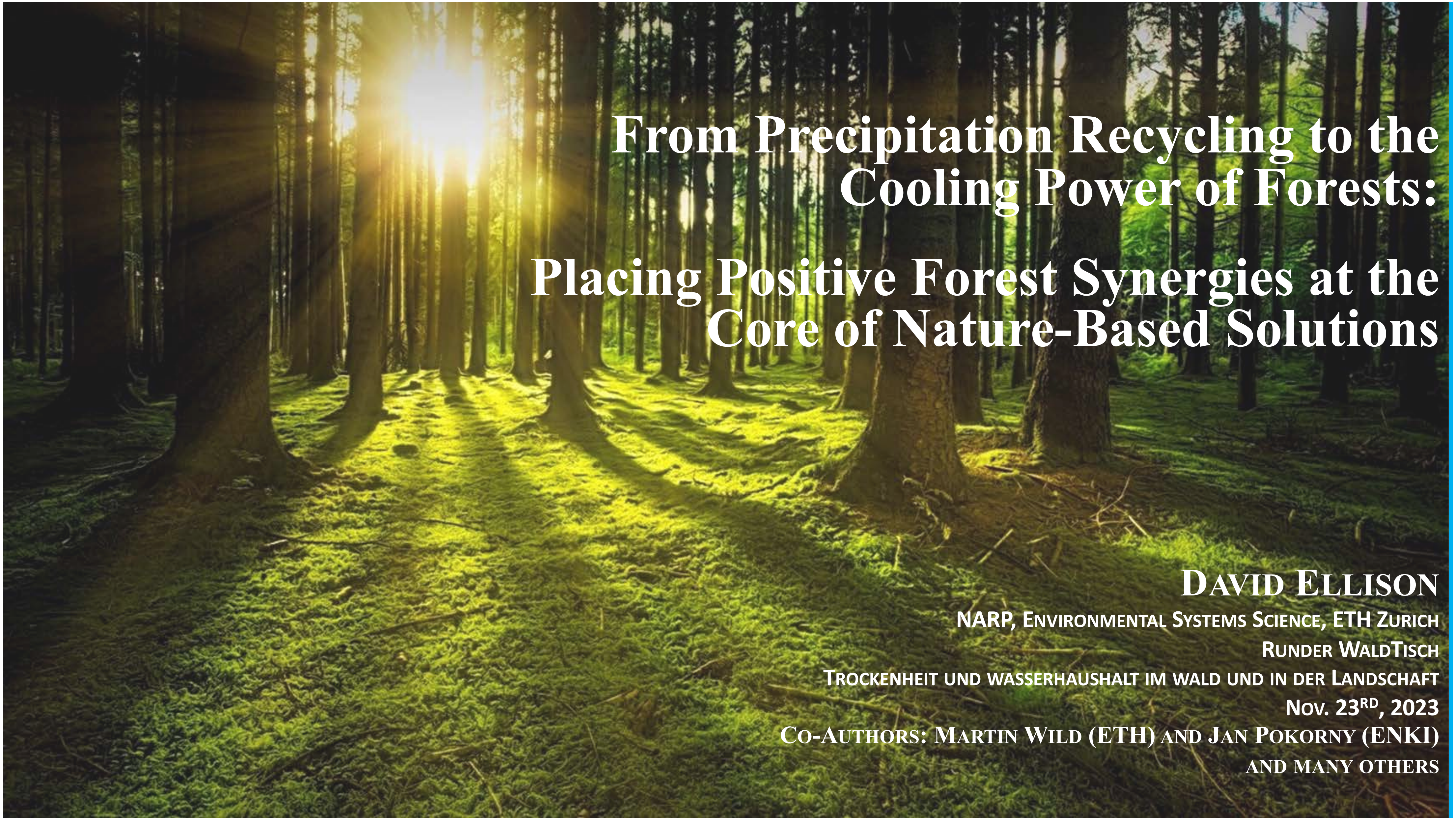

From Precipitation Recycling to the Cooling Power of Forests:

