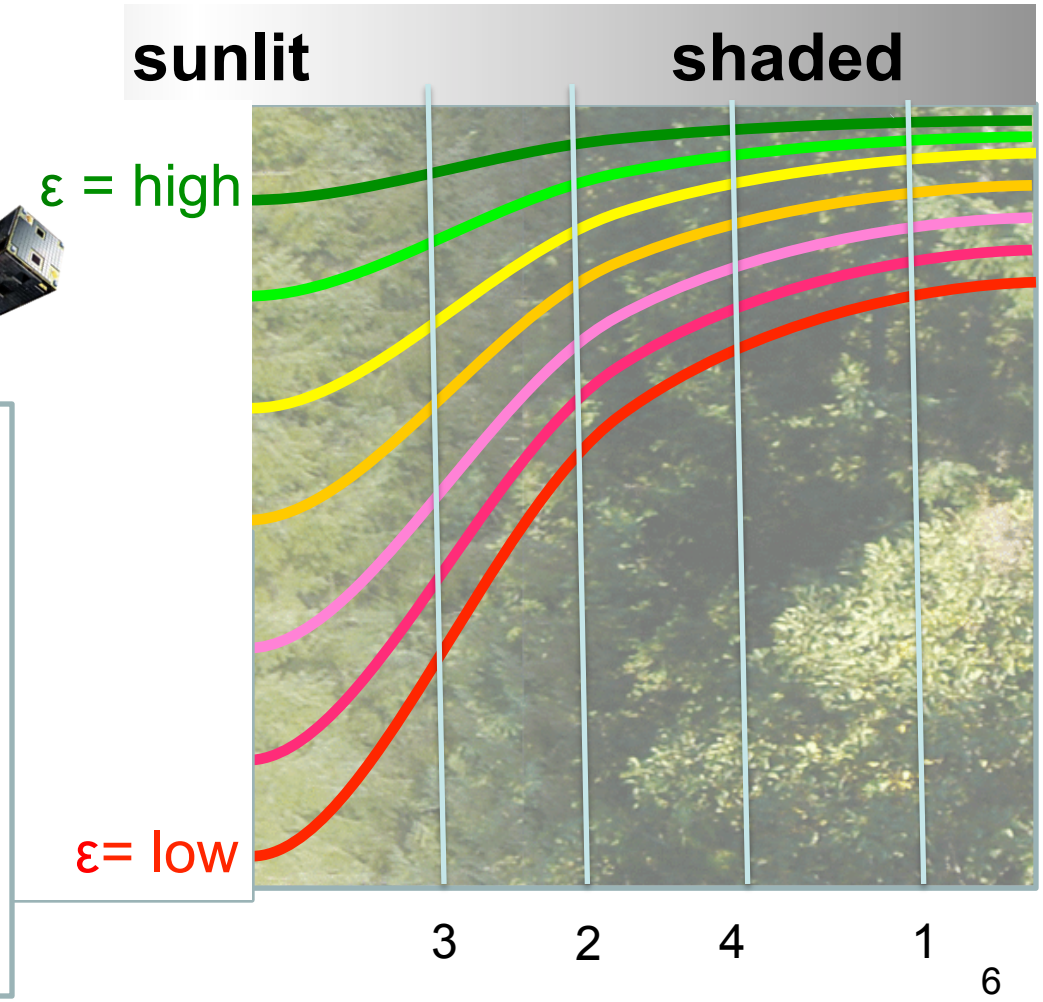
$$\mathrm{PRI}' = \{[\delta_{\mathrm{dif}}\varsigma - \alpha_{\mathrm{sh}}(\Delta + \varsigma)][\alpha_{\mathrm{sh}}\delta_{\mathrm{dif}}(\varsigma + 2\rho_{\mathrm{rsh}}) + (1-\alpha_{\mathrm{sh}})(\Delta + \varsigma + 2\rho_{\mathrm{rsh}})] - [\alpha_{\mathrm{sh}}\delta_{\mathrm{dif}}\varsigma + (1-\alpha_{\mathrm{sh}})(\Delta + \varsigma)][\delta_{\mathrm{dif}}(\varsigma + 2\rho_{\mathrm{rsh}}) - \alpha_{\mathrm{sh}}(\Delta + \varsigma + 2\rho_{\mathrm{rsh}})]\} / [\alpha_{\mathrm{sh}}\delta_{\mathrm{dif}}(\varsigma + 2\rho_{\mathrm{rsh}}) + (1-\alpha_{\mathrm{sh}})(\Delta + \varsigma + 2\rho_{\mathrm{rsh}})]^2.$$

Unstressed canopy PRI

Hall et al. Rem. Sens. Environ. (2008,2012)

