On the Objectives of Landscape Restoration: Forest Carbon, Water, and Energy Cycle Synergies & Nature-Based Solutions

David Ellison

Natural Resource Policy Group (NARP), Environmental Systems Science, ETH Zurich
Land Systems and Sustainable Land Management (LS-SLM), Geography Institute, U. Bern

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REVIEW

On the forest cover–water yield debate: from demand- to supply-side thinking

DAVID ELLISON*†‡, MARTYN N. FU

*Institute for World Economics, Hungarian Academ
Swedish University of Agricultural Sciences, 90183
Umeå University, Umeå, Sweden, §Department of A
75007 SE Uppsala, Sweden, ¶Department of Earth S

Abstract

Several major articles from the past decade and
yield is negative: additional forest cover will re
second group of authors argue the opposite: p
and intensify the hydrologic cycle. Obtaining s
ficult due to the larger scales at which the posi
est cover is *inextricably* linked to precipitation.
contributes to the availability of atmospheric m
of precipitation events and increasing water yi
sonal relationships heighten the importance of
perspectives. This clarifies the generally benef
logic cycle. While evidence supports both sides
– at larger scales, trees are more clearly linked
tion, land conversion from forest to agricultu
precipitation, prompting us to think of forest
product water footprints, estimate the value of
strategies and otherwise manage land use mus

Keywords: afforestation, climate change adaptation

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Introduction

Water availability – both now and in the futu
the utmost importance. However, the role o
their impact on precipitation, water yield
hydrologic cycle more generally remain h
tested. Afforestation strategies to ameliorate d
flows have come under increasing scrutiny a
(Calder, 2002; Jackson *et al.*, 2005; Trabucco *et*
Malmer *et al.*, 2009). Although the global war
climate change adaptation potential of forests
ciated ecosystem services are mobilized to bo
tial carbon sequestration, fossil fuel substitu
biodiversity protection; the potentially benef

Correspondence: David Ellison, tel. + 36 30 929 5246, fax + 36 1 224 6761, e-mail: EllisonDL@gmail.com

Research paper

CrossMark

14

Upwind forests: managing moisture recycling for nature-based resilience

D. Ellison, L. Wang-Erlandsson, R. van der E

Trees and forests multiply the oceanic supply of freshwater through moisture recycling, pointing to an urgent need to halt deforestation and offering a way to increase the water-related benefits of forest restoration.

Efficient and effective for
water-related nature-base
tions to challenges in huma
opment require a holistic unders
of the role of forest–water inter
in hydrologic flows and water su
local, regional and continental lan
Forest and water resource mana

GLOBAL FOREST GOALS

United Nations FORUM ON FORESTS

Background Analytical Study 2

Forests and Water [1]

David Ellison [2]

Background study prepared for

nature geoscience

ARTICLES

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Check for updates

OPEN

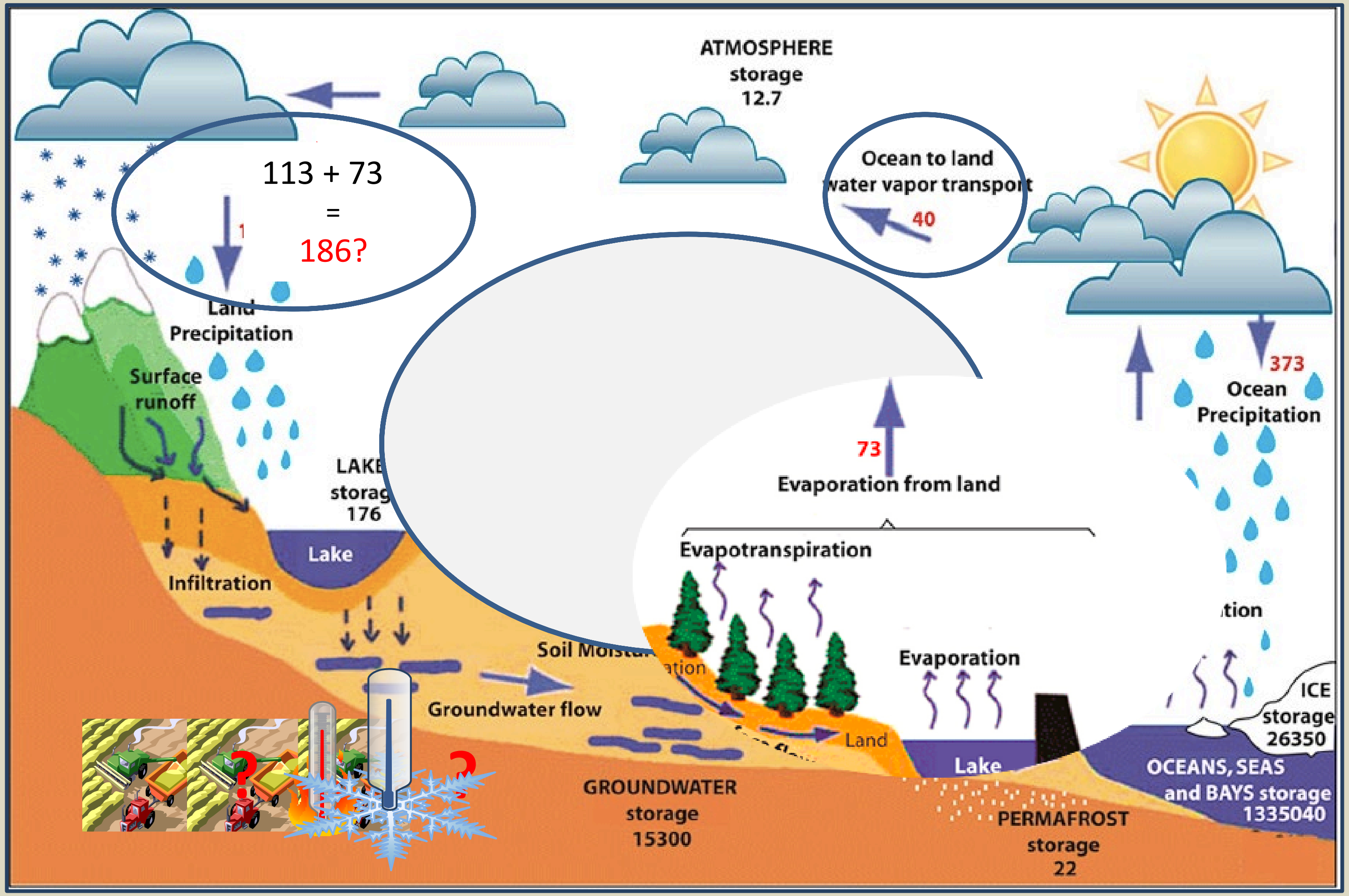
Shifts in regional water availability due to global tree restoration

