Does carbon sequestration of semi-arid forests contribute to climate change mitigation?

Dan Yakir, and the Yatir Team,

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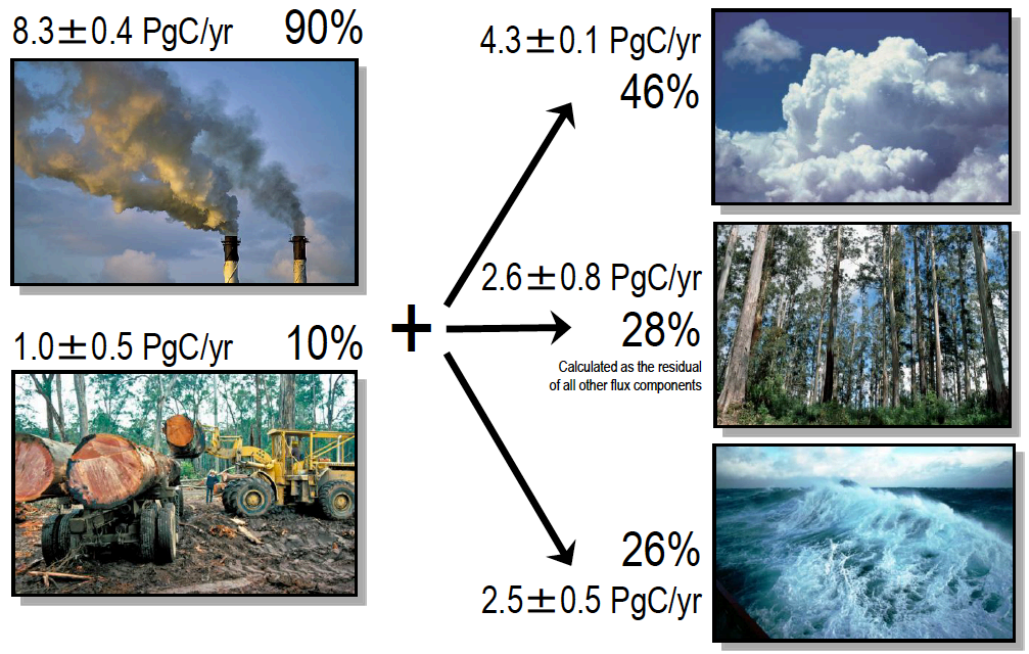
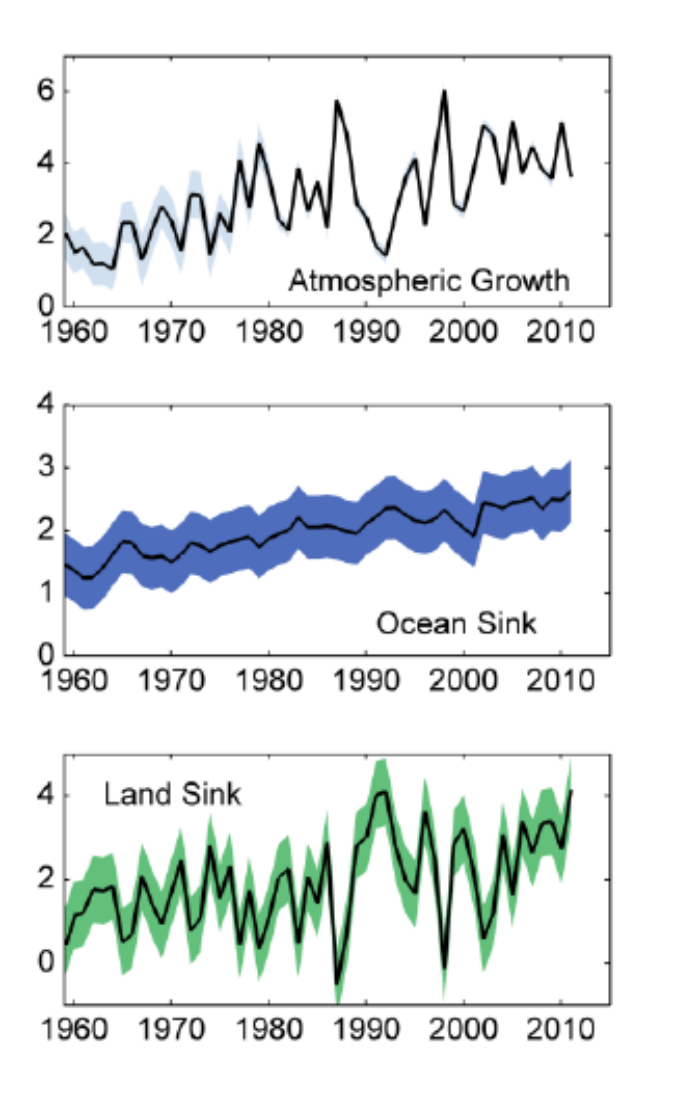
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

The long-term team

I. The mitigation role of land vegetation: 28%, going strong…

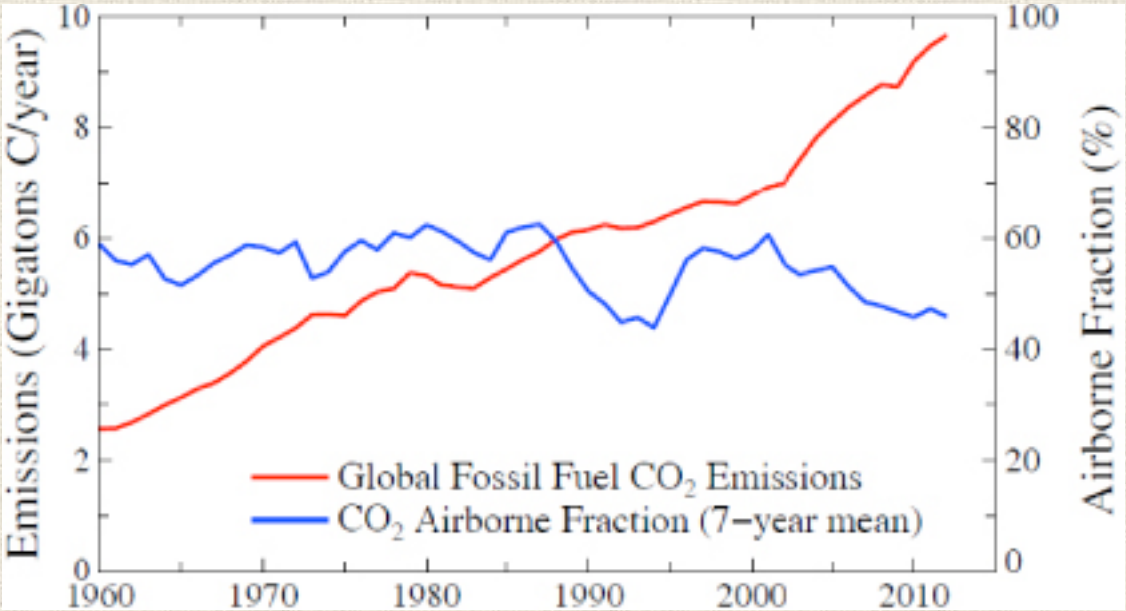
9.3 = 4.3 + 2.5 + 2.6
Emission= atm. Ocean land





Terrestrial sink increase with emission

…around 2000, change of emission rate from 1:5%/yr to 3:1%/yr; airborne fraction-down from ~55 to ~45



CO_2 fertilization effect is likely the major effect..