Orbital Canopy PRI' and ε



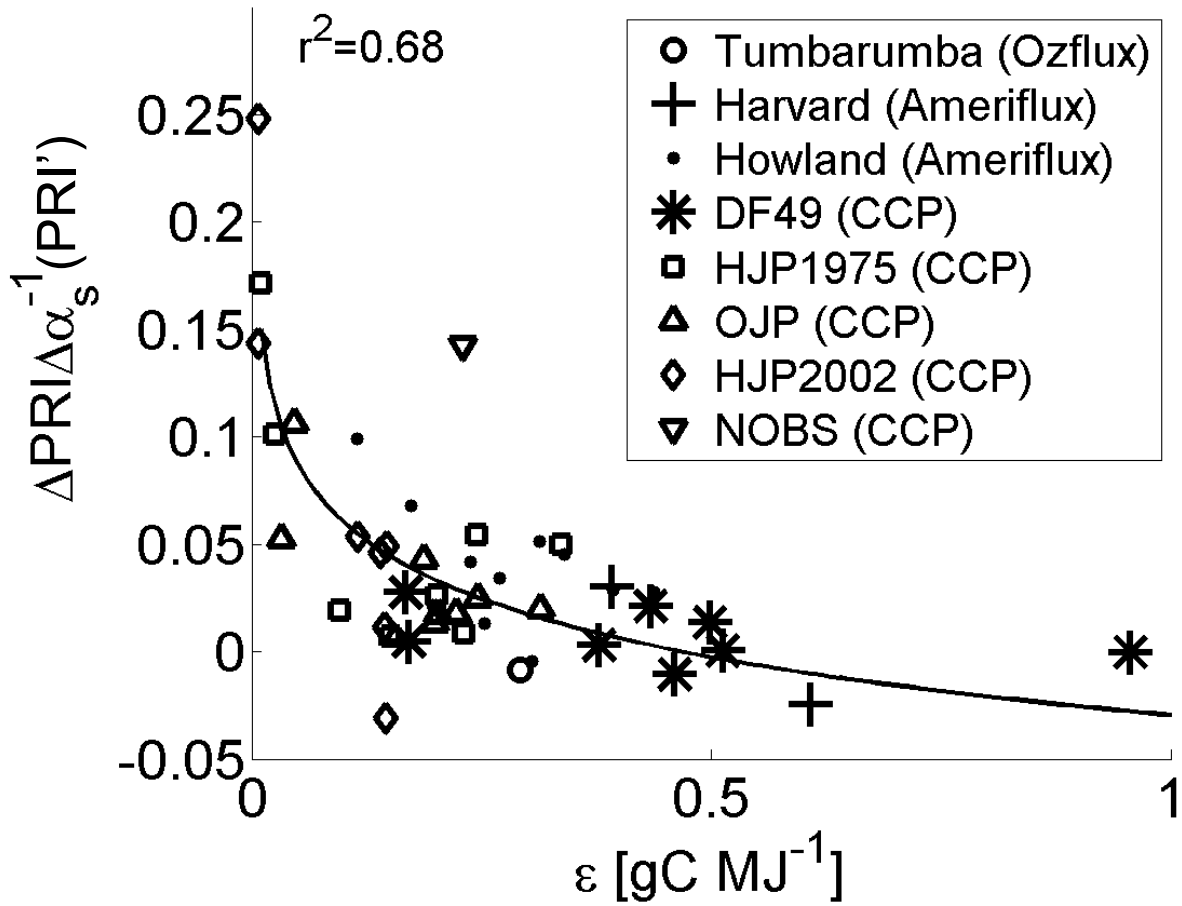


Hall et al. Rem. Sens. Environ. (2008,2012)

Differences Among Test Sites

Hilker et al., Journal of Geophysical Research (2011)

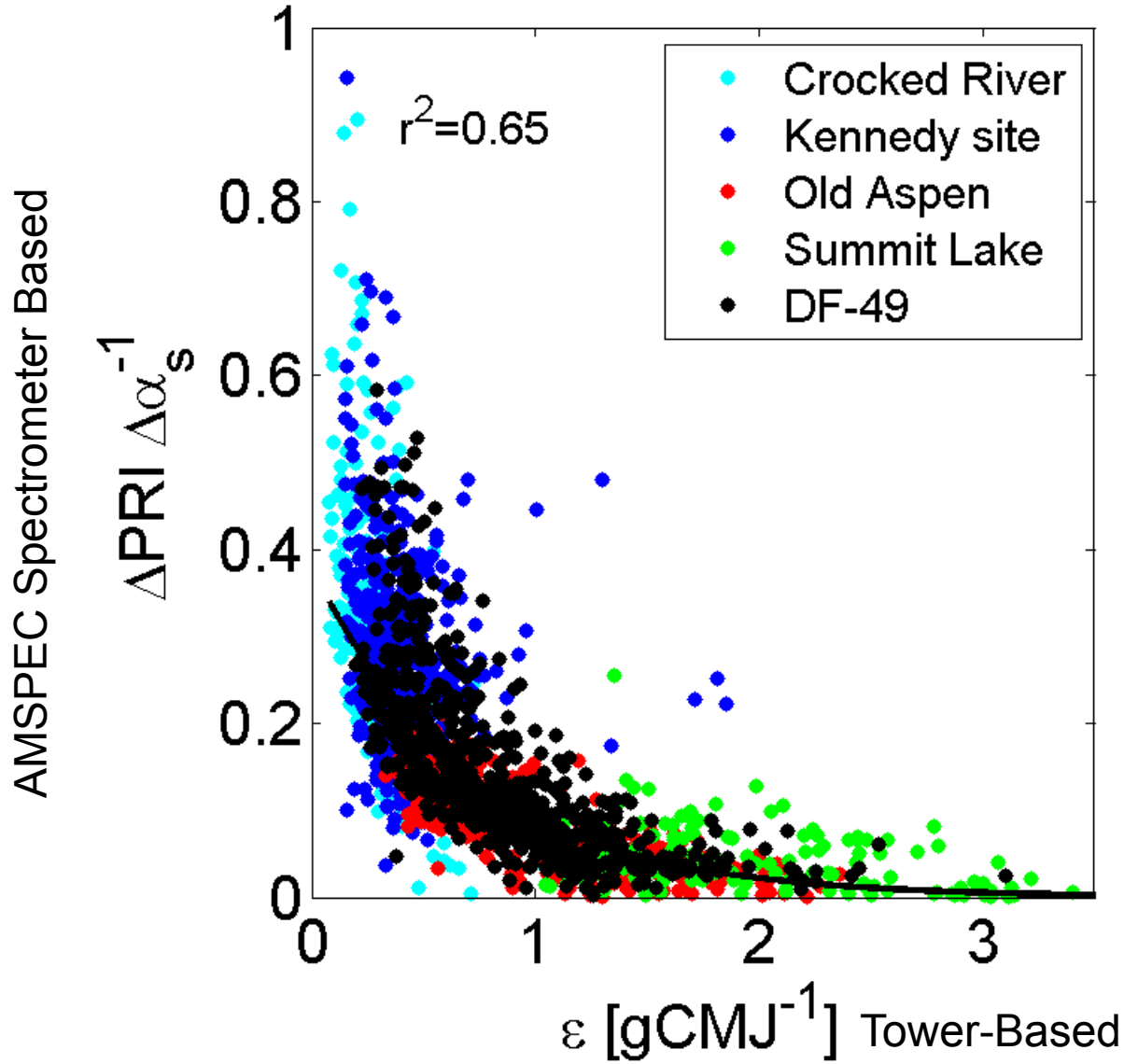
Satellite-derived Photosynthesis



Hilker et al., Journal of Geophysical Research (2011)