Anne J. Hoek van Dijke[1,2,3], Martin Herold[2,4], Kaniska Mallick[1], Imme Benedict[5], Miriam Machwitz[1], Martin Schlerf[1], Agnes Pranindita[6,7], Jolanda J. E. Theeuwen[8,9], Jean-François Bastin[10] and Adriaan J. Teuling[3]

Tree restoration is an effective way to store atmospheric carbon and mitigate climate change. However, large-scale tree-cover expansion has long been known to increase evaporation, leading to reduced local water availability and streamflow. More recent studies suggest that increased precipitation, through enhanced atmospheric moisture recycling, can offset this effect. Here we calculate how 900 million hectares of global tree restoration would impact evaporation and precipitation using an ensemble of data-driven Budyko models and the UTrack moisture recycling dataset. We show that the combined effects of directly enhanced evaporation and indirectly enhanced precipitation create complex patterns of shifting water availability. Large-scale tree-cover expansion can increase water availability by up to 6% in some regions, while decreasing it by up to 38% in others. There is a divergent impact on large river basins: some rivers could lose 6% of their streamflow due to enhanced evaporation, while for other rivers, the greater evaporation is counterbalanced by more moisture recycling. Several so-called hot spots for forest restoration could lose water, including regions that are already facing water scarcity today. Tree restoration significantly shifts terrestrial water fluxes, and we emphasize that future tree-restoration strategies should consider these hydrological effects.

In June 2021, the United Nations declared the Decade on ... to the deeper roots of trees (facilitating access to water during dry

Global Hydrologic Cycle and Variations in Land Cover



(Gimeno et al 2012)

The total amount of water available for rainfall on the Land Surface is variable and depends heavily on the density and extent of tree and forest cover.

More tree and forest cover can positively affect the relative intensity of the hydrologic cycle across the land surface

Precipitation Recycling: Large and important benefits from increased wetland and forest cover!

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REVIEW

Global Change Biology WILEY

Even cooler insights: On the power of forests to (water the Earth and) cool the planet

David Ellison[1,2] | Jan Pokorný[3] | Martin Wild[4]

[1]Natural Resource Policy Group (NARP), Environmental Systems Science, ETH Zurich, Zurich, Switzerland

[2]Land Systems and Sustainable Land Management Unit (LS-SLM), Institute of Geography, University of Bern, Bern, Switzerland

[3]ENKI, Třeboň, Czech Republic

[4]Institute for Atmospheric and Climate Science, Environmental Systems Science, ETH Zurich, Zurich, Switzerland

Correspondence
David Ellison, Natural Resource Policy Group (NARP), Environmental Systems Science, ETH Zurich, Zurich, Switzerland.
Email: ellisondl@gmail.com

Abstract

Scientific innovation is overturning conventional paradigms of forest, water, and energy cycle interactions. This has implications for our understanding of the principal causal pathways by which tree, forest, and vegetation cover (TFVC) influence local and global warming/cooling. Many identify *surface albedo* and *carbon sequestration* as the principal causal pathways by which TFVC affects global warming/cooling. Moving toward the outer latitudes, in particular, where snow cover is more important, surface albedo effects are perceived to overpower carbon sequestration. By raising surface albedo, deforestation is thus predicted to lead to surface cooling, while increasing forest cover is assumed to result in warming. Observational data, however, generally support the opposite conclusion, suggesting surface albedo is poorly understood. Most accept that surface temperatures are influenced by the interplay of surface albedo, incoming shortwave (SW) radiation, and the partitioning of the remaining, *post-albedo*, SW radiation into latent and sensible heat. However, the extent to which the avoidance of sensible heat formation is first and foremost mediated by the presence (absence) of water and TFVC is not well understood. TFVC both mediates the availability of water on the land surface and drives the potential for latent heat production (evapotranspiration, ET). While latent heat is more directly linked to *local* than *global* cooling/warming, it is driven by photosynthesis and carbon sequestration and powers additional cloud formation and top-of-cloud reflectivity, both of which drive global cooling. TFVC loss reduces water storage, precipitation recycling, and downwind rainfall potential, thus driving the reduction of both ET (latent heat) and cloud formation. By reducing latent heat, cloud formation, and precipitation, deforestation thus powers warming (sensible heat formation), which further diminishes TFVC growth (carbon sequestration). Large-scale tree and forest restoration could, therefore, contribute significantly to both global and surface temperature cooling through the principal causal pathways of carbon sequestration and cloud formation.

KEYWORDS
boreal, carbon, clouds, deforestation, forest cooling, latent heat, latitude, planetary boundaries, reforestation, restoration, solar radiation, surface albedo, surface temperature, temperate, tropics

Ellison, David, Jan Pokorny, Martin Wild (2024). Even Cooler Insights: On the Power of Forests to (Water the Earth and) Cool the Planet, *Global Change Biology*, **30**, 2: e17195.

CLOUD FORMATION

How much of an impact could increased cloud cover have?

Estimated Effect of Increased Forest Cover on the Net Radiative Balance (EEI) and TFVC Drawdown	Estimated Historical Forest Cover Loss (FCL)		Formulas	Logic
	-40%	-50%	(FAO estimate)	cropland + urban settlement conversions
Land Latent Heat Flux (LHF, Wm^2)	38.0	38.0	(Wild, 2015)	Terrestrial Latent Heat Flux
Current Annual TFVC CO_2 Drawdown ($GtCO_2$ -eq yr-1)	-12.5	-12.5	IPCC AR6 WGIII Ch7	Annual TFVC Drawdown
Lost Latent Heat Flux (compared to 100% Forest Cover, Wm^2)	-25.3	-38.0	= (LHF/FC) * (1-FC)	Lost terrestrial latent heat flux (assuming all land can be converted)
Potential LHF (PLHF) with cropland conversion to forest (Wm^2)	10.1	15.2	= (x * .80) * (1 - 0.5)	Potential additional terrestrial latent heat flux assuming only agricultural land (80% of total loss) can be converted - Cropland LHF = 50% * forest LHF)
% Increase in Latent Heat Flux (assume 100% cropland conversion to forest, minus cropland ET Flux)	21%	29%	= PLHF/LHF	Potential % increase in LHF
Change in top-of-cloud OLW (assuming initial 28 Wm^2 OLW flux)	1.7	2.3	= (28 * (PLHF/LHF)) * .29	Estimated change in outgoing LW flux (adj. for 29% land cover) - increases in cloud cover reduce the OLW flux
Change in top-of-cloud OSW (assuming 64 Wm^2 outward reflectivity)	-3.9	-5.3	= -(64* (PLHF/LHF)) *.29	Estimated change in outgoing SW flux (adj. for 29% land cover) - increases in cloud cover increase the OSW flux
Estimated Change in EEI from change in cloud cover (Wm^2)	-2.2	-3.0	= SUM (ΔOLW + ΔOSW)	Potential Change in EEI from Increased Cloud Cover
Estimated Change in Total Annual TFVC Drawdown ($GtCO_2$-eq yr^{-1})	-8.3	-12.5	= (DD/FC) * (1-FC)	Potential Change in TFVC Drawdown from Increased TFVC

IPCC AR6 WGI Ch7: the EEI is estimated at 0.5 ± .185 Wm^2 (for the period 1971-2006), and 0.79 ± .27 Wm^2 for the period 2006-2018

These back-of-the-envelope calculations presumably overestimate factors such as reduced temperatures (with more TFVC), E over water bodies, magnitude, etc.