Placing Positive Forest Synergies at the Core of Nature-Based Solutions

DAVID ELLISON
NARP, ENVIRONMENTAL SYSTEMS SCIENCE, ETH ZURICH
RUNDER WALDTISCH
TROCKENHEIT UND WASSERHAUSHALT IM WALD UND IN DER LANDSCHAFT
NOV. 23RD, 2023
CO-AUTHORS: MARTIN WILD (ETH) AND JAN POKORNY (ENKI)
AND MANY OTHERS

Global Change Biology

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REVIEW

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

DAVID ELLISON*†‡, MARTYN N. FU

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Abstract

Several major articles from the past decade and
yield is negative: additional forest cover will re
second group of authors argue the opposite: f
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 adaptatio

Received 17 October 2011; revised version received 17 O

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 warr
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

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ELSEVIER

Research paper

Trees, forests and water: Cool insights for a hot world

David Ellison[a,b,*], Cindy E. Morris[c,d], Br
Daniel Murdiyarso[i,j], Victoria Gutierrez
Jan Pokorny[o], David Gaveau[i], Dominick
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Energy
Climate
Carbon
Reforestation
Mitigation

ABSTR

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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 land
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

https://doi.org/10.1038/s41561-022-00935-0

Check for updates

OPEN

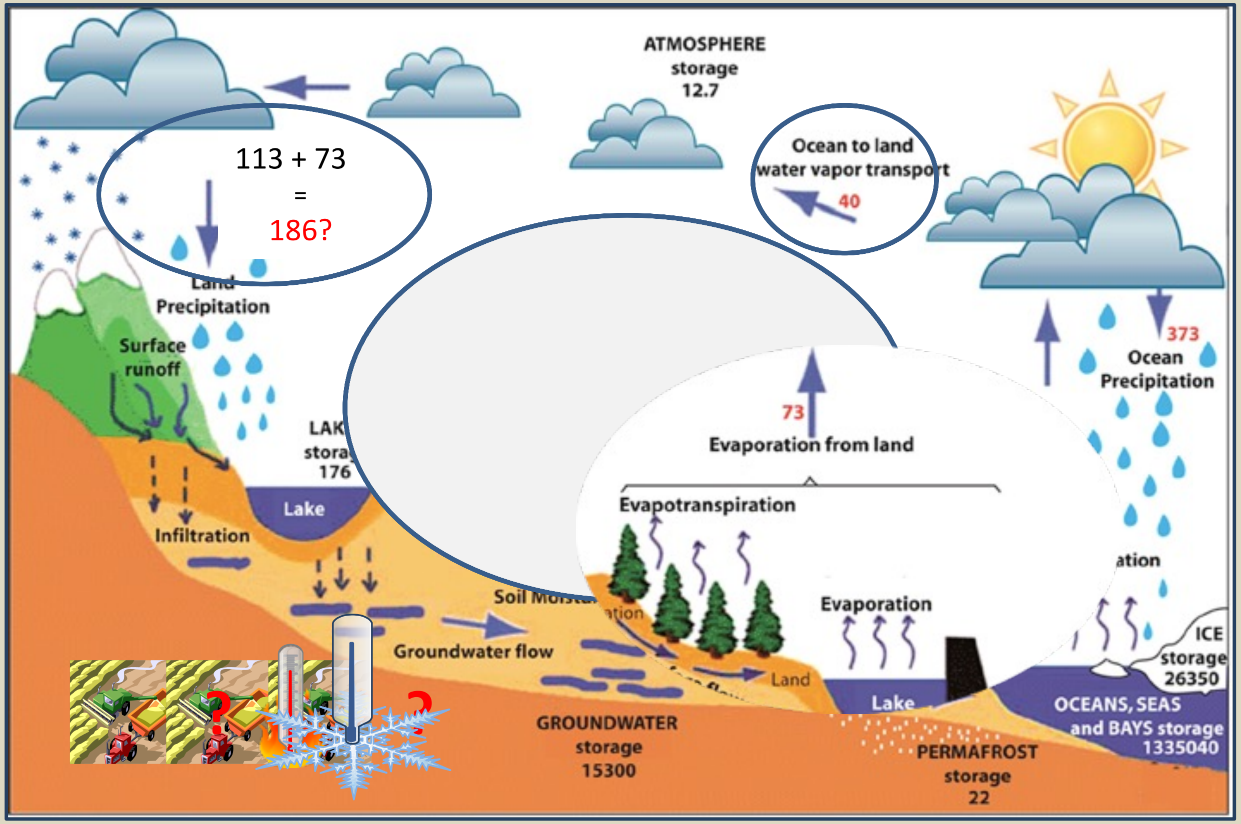
Shifts in regional water availability due to global tree restoration

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)

There are large and important benefits from increased wetland and forest cover!