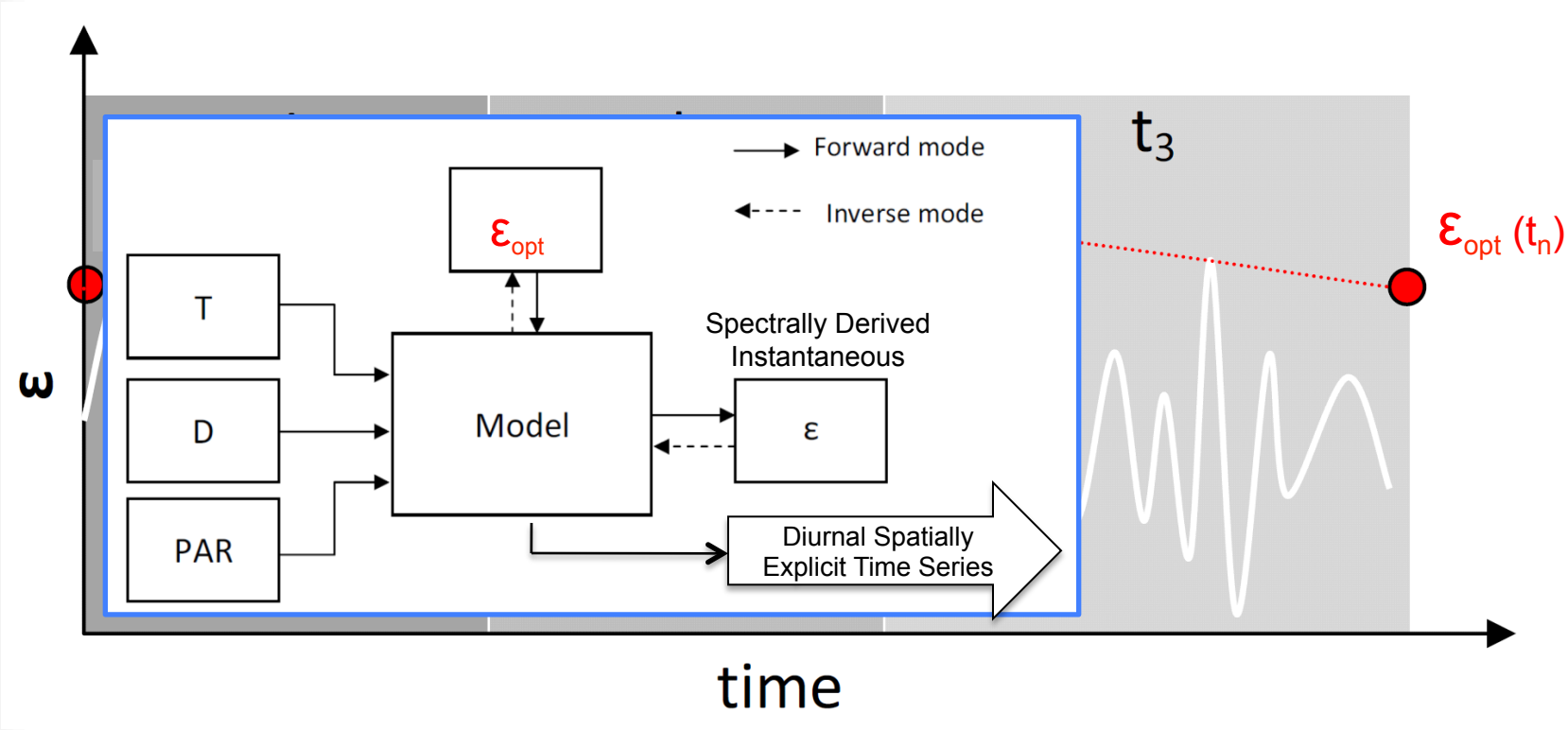
Remote sensing of ε across sites

1st derivative of PRI (wrt α_s) vs. ε



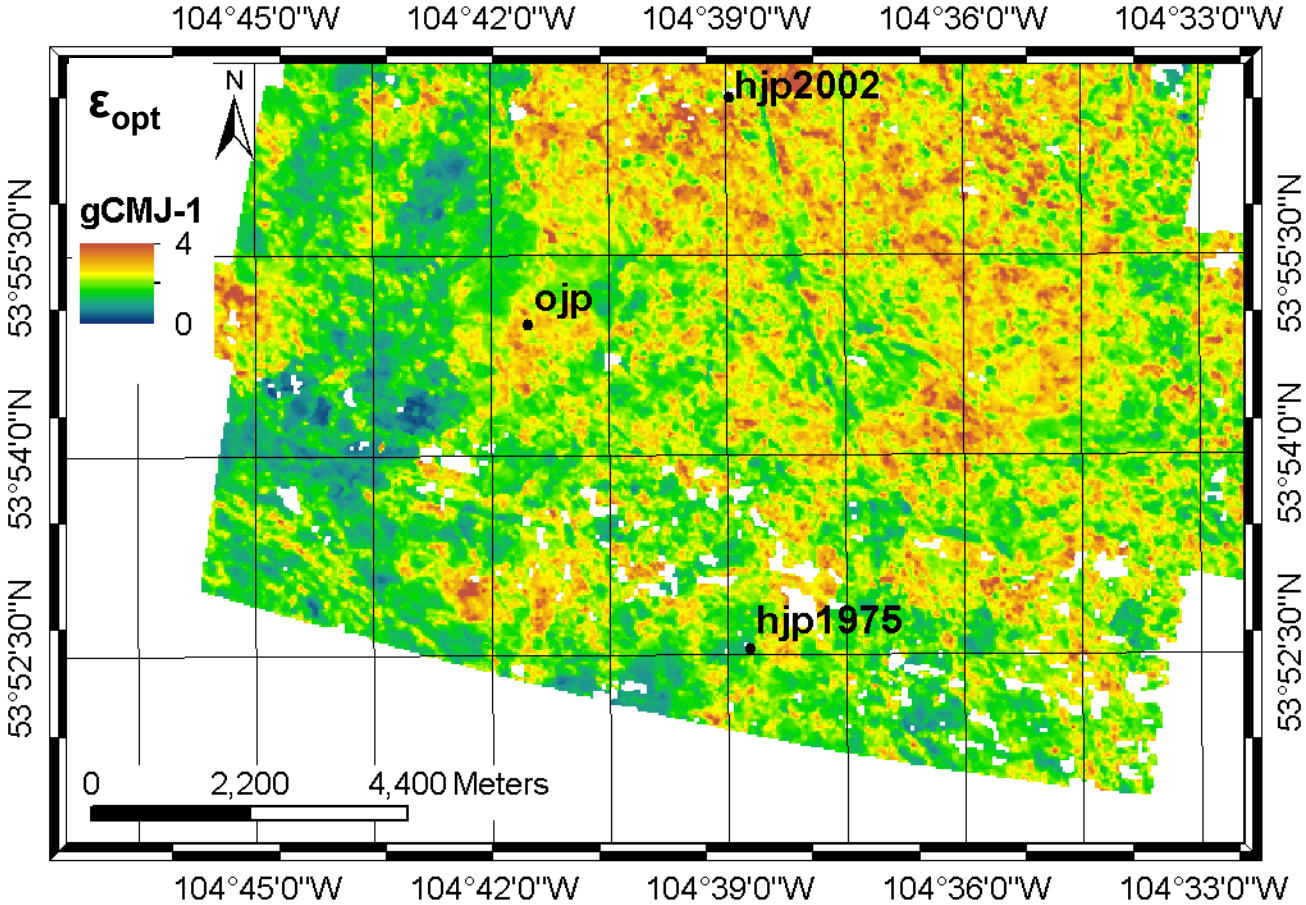
Temporal Scaling of Photosynthesis

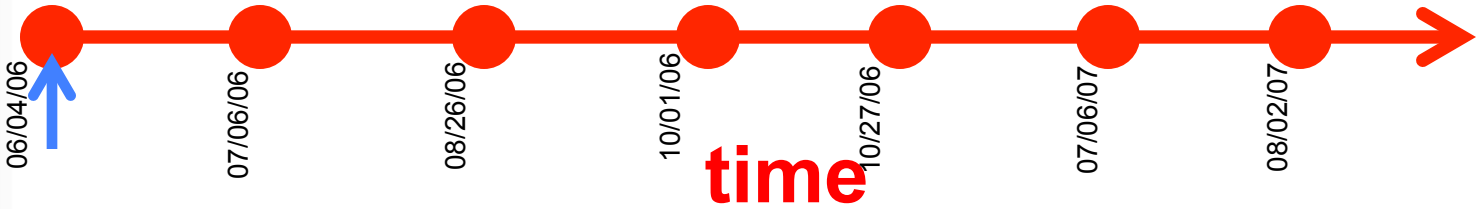
Data assimilation



Hilker et al., Remote Sensing of Environment (submitted)