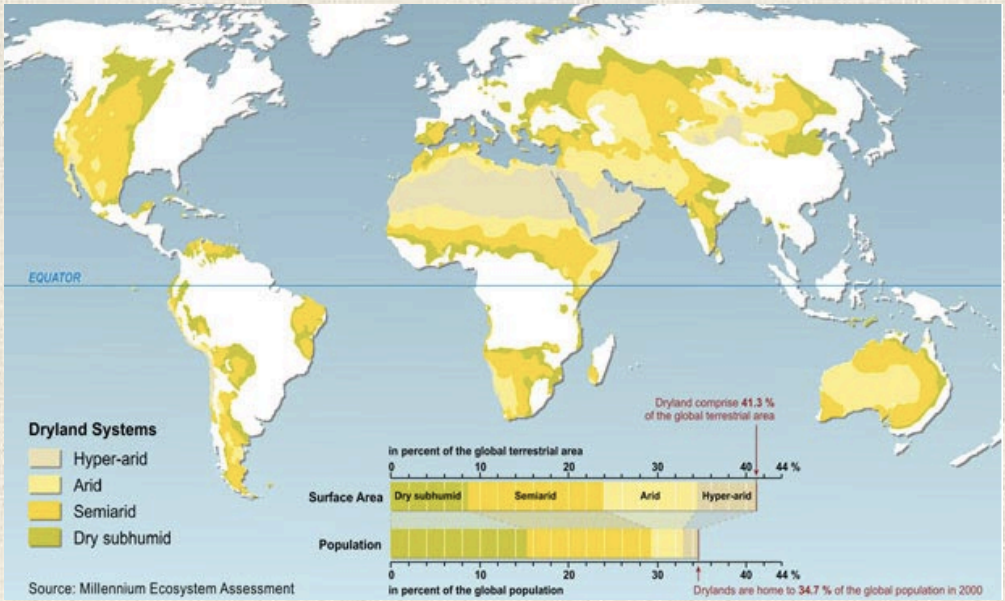
Hansen et al 2013

II. The importance of semi-arid ecosystems

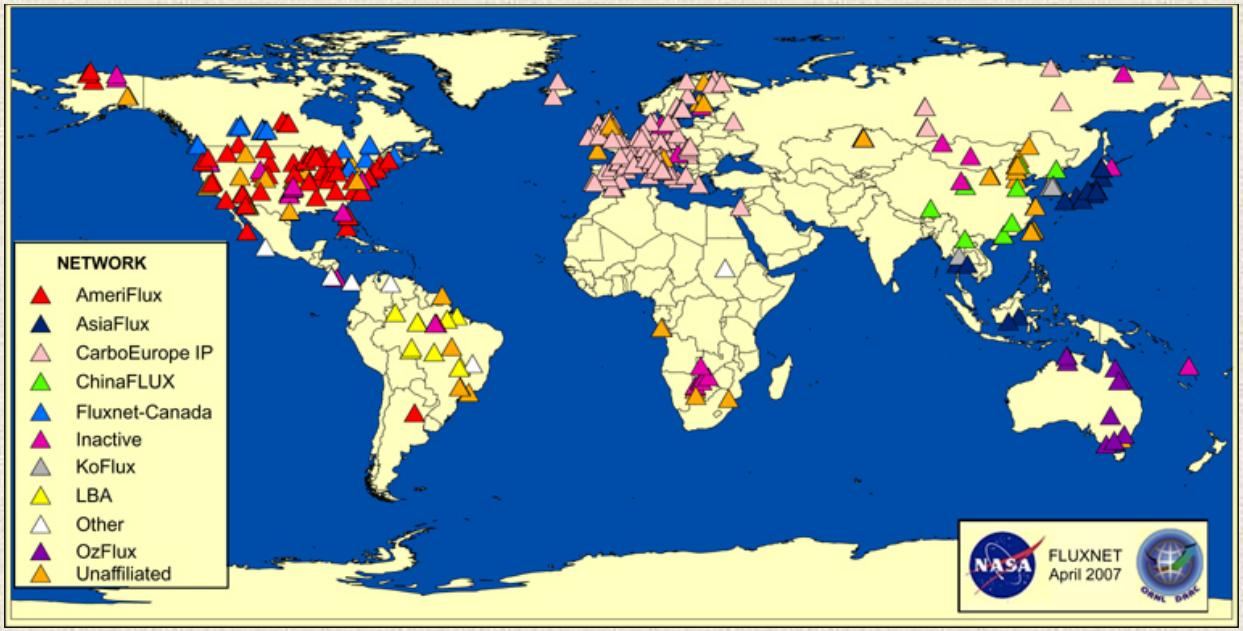
≈ 1/3 of the world ‘s population lives in dry, arid, subhumid regions.

≈ 38% - 47% of the Earth ‘s land area are such areas.

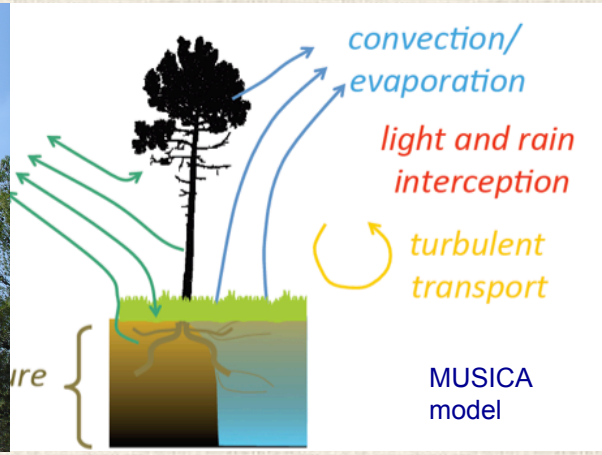
≈ 0.04 % desertification increase yr^{-1} (3 times Israel).