Principal Conclusions from the Precipitation Recycling Literature

1) 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.

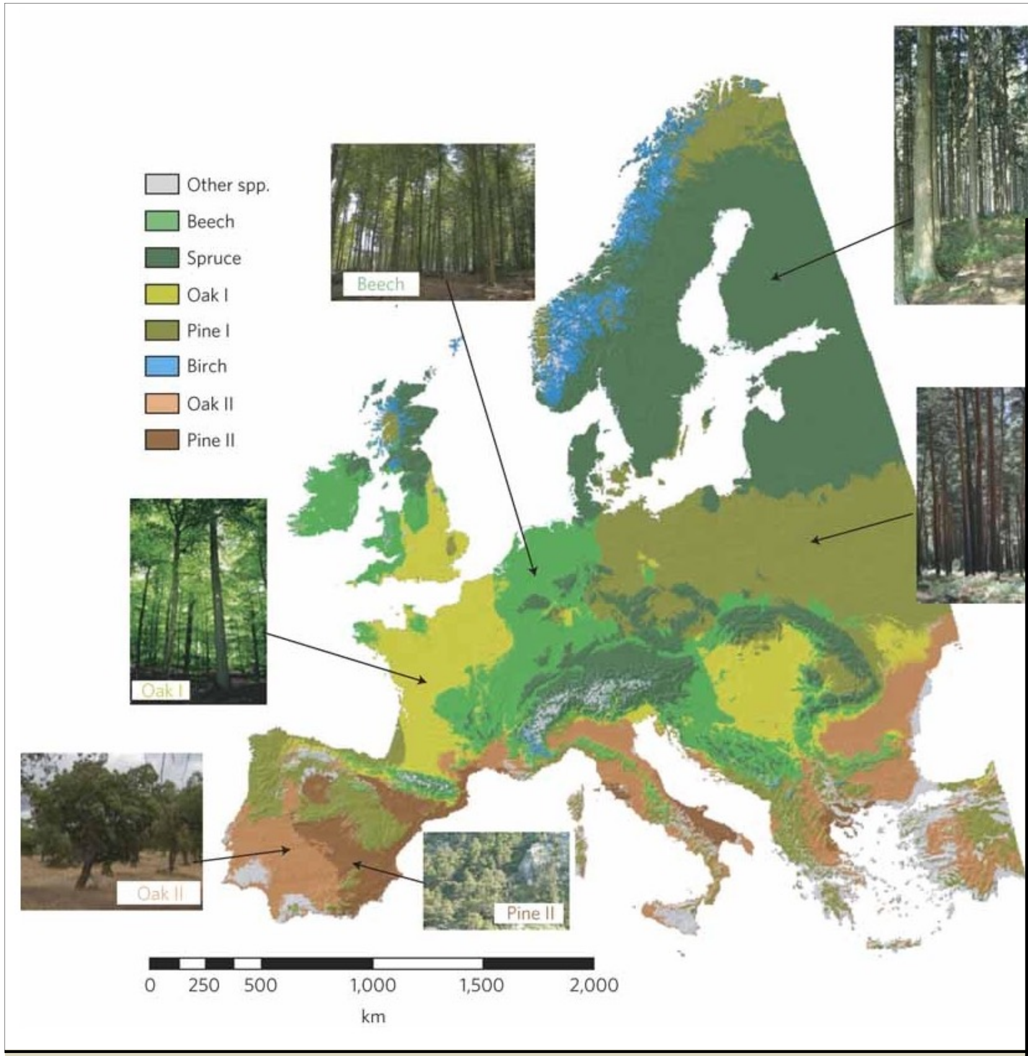
2) More tree and forest cover can positively affect the relative intensity of the hydrologic cycle across the land surface

3) It is perhaps difficult to appreciate just how new this finding is. 15 years ago, this was not an accepted paradigm.