Two years of ε_{opt} from CHRIS-PROBA

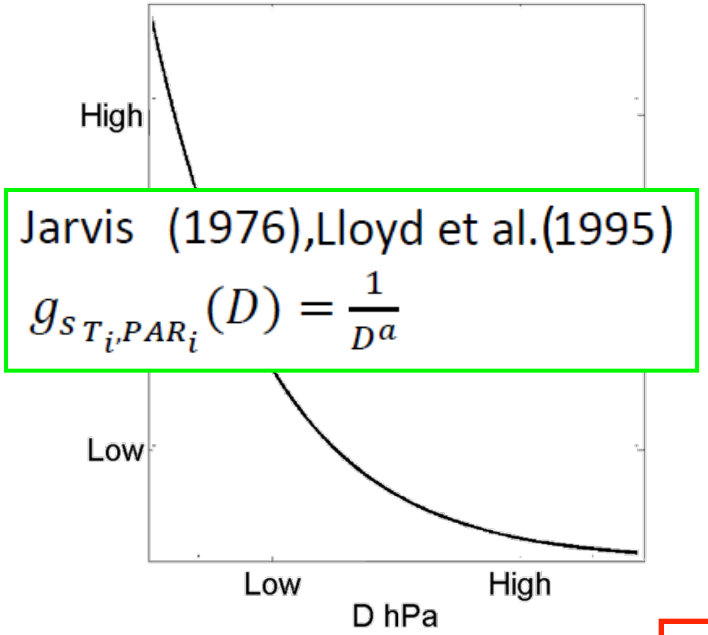




Response functions

Hall et al. RSE (2012)

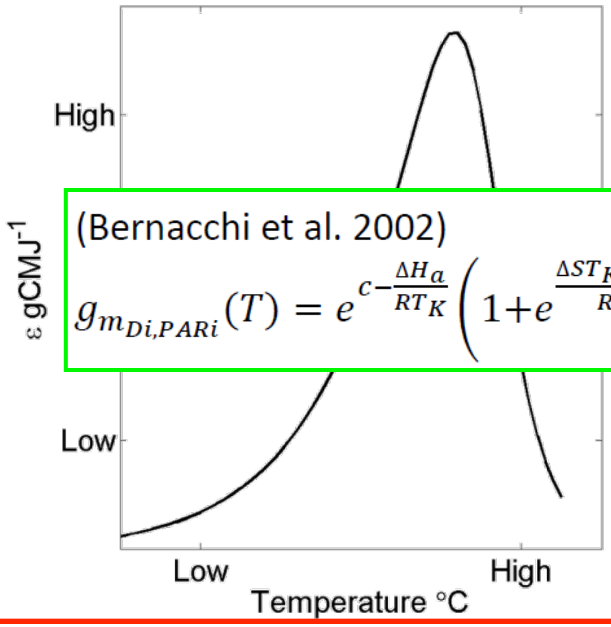
A



Jarvis (1976),Lloyd et al.(1995)

$$g_{s_{T_i,PAR_i}}(D) = \frac{1}{D^a}$$

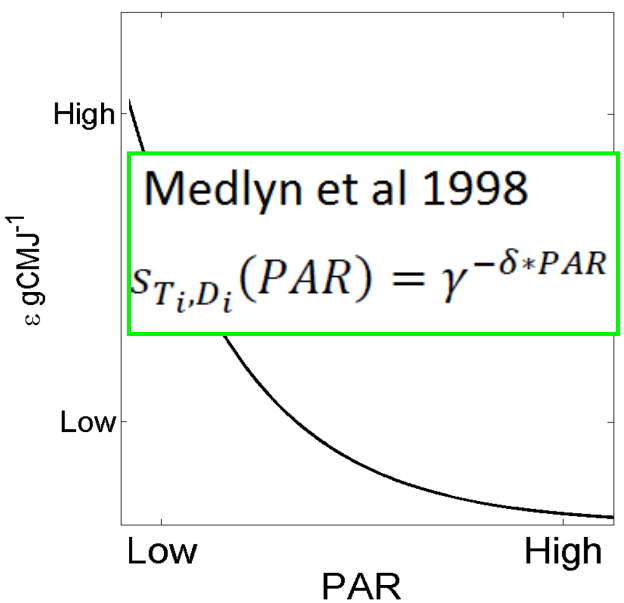
B



(Bernacchi et al. 2002)

$$g_{m_{Di,PARi}}(T) = e^{c-\frac{\Delta H_a}{RT_K}}\left(1+e^{\frac{\Delta ST_K-\Delta H_d}{RT_K}}\right)^{-1}$$

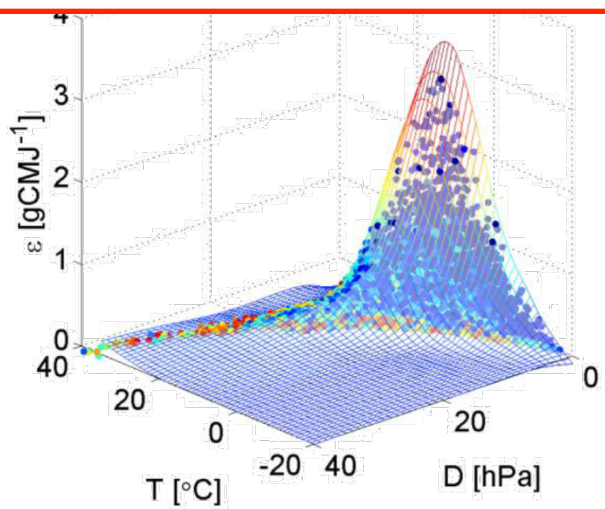
C



Medlyn et al 1998

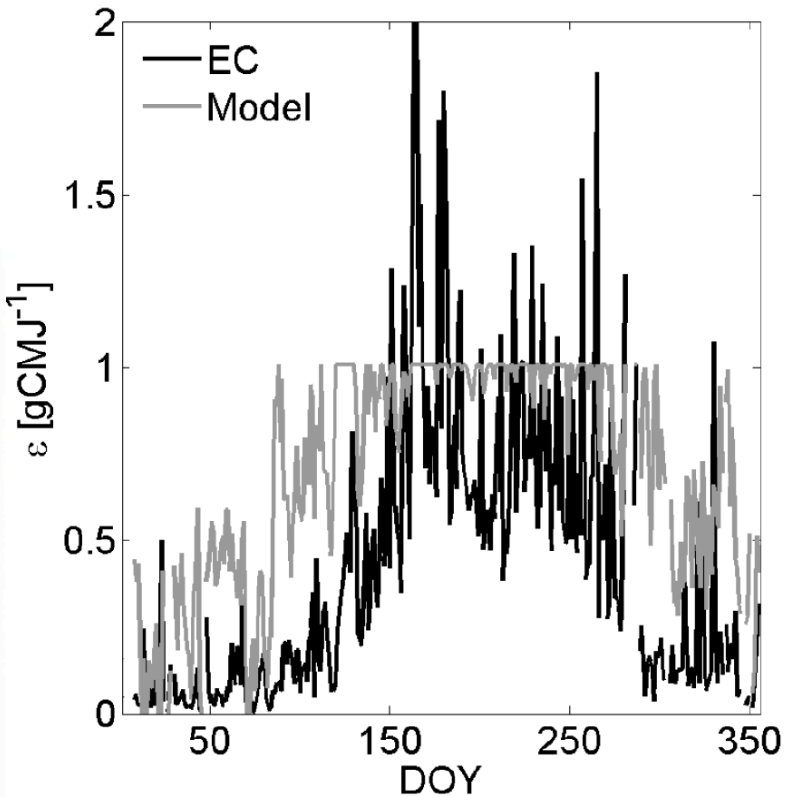
$$s_{T_i,D_i}(PAR) = \gamma^{-\delta * PAR}$$

$$f(D,T,PAR) = e^{c-\frac{\Delta H_a}{RT_K}}\left(1 + D^a + e^{\frac{\Delta ST_K-\Delta H_d}{RT_K}}\right)^{-1}\gamma^{-\delta * PAR}$$