Direct causal effects of CO2 Emissions/Removals

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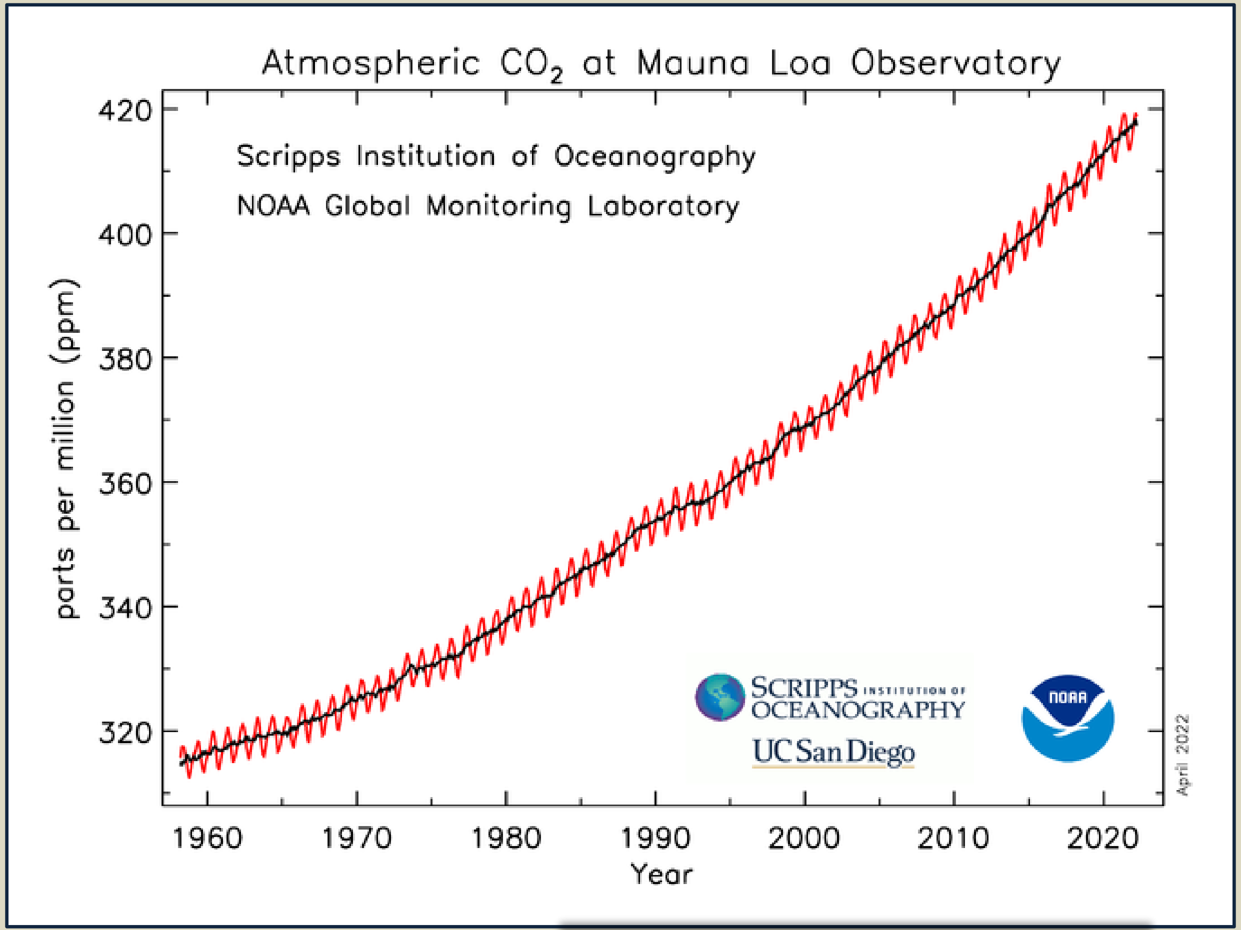
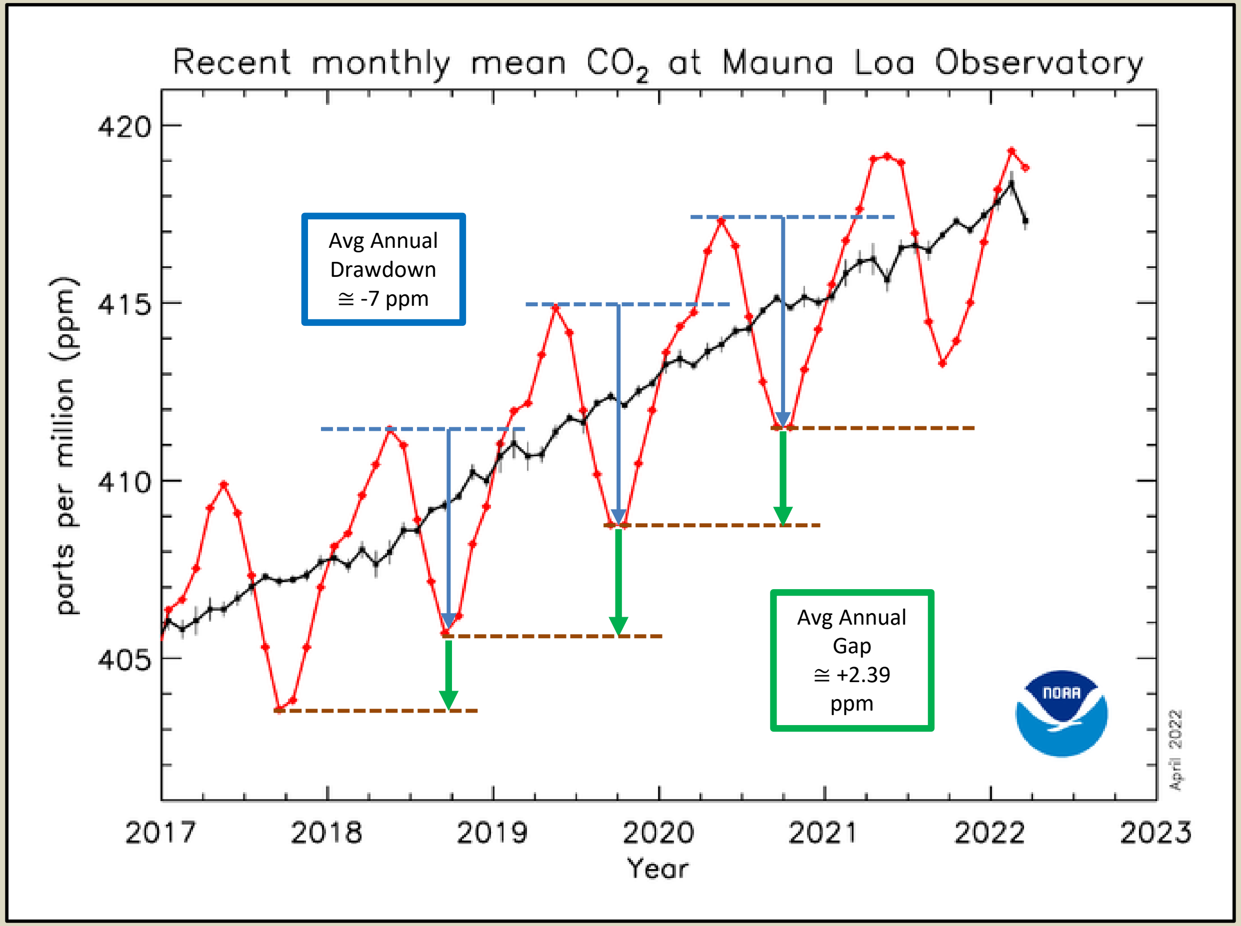