…in spite of its importance: Poor correlation between research sites and climate diversity: Semi-arid regions poorly represented



The Yatir research (flux) site (2000-present)



III. Extreme events vs. extreme environment…

Vol 437|22 September 2005|doi:10.1038/nature03972 nature

LETTERS

Europe-wide reduction in primary productivity caused by the heat and drought in 2003

…, N. Viovy[1], A. Granier[4], J. Ogée[5], V. Allard[6], M. Aubinet[7], N. Buchmann[8], …ra[10], F. Chevallier[1], N. De Noblet[1], A. D. Friend[1], P. Friedlingstein[1], T. Grünwald[9], …[11], A. Knohl[12,13], G. Krinner[14], D. Loustau[5], G. Manca[2]†, G. Matteucci[15]†, F. Miglietta[16], …le[2], K. Pilegaard[18], S. Rambal[17], G. Seufert[15], J. F. Soussana[6], M. J. Sanz[10], E. D. Schulze[12], …i[2]

Climate extremes and the carbon cycle

Markus Reichstein[1], Michael Bahn[2], Philippe Ciais[3], Dorothea Frank[1], Miguel D. Mahecha[1], Sonia I. Seneviratne[4], Jakob Zscheischler[1,4,5], Christian Beer[1,6], Nina Buchmann[4], David C. Frank[7,8], Dario Papale[9], Anja Rammig[10], Pete Smith[11], Kirsten Thonicke[10], Marijn van der Velde[12], Sara Vicca[13], Ariane Walz[14] & Martin Wattenbach[15]

- *Extreme Events*, result in dramatic negative effects on C cycle
- vs.
- Extreme Environments induce a range of 'adjustments' and stabilize C cycle

Global Change Biology (2003) **9**, 791–799

SHORT COMMUNICATION

Carbon sequestration in arid-land forest

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Biogeosciences

Biogeochemical factors contributing to enhanced carbon storage following afforestation of a semi-arid shrubland

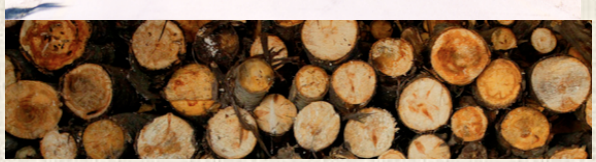
J. M. Grünzweig[1], I. Gelfand[2], Y. Fried[1], and D. Yakir[2]
[1]Robert H. Smith Institute of Plant Sciences and Genetics in Agriculture, Faculty of Agricultural, Food and Environmental Quality Sciences, the Hebrew University of Jerusalem, Rehovot 76100, Israel
[2]Department of Environmental Sciences and Energy Research, Weizmann Institute of Science, Rehovot 76100, Israel

A range of 'Ecosystem Services' provided by semi-arid afforestation

Table 1. Indicators of carbon use efficiency in pine forests: Gross primary productivity (GPP), ecosystem respiration (R_e) and net ecosystem exchange (NEE) of carbon for the 12 European pine forest sites (62 data years, *36*), for the entire global Fluxnet network (*43*), and for semiarid forest (Yatir; *44*).

Pine forest	GPP	Re	NEE	NEE/GPP
European (Carboeurope)	1142	944	200	0.17
Global (FluxNet)	1540	1280	260	0.17
Semi-arid (Yatir)	820	600	220	0.27

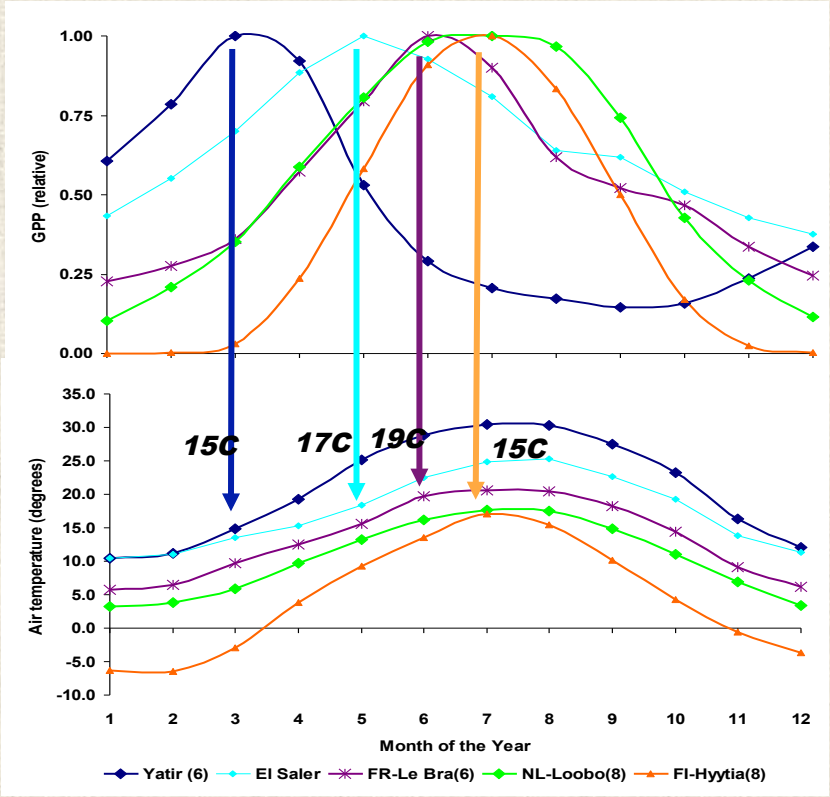
gr carbon m^{-2}



What are the ingredients of sustainable dryland forest?

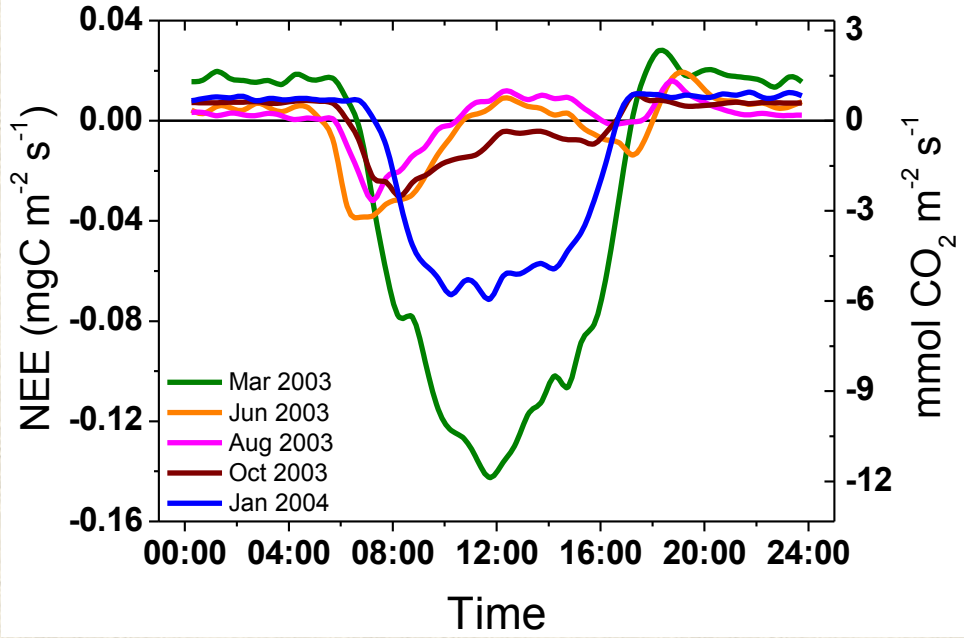
1) Phenology:

- "homeostatic-like" response across climates
- continued summer activity primes the system for following season

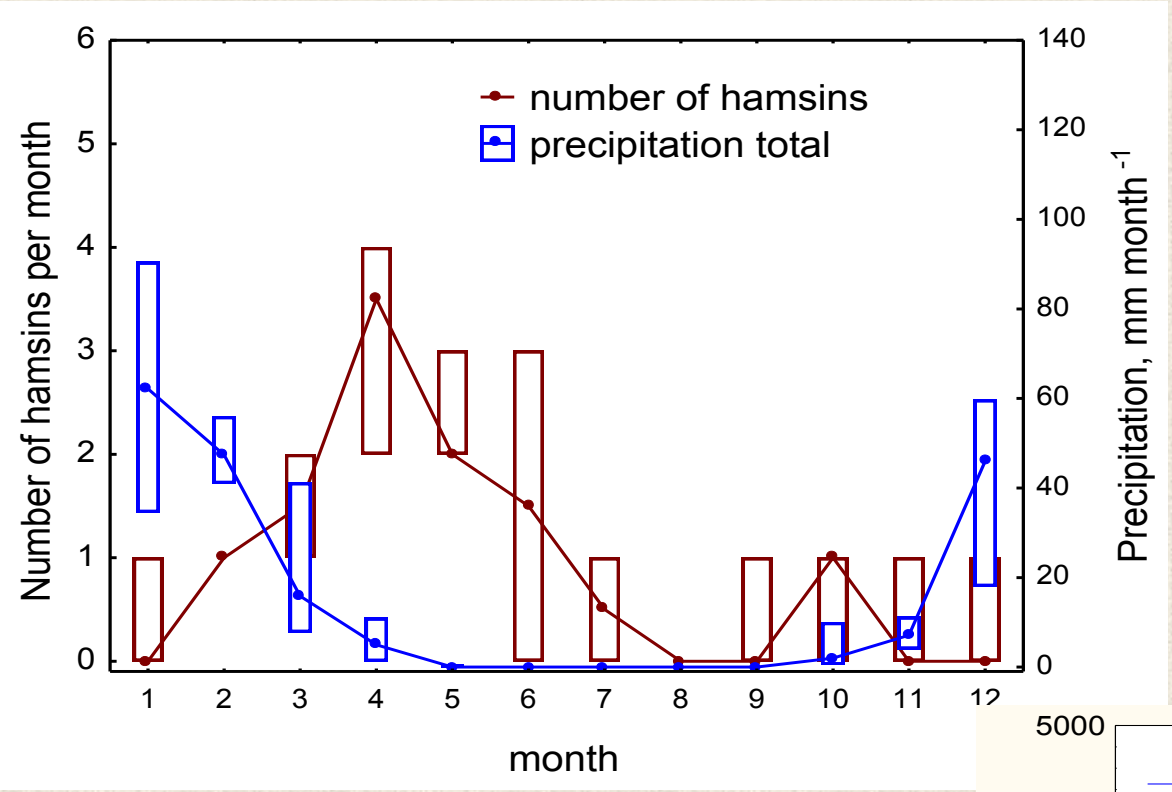


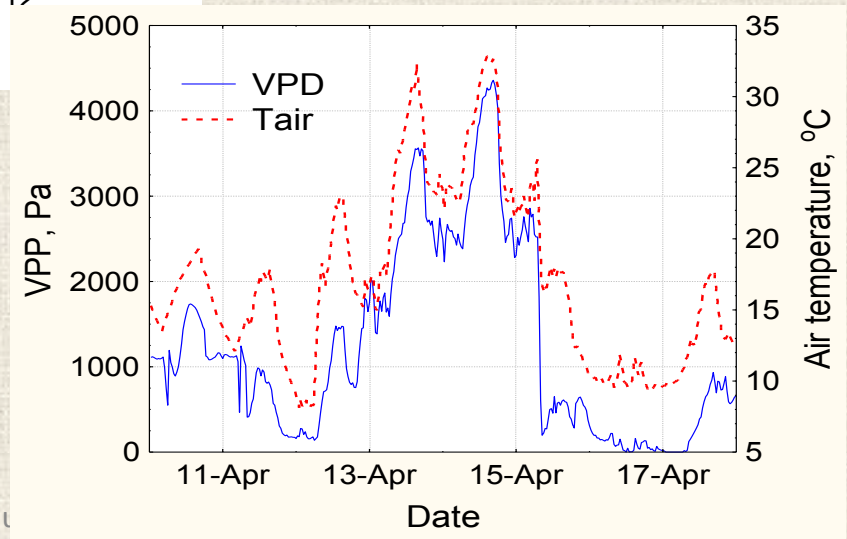
Annual cycle

Daily cycle

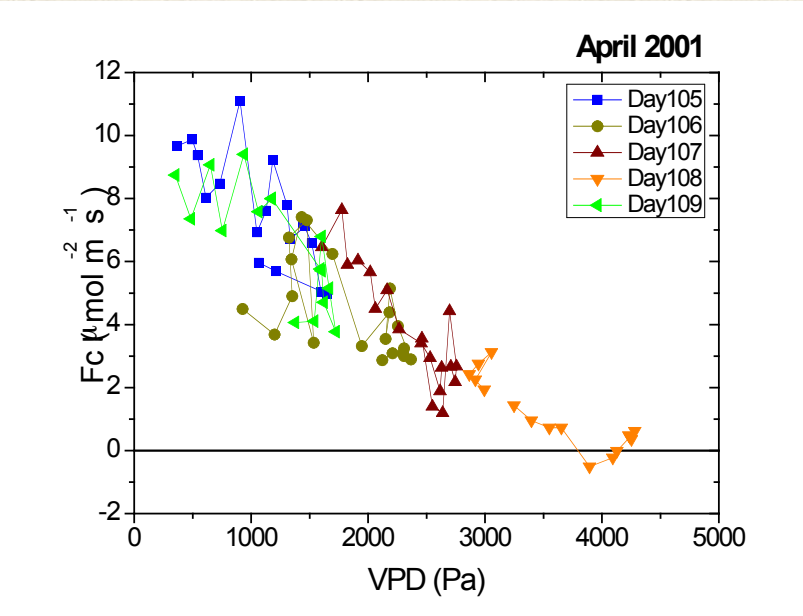


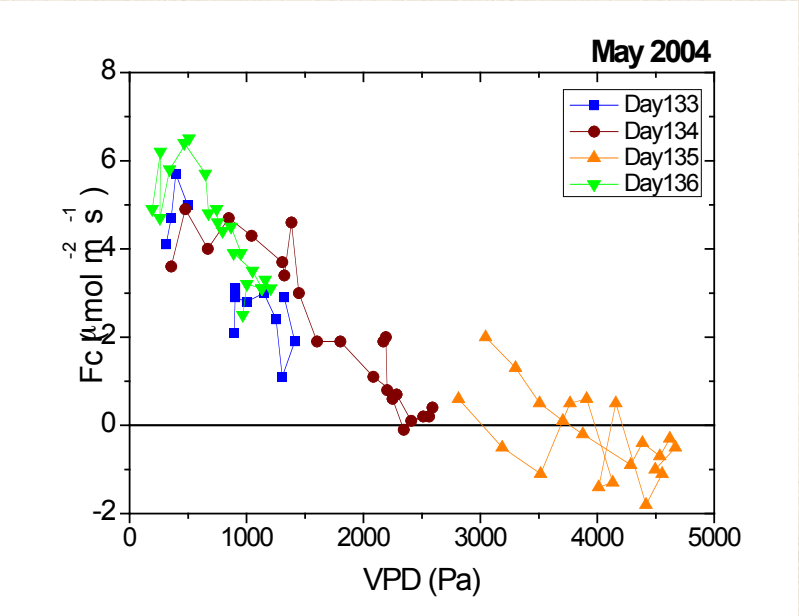