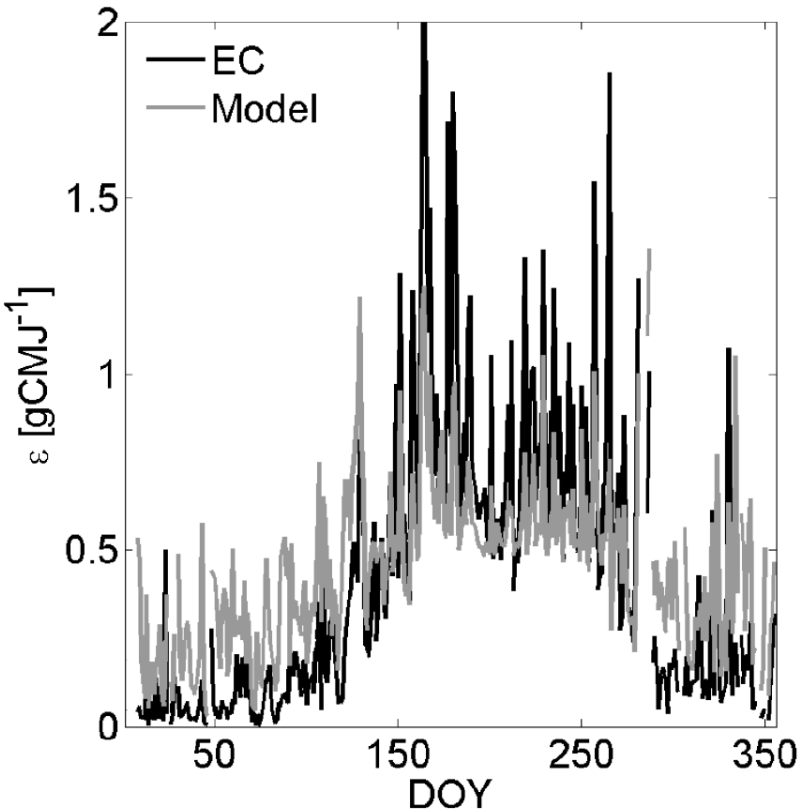


Model comparison: GPP

MODIS GPP model:
Tower f_{PAR}, PAR, MODIS ε

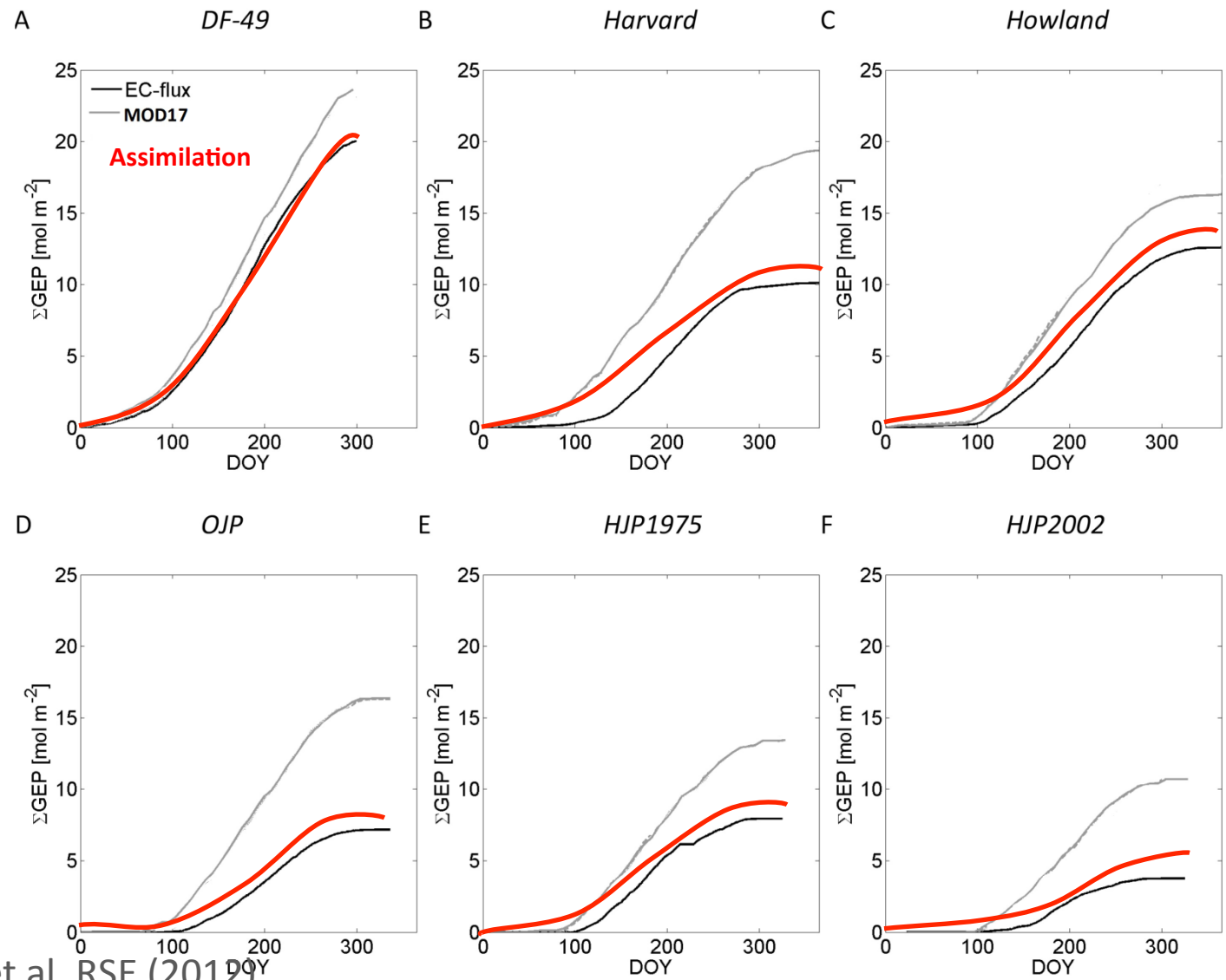


Data assimilation model:
Tower f_{PAR}, PAR, assimilated ε



Hilker et al. RSE (2012)