The annual drawdown/re-emission gap (imbalance) is growing:
1960: +0.82 ppm
2020: +2.39 ppm
(IPCC AR6 WGI Ch5).

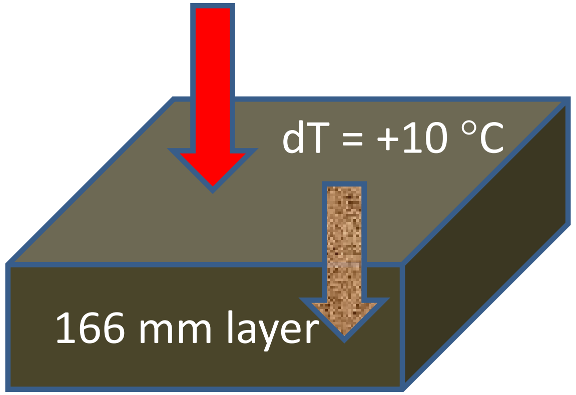
All or most of this gap could be eliminated by:

1) Stopping deforestation
2) Restoring historically lost forest cover

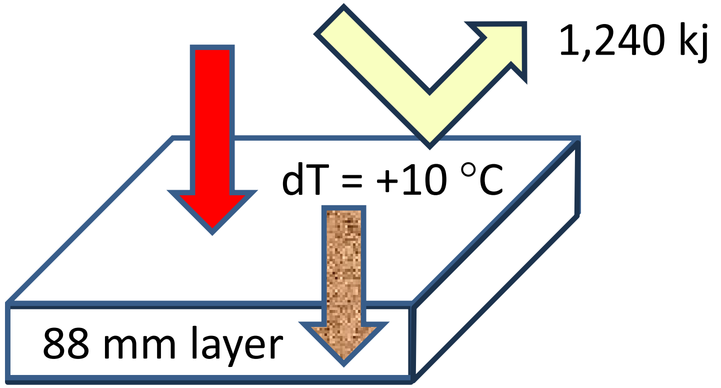


The Consequences of Albedo on Various Surfaces

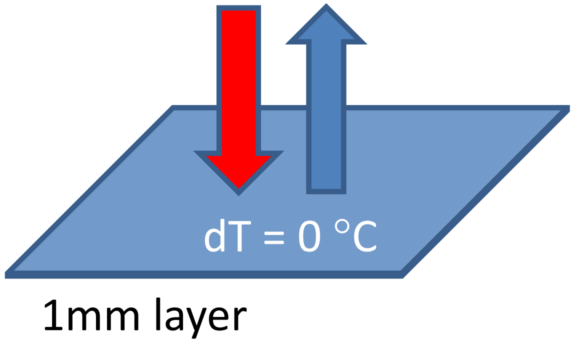
2,480 kj of energy will warm a 1 m^2, 288 kg block of dark-colored concrete by 10°C. The energy remains stored on the surface.



The same amount of energy (2,480 kj) will warm a 1 m^2, 144 kg block of light-colored concrete by 10°C. Some energy is reflected back toward space. The energy remains stored on the surface.



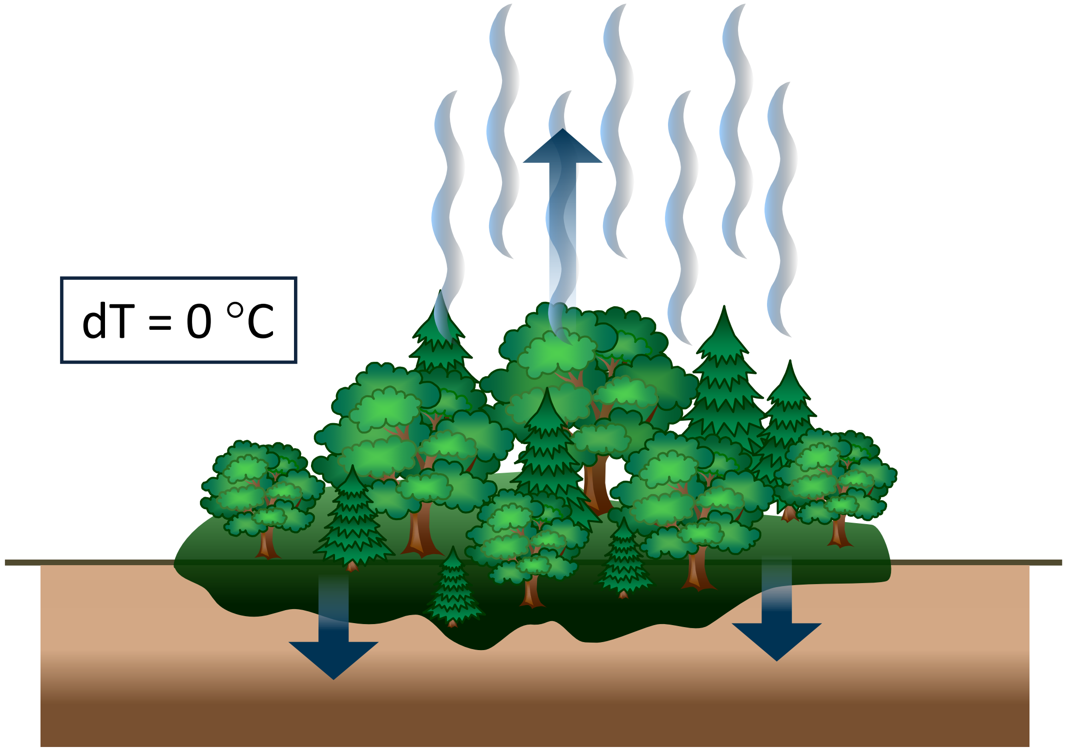
The same amount of energy (2,480 kj) is required to evaporate 1 mm of water from a 1 m^2 surface. The surface temperature does not change.