2. Resilience: Heat waves most abundant during peak activity period

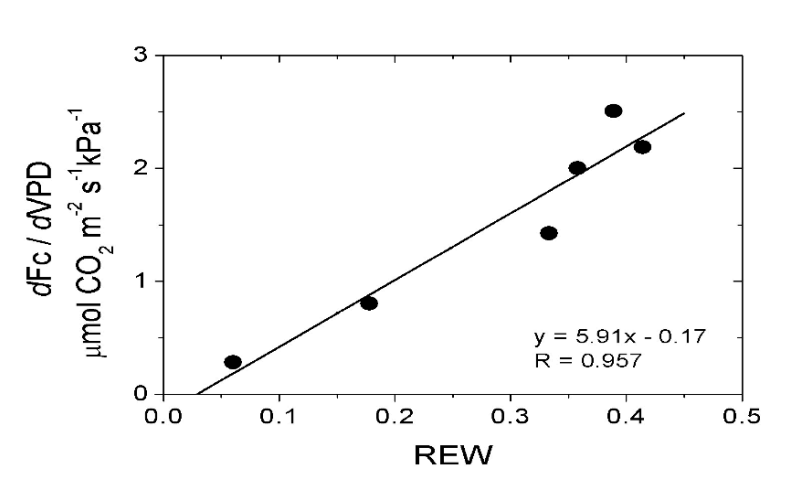




2a. Resilience: full recovery in episodic heat waves:

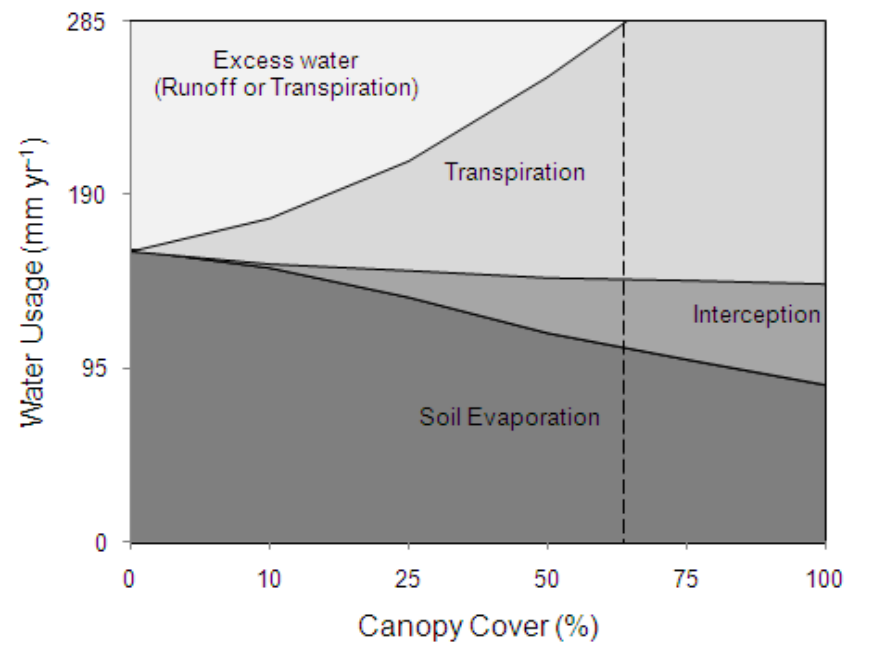






Soil moisture vs air moisture stress

3. **Efficient hydrology:** ET is ~95% of P



P = 289 mm (100%)

61 mm: E_s (~10%), I (~11%), R (0%)