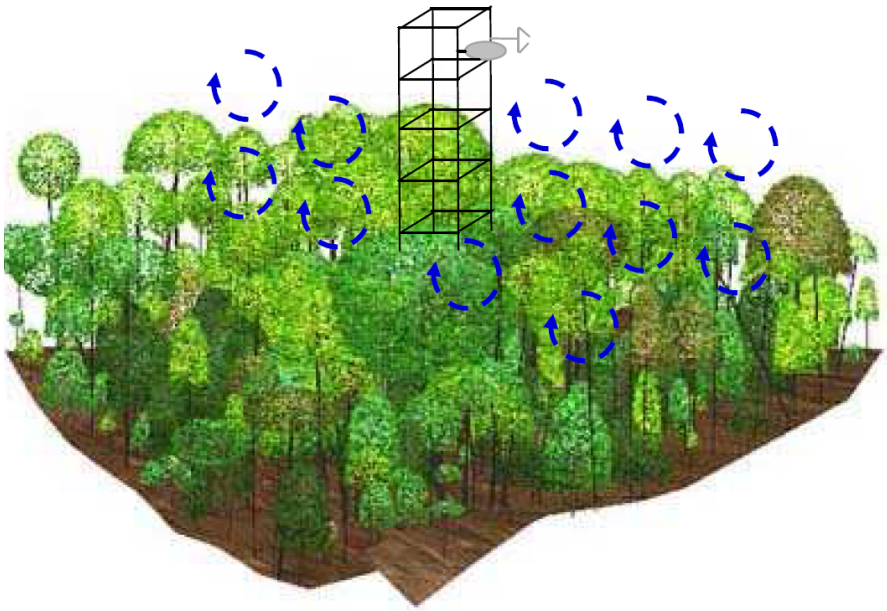
Comparing Fluxes: EC, MODIS, Data assimilation model



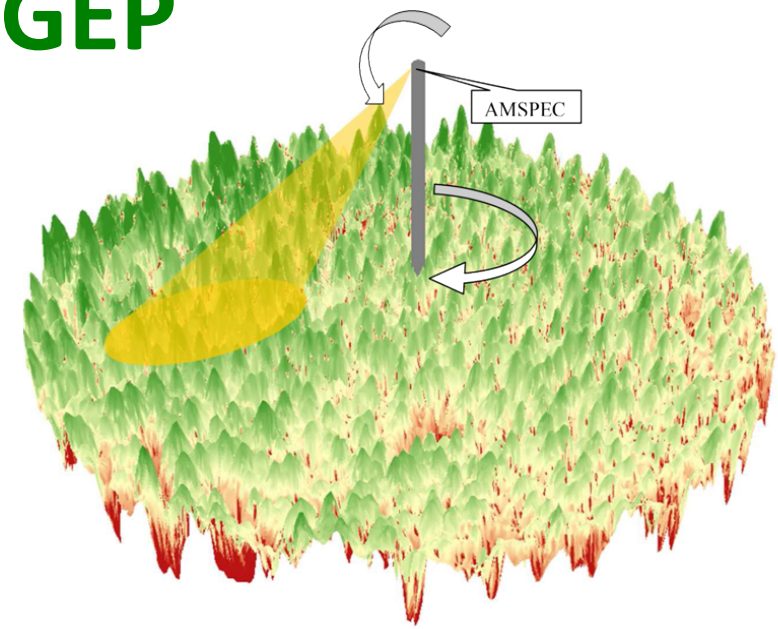
Hilker et al. RSE (2012)

Respiration

NEP



GEP

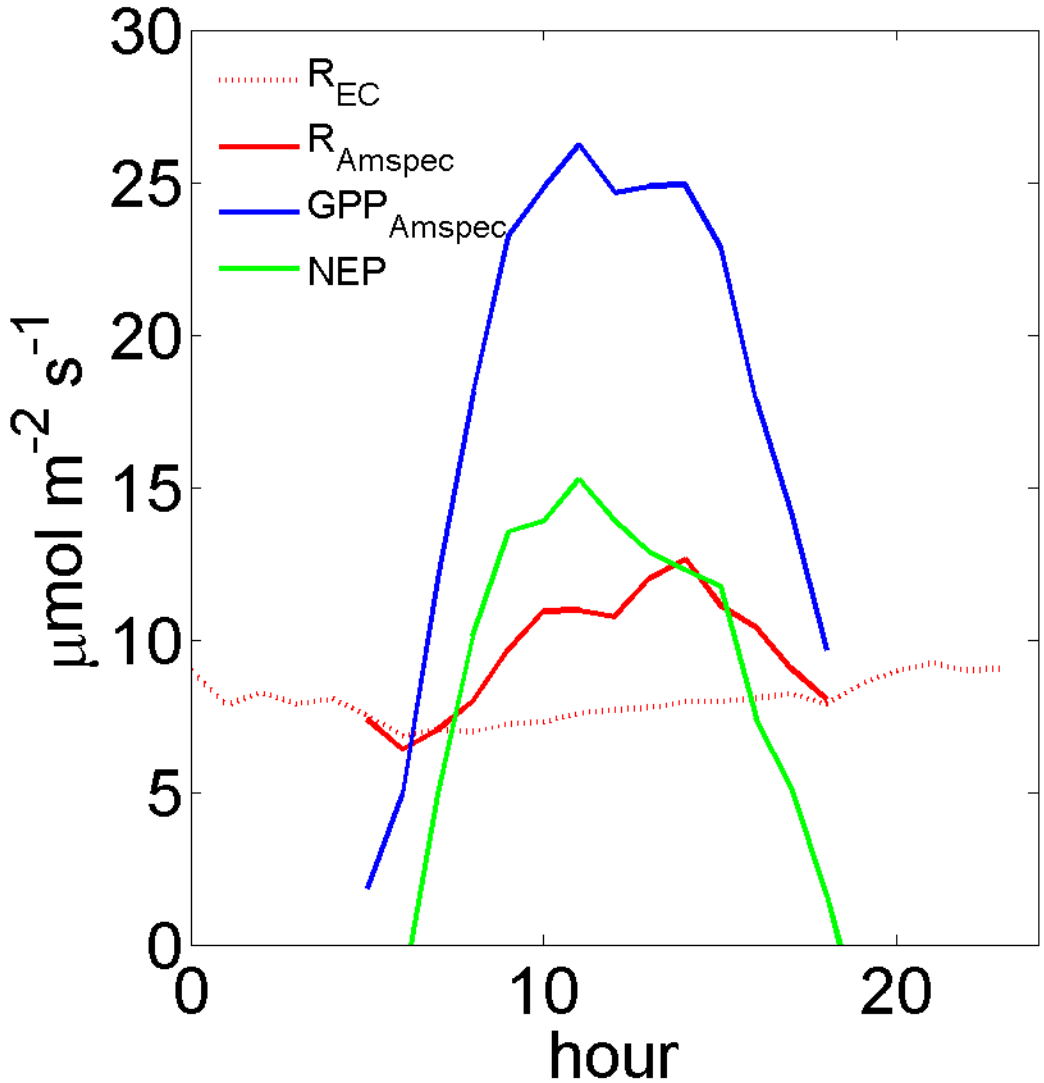


→ GPP=NPP-R

We can determine R independently of T_{Soil}

Hilker et al. Ag and For Met (2012)