(Bader, Ungvari and Ellison, work-in-progress)

Albedo and Tree/Forest Cover

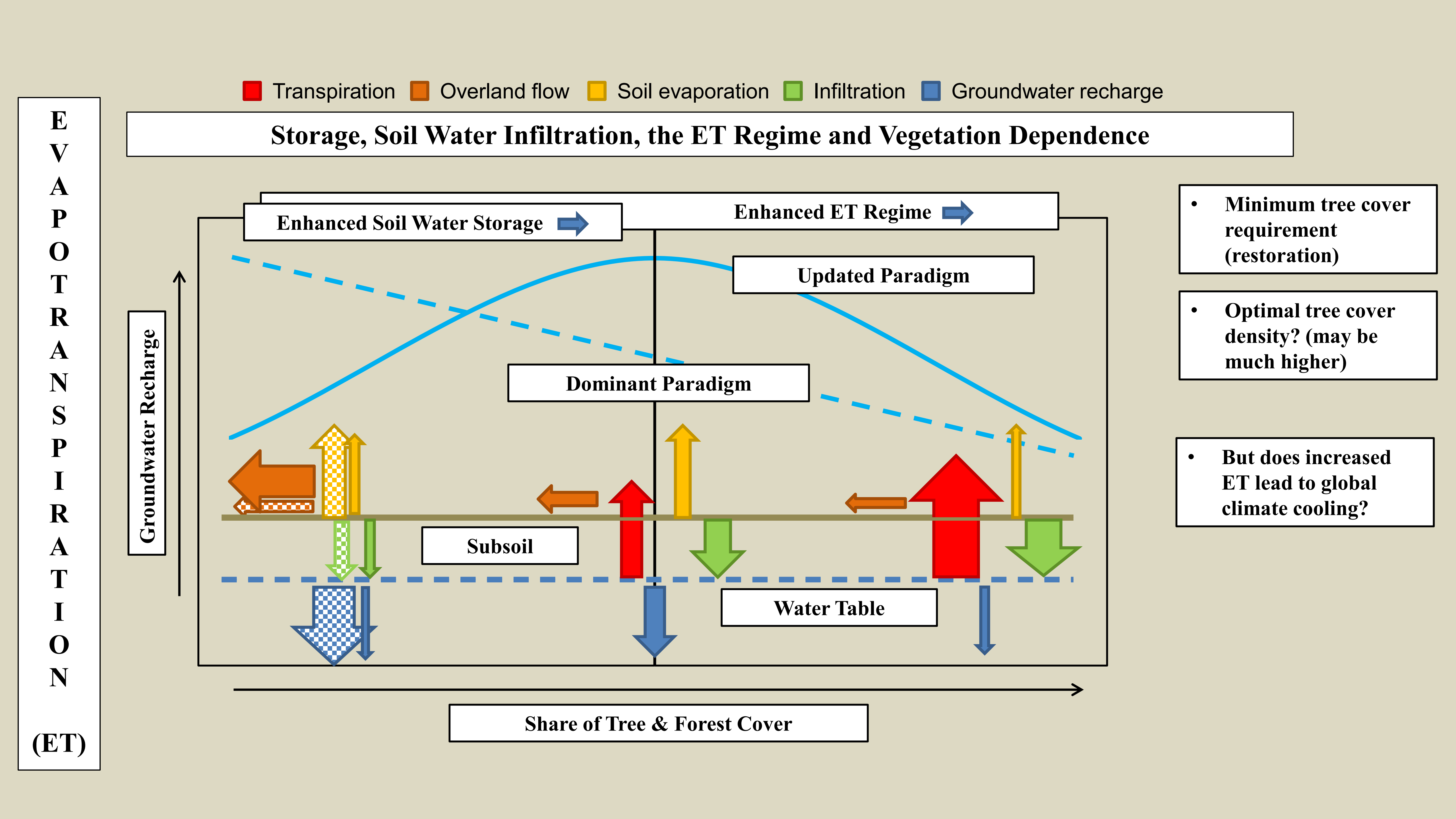
If 1 mm of water is available in tree and forest cover, 2,480 kj will evaporate 1 m^2 of this water and surface temperature will remain unchanged.



Tree and Forest Cover facilitate energy exchange for two principal reasons:

1) Facilitate evapotranspiration, moving water from the land surface into the atmosphere

2) Store water on the land surface through infiltration and groundwater recharge


EVAPOTRANSPIRATION (ET)
Transpiration
Overland flow
Soil evaporation
Infiltration
Groundwater recharge
Storage, Soil Water Infiltration, the ET Regime and Vegetation Dependence
Enhanced Soil Water Storage
Enhanced ET Regime
Updated Paradigm
Dominant Paradigm
Groundwater Recharge
Subsoil
Water Table
Share of Tree & Forest Cover
• Minimum tree cover requirement (restoration)
• Optimal tree cover density? (may be much higher)
• But does increased ET lead to global climate cooling?

We Know ET Cools the Land Surface, But What does Albedo Tell Us?