Infiltrated water = 228 mm ; 79%

26 mm, E_s (9%)

tSWC = 202 mm ; 70%

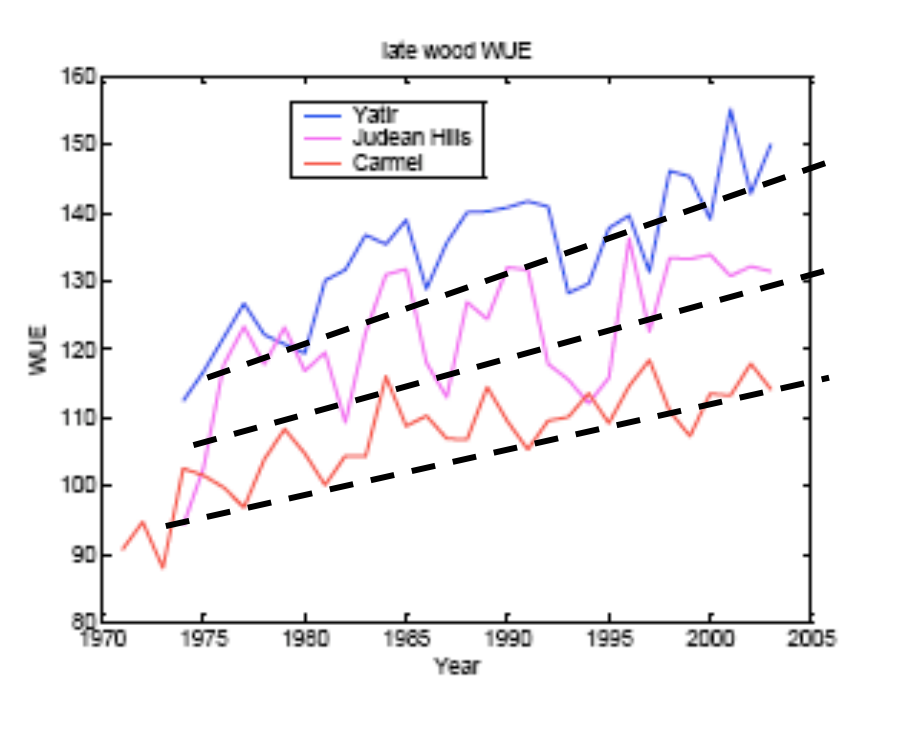
38 mm: S (~5%) + T_u (~8%)

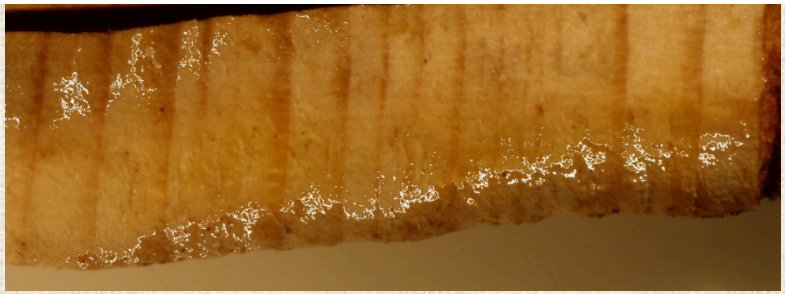
T_t = 164 mm ; 57%

P = R + S + **ET**
P, precipitation
I, interception
R, runoff
S, deep soil recharge
ET, evapotranspiration

ET = $T_t + T_u + I + E_s$
T_t, tree transpiration
T_u, understory vegetation transpiration
I, leaf and soil surface interception
E_s, soil evaporation

4. Increasing WUE: ^{13}C derived WUE: ~25% increase in WUE (CO_2 "fertilization effect")





Yatir site

Oecologia (2011) 167:573–585
DOI 10.1007/s00442-011-2010-4

GLOBAL CHANGE ECOLOGY - ORIGINAL PAPER

Increase in water-use efficiency and underlying processes in pine forests across a precipitation gradient in the dry Mediterranean region over the past 30 years

Kadmiel Maseyk · Debbie Hemming · Alon Angert · Steven W. Leavitt · Dan Yakir

Globally

LETTER

doi:10.1038/nature12291

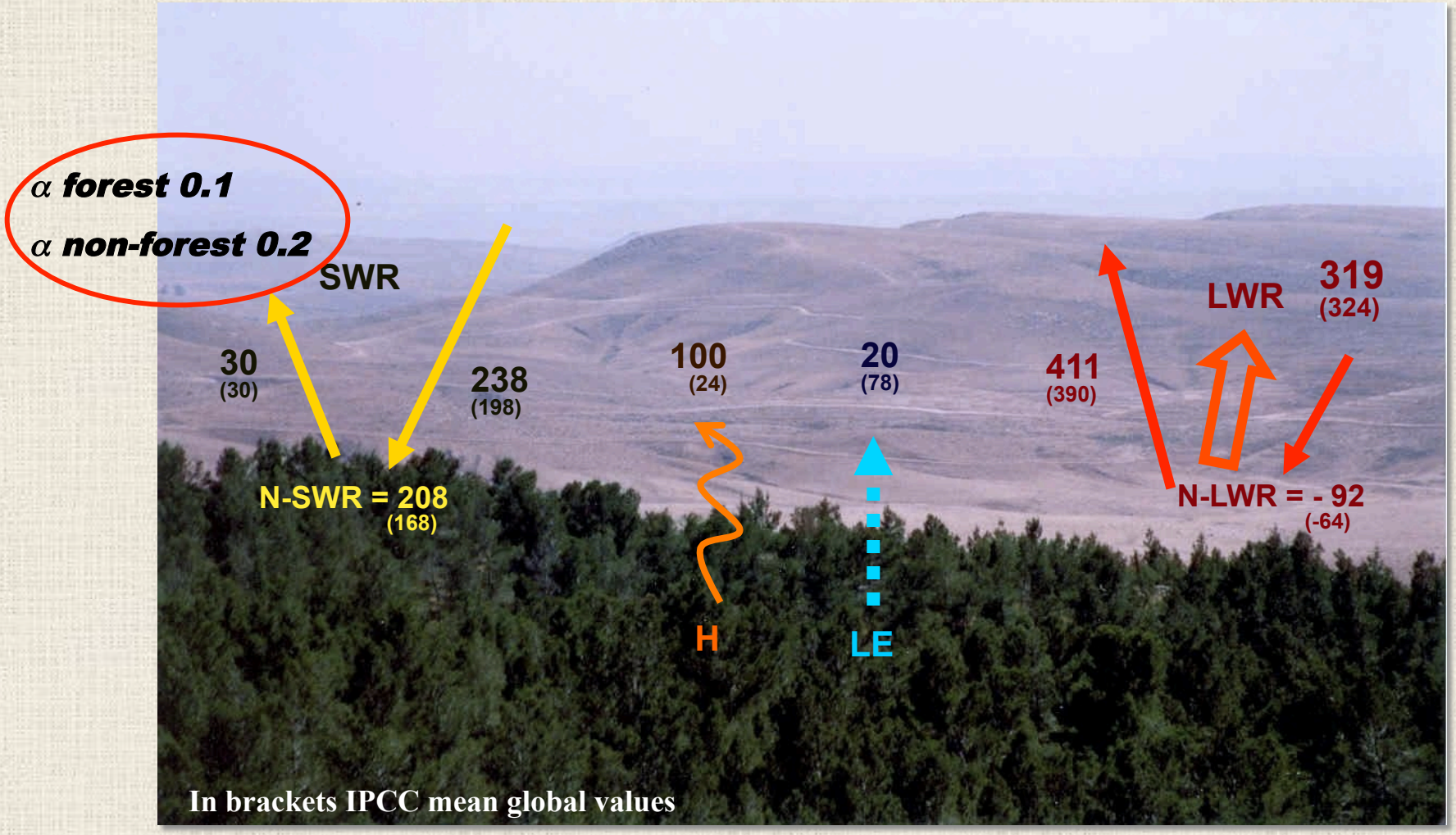
Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise

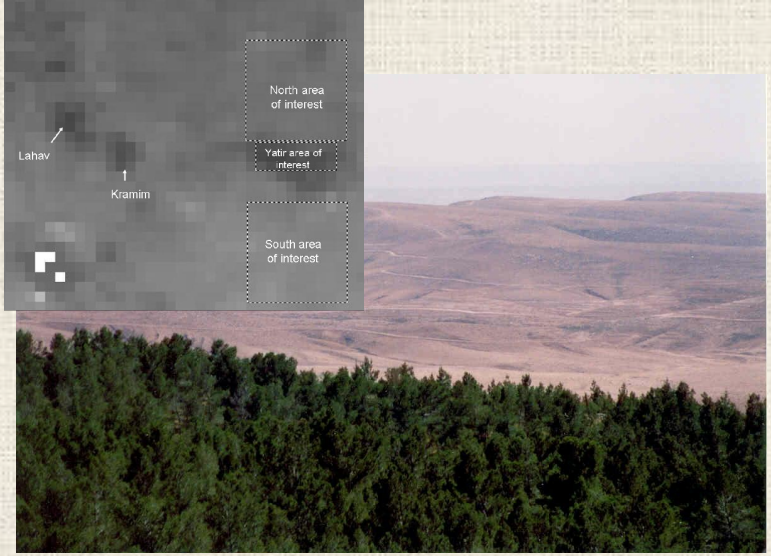
Trevor F. Keenan[1], David Y. Hollinger[2], Gil Bohrer[3], Danilo Dragoni[4], J. William Munger[5], Hans Peter Schmid[6] & Andrew D. Richardson[1]

- CO_2 up 330 to 380 ppm
- T up ~1.5C,
- No trend in P
- Tree age variable

However…

5. CANOPY ENERGY BALANCE: direct interactions with the climate system (3 y mean values; W M^{-2})





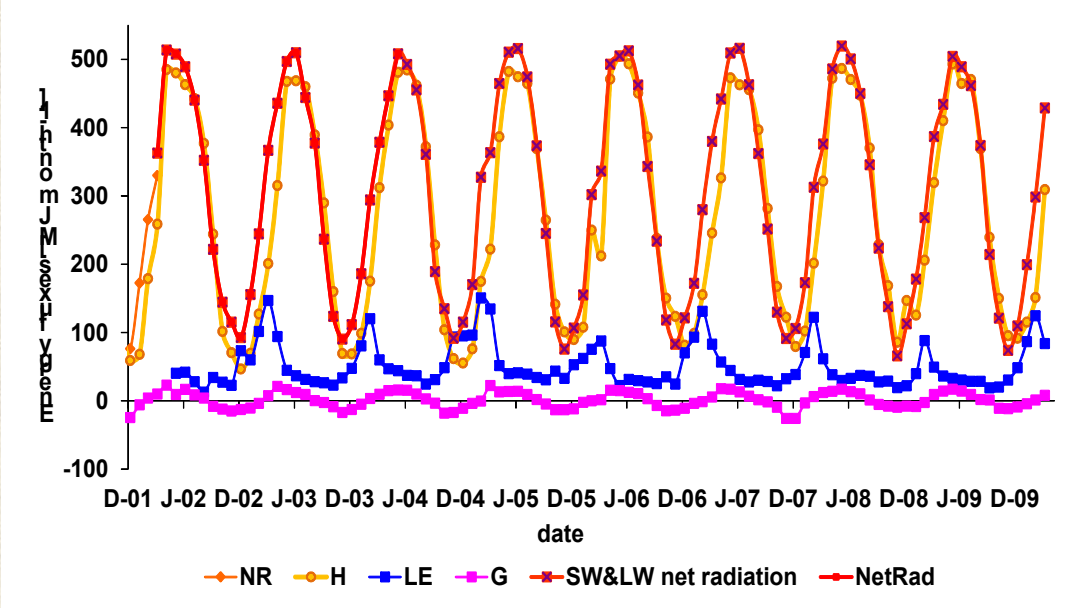
Albedo effect: High radiation,
low cloud, reflective background…

Water-cooled canopy…

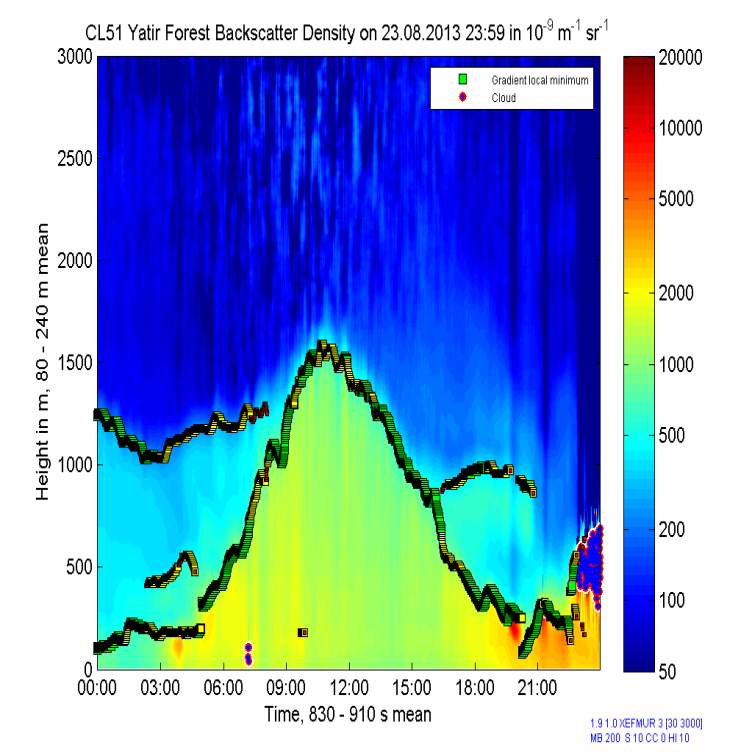
Air-cooled canopy…
('convector effect')

*Cooling relative to non-forest area:
~5C annual mean
Up to ~30C in summer mid-day