Diurnal variability of R



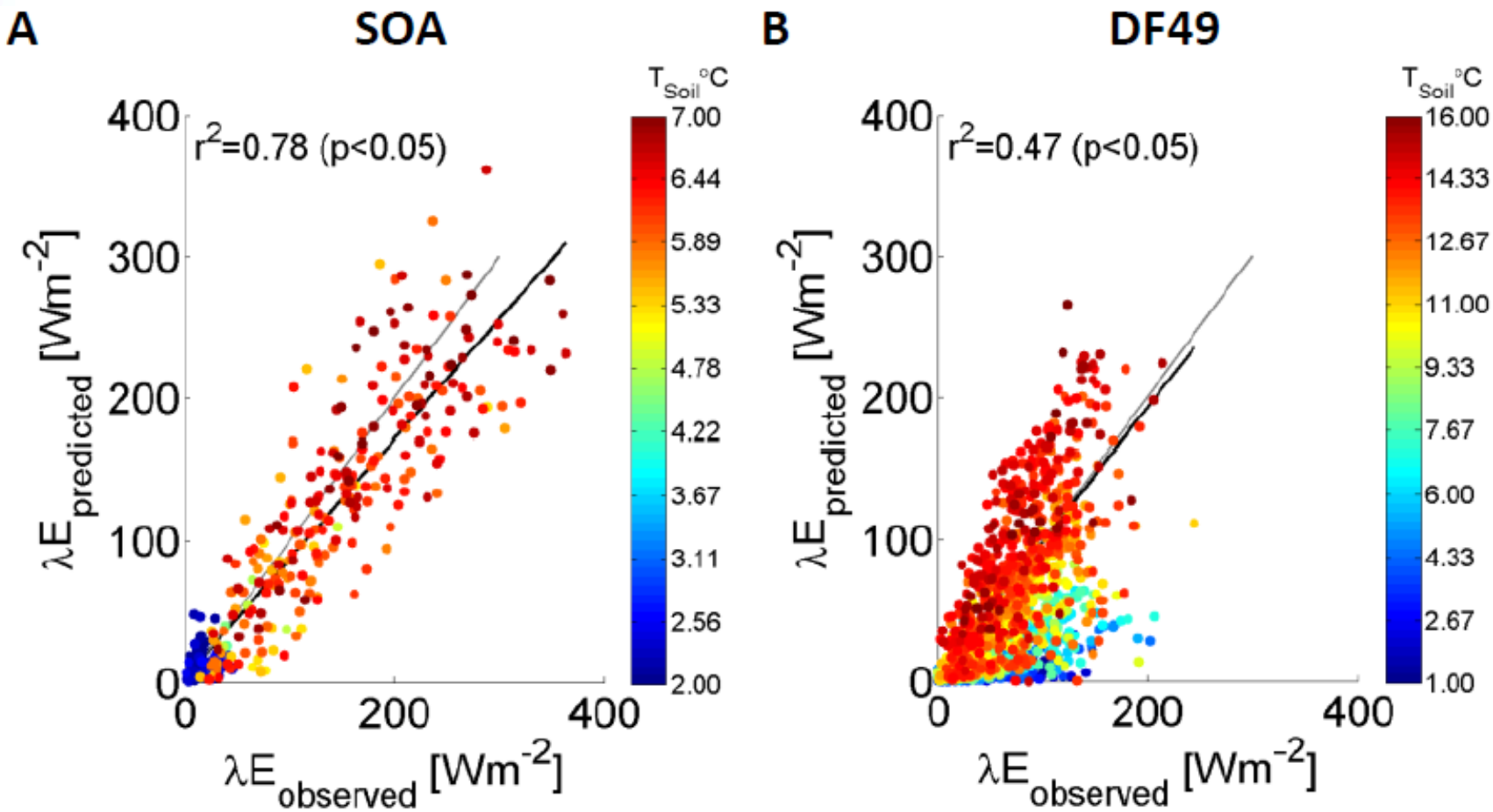
Hilker et al. Ag and For Met (2012)

Energy balance

H	λE
$$H = \frac{\rho c_\rho (T_c - T_A)}{r_a}$$	$$\lambda E = \frac{\rho c_\rho \partial_e}{\gamma (r_c + r_a)}$$

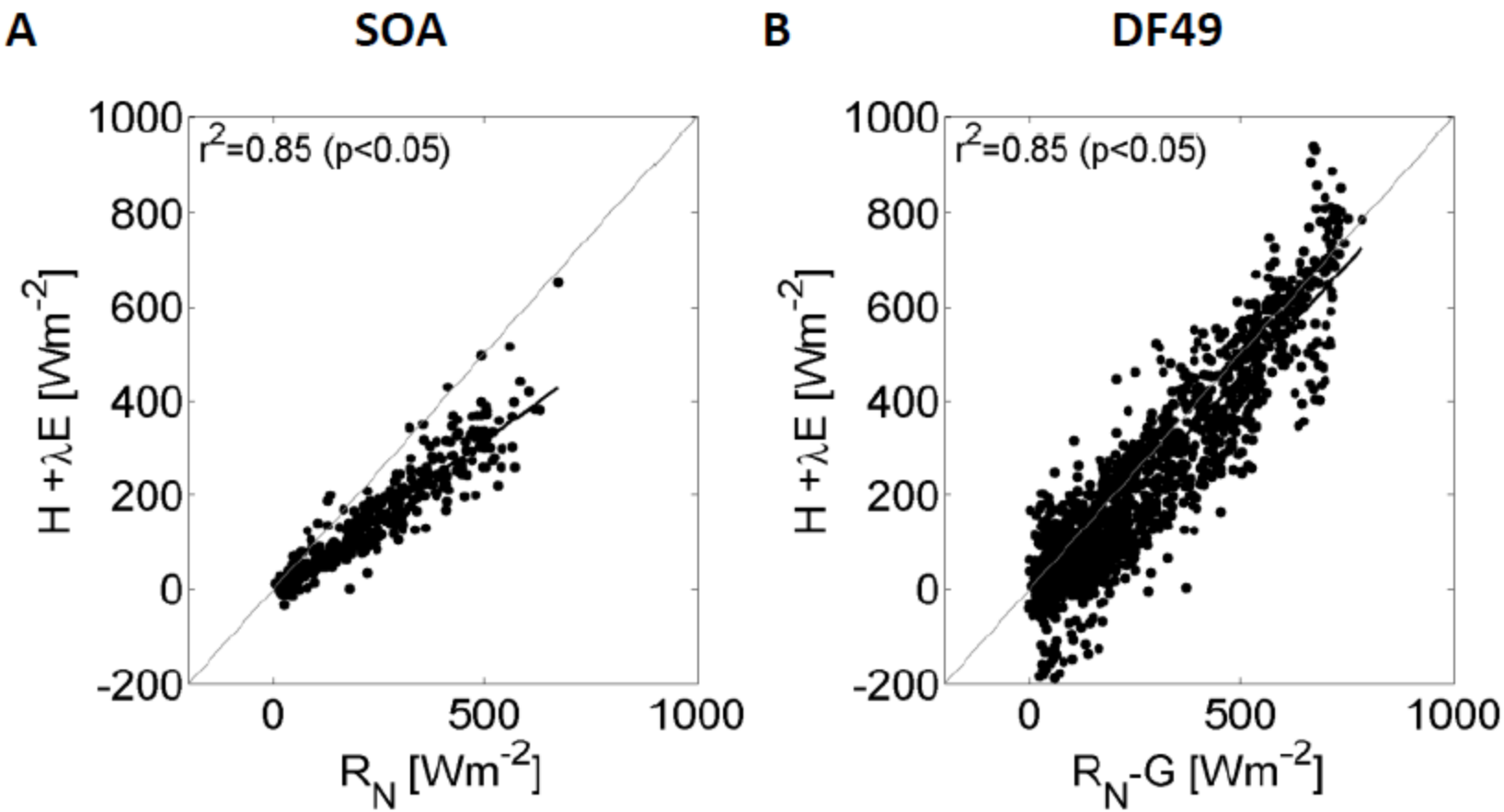
Hilker et al. GCB (2012)

Energy Balance: λE



Hilker et al. GCB (2012)

Energy Balance
(spectral) $\lambda E + H$ = (tower) $R_N - G$?