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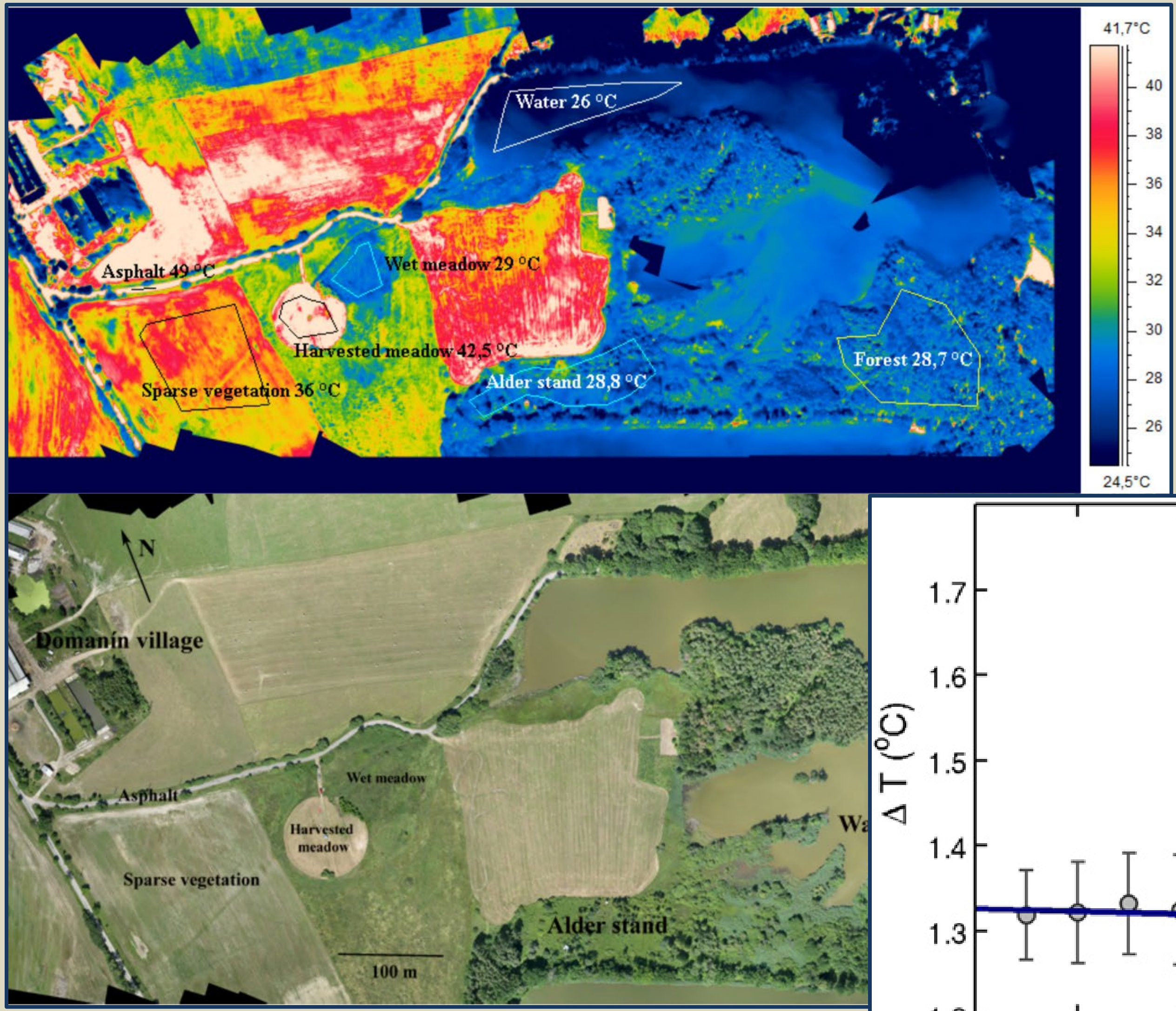
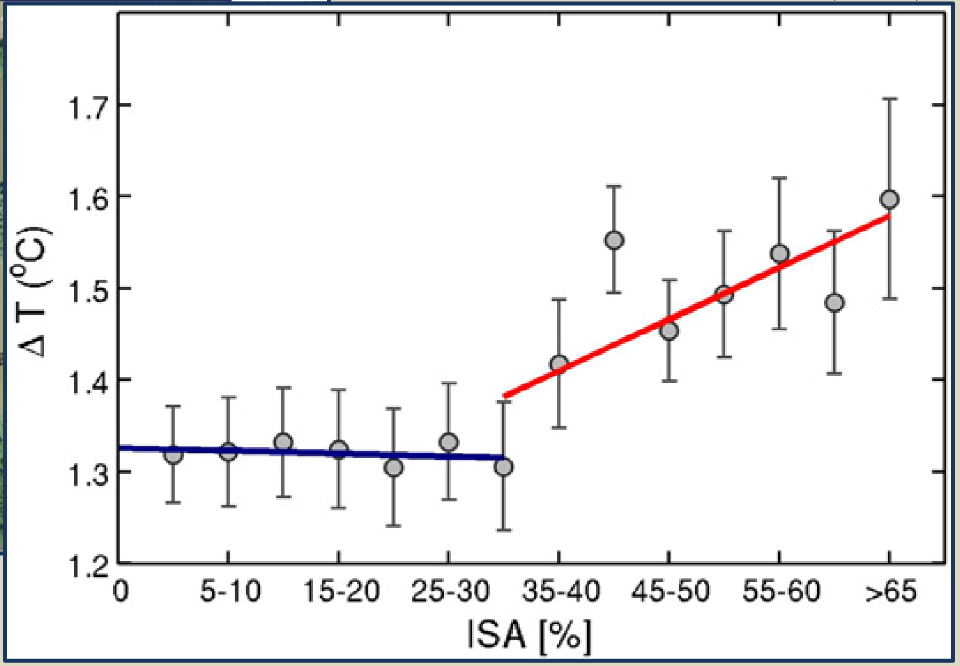
(ET)



(Pokorny, Hesslerova et al., 2013)

- Forest-water interactions ***dissipate solar energy***
- ***Transpiration and Evaporation*** require energy
- ***Reduced Surface Warming*** is the result.