Monthly mean energy fluxes over the Yatir forest



Boundary layer dynamics



H similar magnitude to Rn most of the year

Low aerodynamic resistance: *"canopy convector effect"*

Lower surface temperature *in forest: 5C (up to 30C)*

Large H may affect PBL

Possible effects on local circulation…

Semi-arid afforestation balance sheet:

Variable	Forest	Shrubland	
Global radiation (Eg, Wm^{-2})	238	238	
Albedo (unit-less)	0.11	0.21	*d=+23.8 Wm^{-2}*
Net solar radiation (Sn, Wm^{-2})	212	188	
Net longwave radiation (Ln, Wm^{-2})	-96	-121	*d=+25 Wm^{-2}*
Net radiation (Rn=Sn+Ln, Wm^{-2})	115	67	*d=+48 Wm^{-2}*
Skin temperature [°C]	19	24*	

1. Cooling effect: C sequestration ~2.2 t ha-1 Decreasing radiation load <1 W m^{-2}

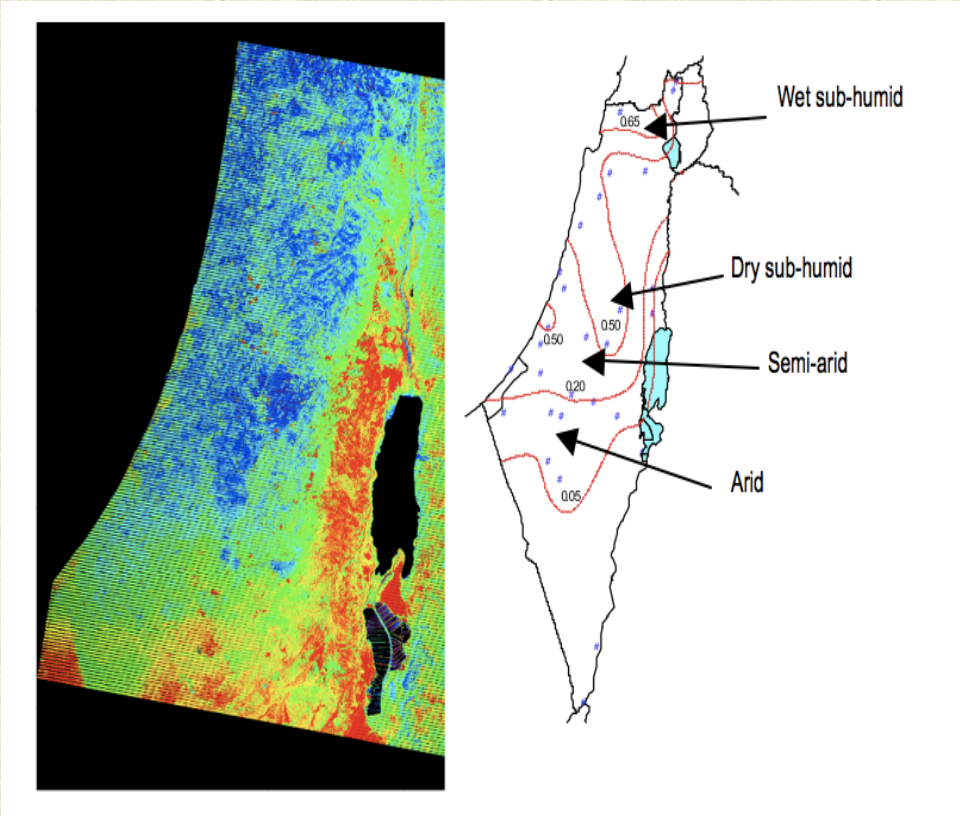
2. Warming effect: Increased surface radiation load ~48 w m^{-2}

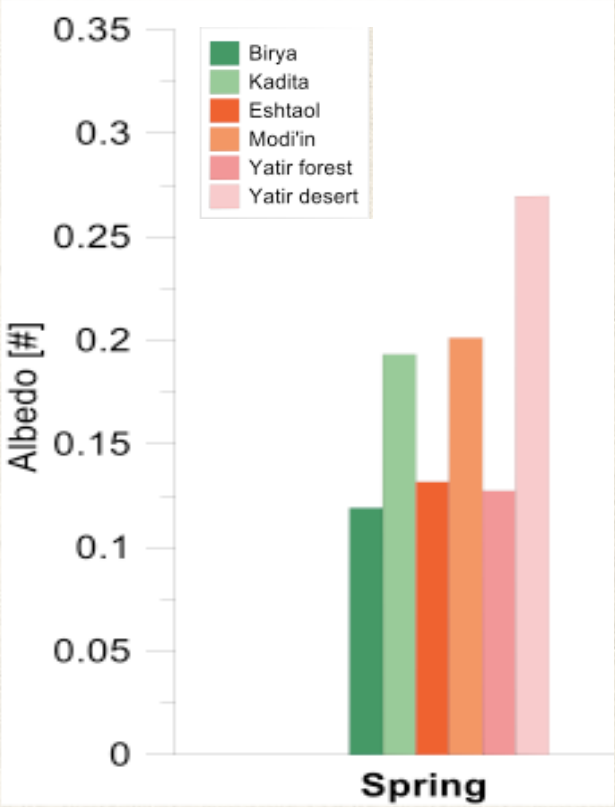
3. Balanced achieved only after 50-80 years of C sequestration

4. **….worst case scenario…**

Extending the range with the WIS Mobile flux lab

Variations in forestation effect on albedo





Bottom-line II:

- Land biosphere is a critical component in mititgation
- Dry, semi-arid and forest are significant compoent I this framework
- Wide range of adjustments (phenology, CUE, WUE, NUE, available ecotypes) will maintain forest (pine) cover and relatively high C sequestration potential under drying conditions.
- ***But,*** forests interactions with climate, can have both positive and negative effects (surface energy warming effects; large sensible heat can affect circulation).

Science AAAS

Contribution of Semi-Arid Forests to the Climate System
Eyal Rotenberg, *et al.*
Science **327**, 451 (2010);
DOI: 10.1126/science.1179998

LETTERS

edited by Jennifer Sills

Forests and Climate: A Warming Paradox

E. ROTENBERG AND D. YAKIR ("CONTRIBUTION OF SEMI-ARID FORESTS TO THE CLIMATE SYSTEM," Reports, 22 January, p. 451) showed that forestation may not be an effective tool for climate change mitigation. They found that in a semi-arid landscape, the warming potential of a forest due to changes in the surface albedo and the longwave radiation emission far outweighs the cooling effect due to carbon sequestration. However, their analysis did not address the fact

Thank you