4) The world of climate science and Global Climate Modeling faces a difficult task:

- It is trying to keep up with a changing science on forest water interactions
- It is not always able to use algorithms and models that are highly attuned to real Earth System functions (these are still being explored)

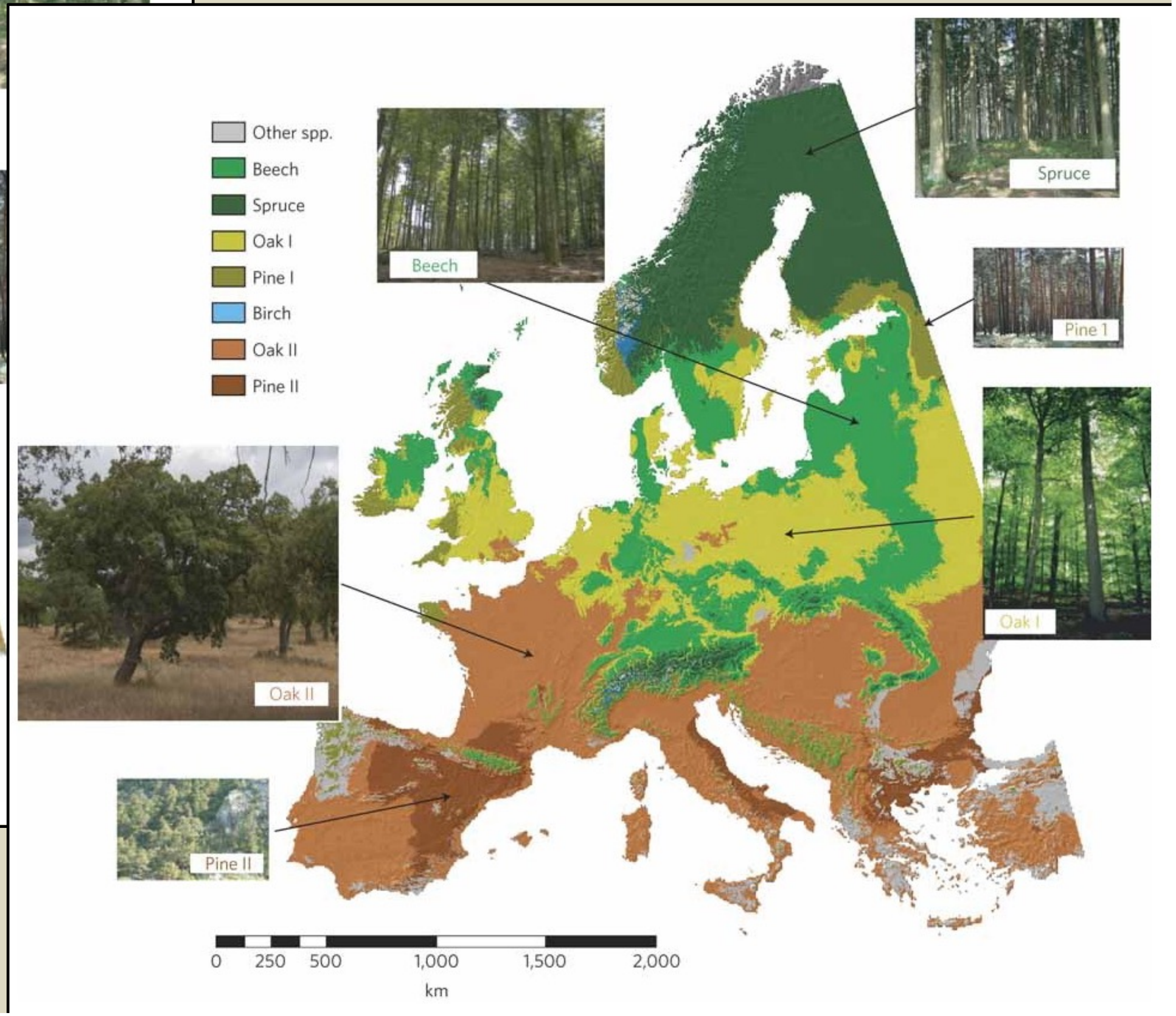
=> Figuring out where the problems are is an art in its own right…



1950-2000

Hanewinkel et al., 2013

2070-2100



Debate on the Advantages of Forests for Cooling/Warming

A L B E D O & L A T E N T H E A T

In line with past findings, the IPCC's AR6 WGI report states, "land use and land cover changes over the industrial period introduce a negative radiative forcing by *increasing the surface albedo*. This effect has increased since 1750, reaching current values of about –0.20 Wm^2 (medium confidence)…"

There have been repeated findings across several decades that deforestation in the Norther Hemisphere across both the temperate and the boreal zone has led to cooling instead of warming.