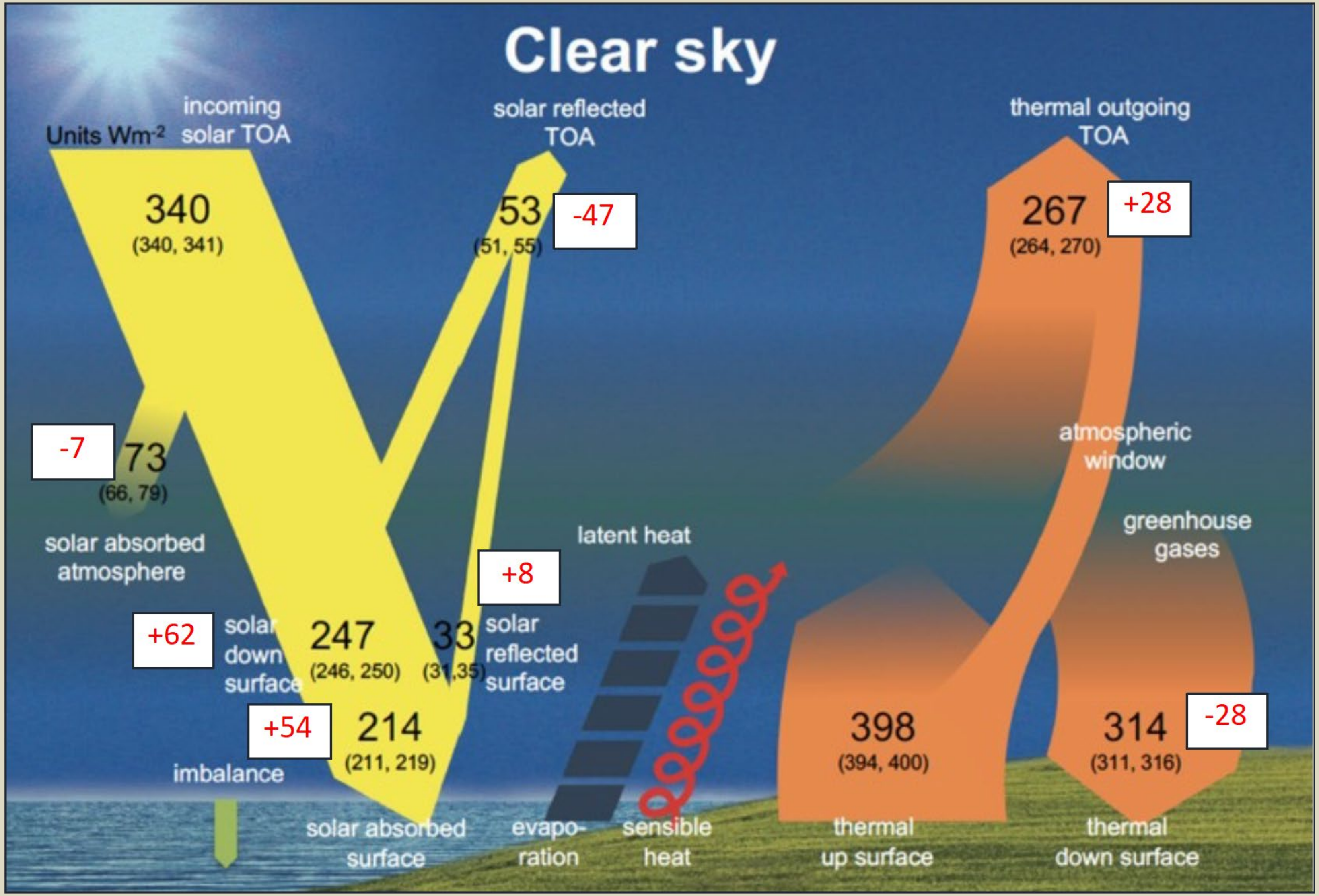
Urban Areas above/below 35% Impervious Surface Area (ISA)



(Bounoua et al., 2015)

Global Energy Budget under Clear Skies

C L O U D F O R M A T I O N



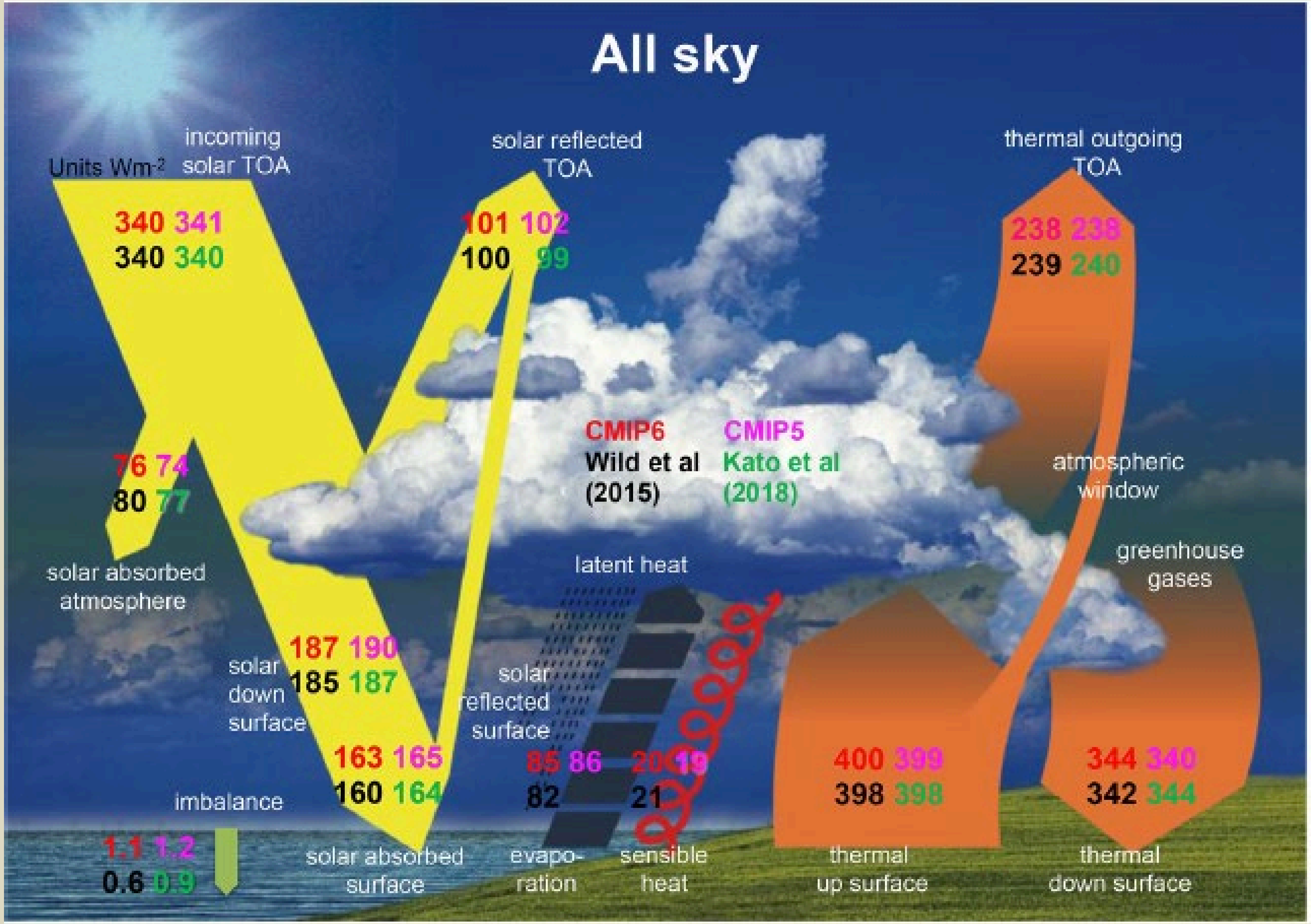
- **This may be about as close as we can get to an estimation of the deforested state (i.e., without clouds).**
- The net result of the increase in the downward solar radiation flux and the increase in the upward thermal heat flux is equivalent to about **+20 Wm² (+5.8 Wm² over the land surface)**
- Suggests deforestation brings significant warming (not cooling)
- The loss of cloud cover matters!

Numbers in red compare the clear sky to the energy budget with clouds.