Hilker et al. GCB (2012)

Recent relevant publications:

1. Hall, F.G., et al., N.C., 2012. Data assimilation of photosynthetic light-use efficiency using multi-angular satellite data: I. Model formulation. Rem. Sens. Environ., 121: 301–308.
2. Hilker, T. et al., 2012a. Data assimilation of photosynthetic light-use efficiency using multi-angular satellite data: II Model implementation and validation. Rem. Sens. Environ., 121: 287–300
3. Hilker, T. et al., 2012b. A new technique for estimating daytime respiration of forest ecosystems. Agr. For. Met.
4. Hilker, T. et al., 2012c. On the Remote Sensing of Heat Fluxes and Surface Energy Balance. Global Change Biology.
5. Hilker, T. et al., 2011. Inferring terrestrial photosynthetic light use efficiency of temperate ecosystems from space. JGR-Biogeosc., 116.
6. Hall, F.G. et al., 2011. PHOTOSYNSAT, photosynthesis from space: Theoretical foundations of a satellite concept and validation from tower and spaceborne data. Rem. Sens. Environ., 115(8): 1918-1925.
7. Hilker, T. et al., 2010. Remote sensing of photosynthetic light-use efficiency across two forested biomes: Spatial scaling. Rem. Sens. Environ., 114: 2863–2874.
8. Hall, F.G. et al., 2008. Multi-angle remote sensing of forest light use efficiency by observing PRI variation with canopy shadow fraction. Rem. Sens. Environ., 112(7): 3201-3211.

Conclusions

1. PRI' quantifies light use efficiency (LUE) independent of ecosystem variations in canopy structure and unstressed reflectance.
2. Near instantaneous multi-angle data are required to simultaneously quantify PRI and shadow fraction.
3. For the first time we have an eddy-correlation independent, spectral method to quantify GPP from towers and space.
4. Used in a data assimilation mode with GPP model, our satellite GPP algorithm can provide high spatial resolution, diurnal estimates of GPP.
   - The ability to infer light use efficiency at regional scales allows us also to infer respiration independently of T_{soil} and
   - To remotely sense the key components of the surface energy balance.
5. A network of AMSPEC sites (@≈30k ea) could help rapidly refine process understanding and modeling in other ecosystems.

Recommendations

- A wide-swath (~700km) satellite (along track multi-angle viewing) with PRI bands, chlorophyll absorption and NIR bands (for Fpar) could provide important advancements in the quantification and understanding of the global carbon, water and energy cycle.

Spaceborne photosynthesis

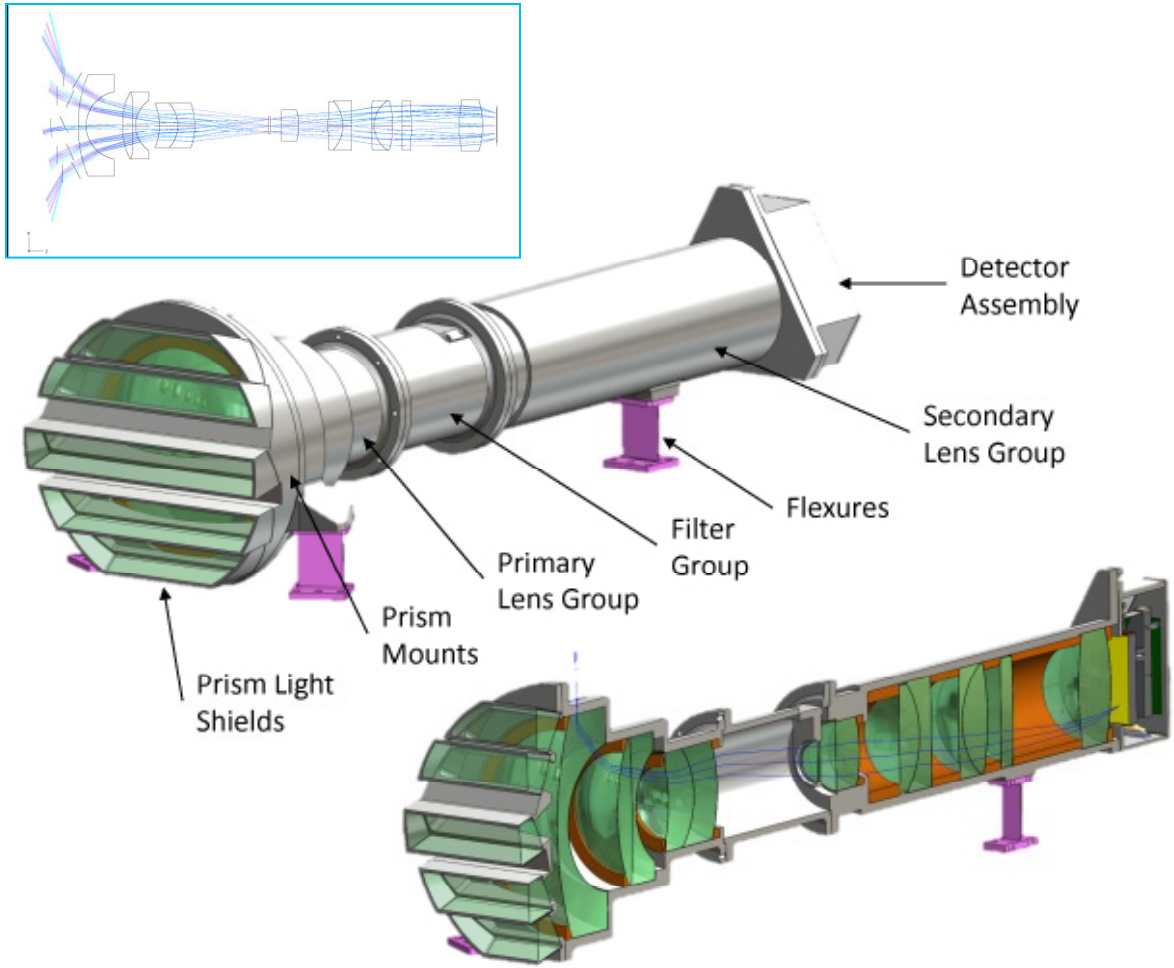


Figure: NASA Goddard Space Flight Center