Some of these articles date back to the early 90's (and may date even further back). Among some of the most recent findings are Lawrence et al. (2022), Windisch et al. (2021).

These findings are troubling because they do not sit well with the observational data on surface temperature change and other analyses of the role and impact of tree and forest cover.

There is clearly disagreement over the impact of forests on cooling/warming at both global and local scales.

Debate on the Advantages of Forests for Cooling/Warming

- ET
- Snow covered surfaces

The Boreal is "energy-limited", not "water-limited"!

Winter days are short or non-existent.

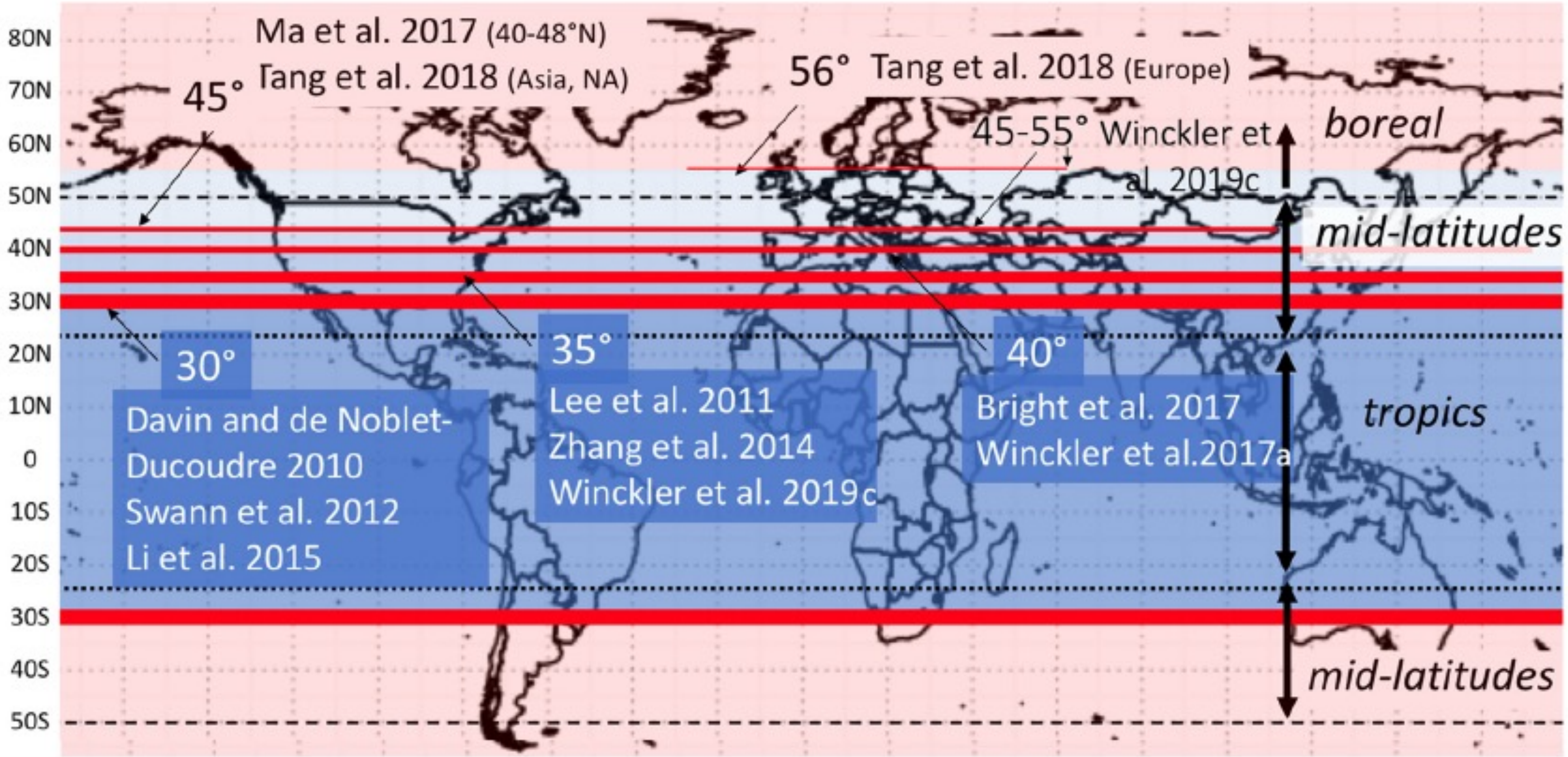


FIGURE 1 | Latitude of net zero biophysical effect of forests on local temperature varies from 30 to 56°N. Above the line, forest cover causes local warming; below the line, forest cover causes local cooling. The thickness of the line indicates the number of studies that show forest cooling up to that threshold. Data sources as indicated.

Lawrence et al., (2022) – The Unseen Effects of Deforestation: Biophysical Effects on Climate

Principal causal pathways by which wetlands and TFVC (tree, forest and vegetation cover) influence temperature and the climate

- Carbon sequestration (& respiration)

Principal focus of UNFCCC

- Surface albedo effects
- Latent heat production (ET)
- Cloud production

Largely ignored by UNFCCC

⇒ Different studies focus on different causal pathways, little consistency across studies

⇒ Almost no studies integrate cloud production with all the other causal pathways

- However, many of these studies are frequently sold as “net effects” models?