Wild et al., (2019)

Global Energy Budget under Skies with Clouds

C L O U D F O R M A T I O N



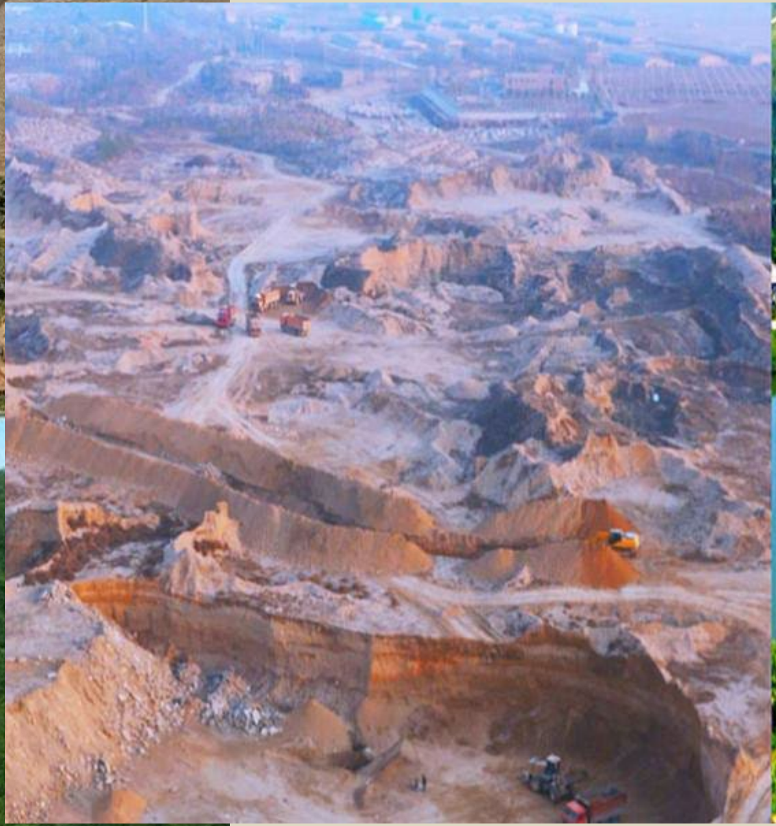
Wild et al., (2020)

Does terrestrial surface cooling (ET) lead to global cooling?

- **ET does lead to cloud formation!**
- **Increases top-of-cloud reflectivity (albedo)**



2001
2019



Some Conclusions:

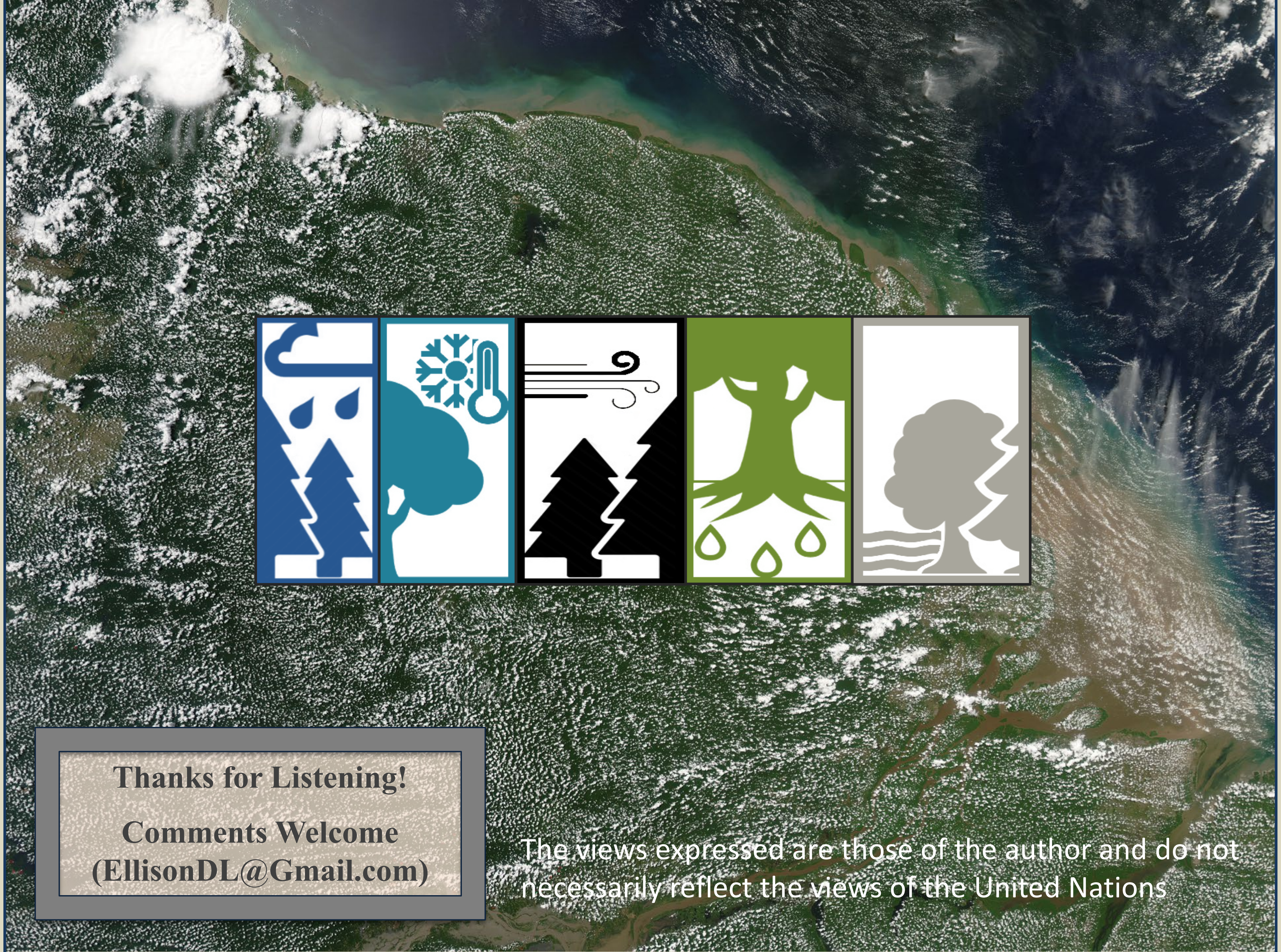
Increased wetland, tree, forest and vegetation cover contributes dramatically to many significant and beneficial outcomes:

- The cross-continental transport and recycling of water and atmospheric moisture
- The cooling of terrestrial surfaces (lowering of surface temperatures) requires TFVC!
- More wetlands and forests can also bring extensive global cooling:
    - Reduction of atmospheric CO2 (carbon sequestration).
    - Increase in cloud cover and top-of-atmosphere reflectivity (through increased ET production).

➢ Each tree is a carbon sink, each tree is a cooling tower, each tree is a potential source of future rainfall.

➢ Degraded landscapes contribute to the land heat sink and promote additional warming

➢ Degraded landscape restoration is necessary to reverse warming and improve the cooling power of trees, forest and vegetation cover.



Thanks for Listening!

Comments Welcome
(EllisonDL@Gmail.com)

The views expressed are those of the author and do not necessarily reflect the views of the United Nations