Direct causal effects of CO2 Emissions/Removals

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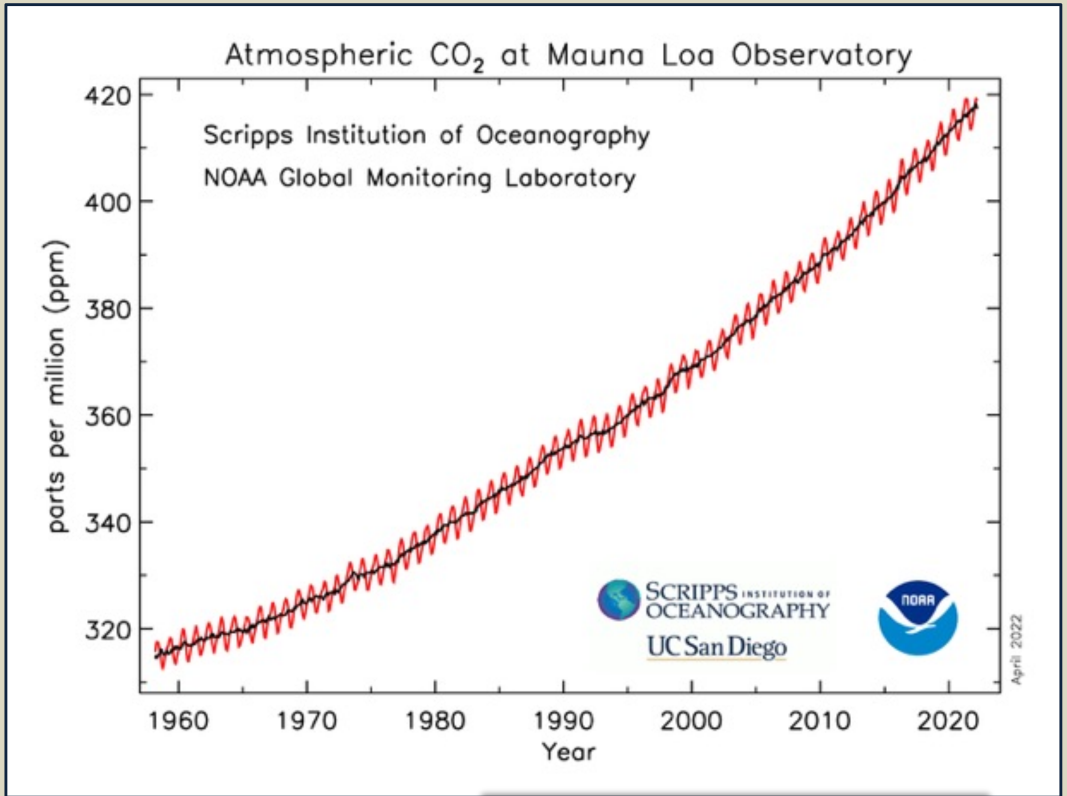
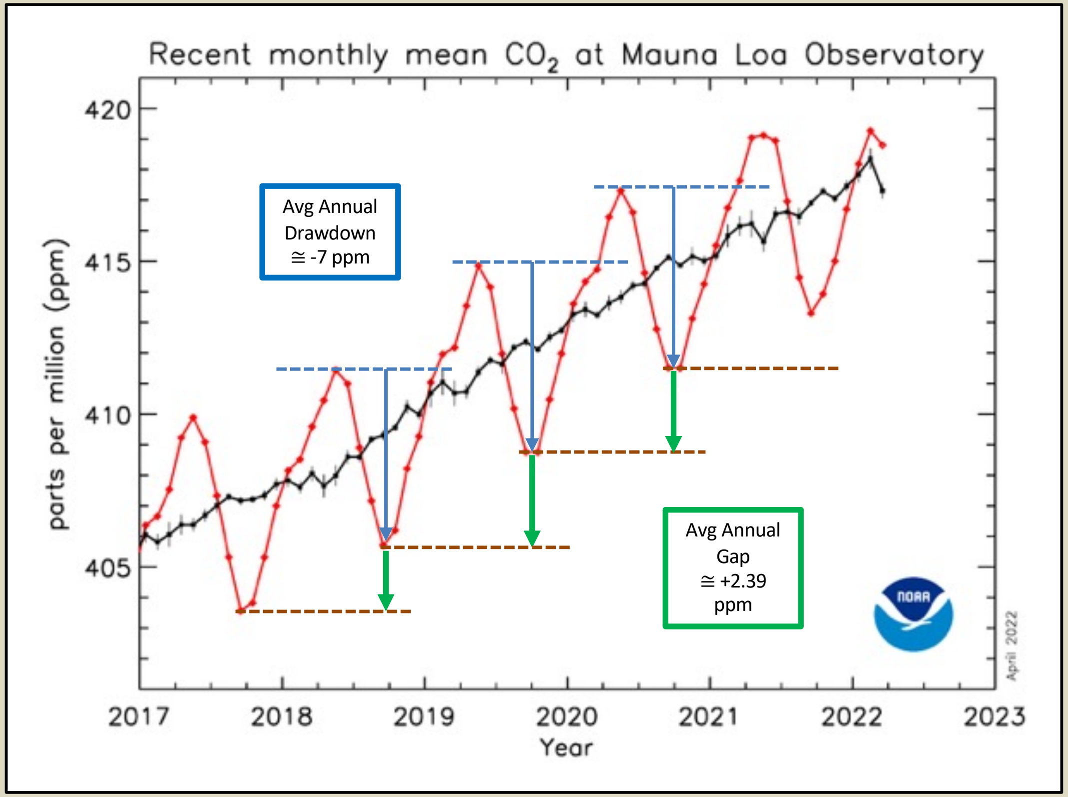


The annual drawdown/re-emission gap (imbalance) is growing:
1960: +0.82 ppm
2020: +2.39 ppm
(IPCC AR6 WGI Ch5).



Direct causal effects of CO2 Emissions/Removals

The current total land use-based drawdown is approximately
-12.5 ± 3.2 $GtCO_2$-eq yr^{-1} (IPCC AR6 WGIII Ch7)

Closing the 2.39 ppm gap would require approximately
-8.53 GtCO2-eq yr^{-1}
in additional removals (or reduced emissions) per year to stabilize,
but not reduce, atmospheric CO2 concentrations.

Much of this could already be achieved by reversing current land use emissions
(i.e., deforestation),
+5.9 ± 4.1 $GtCO_2$-eq yr-1

The additional required removals could potentially be achieved with additional
reforestation and forest landscape restoration
-2.63 $GtCO_2$-eq yr^{-1}

By way of example, Roe et al., (2021) argue that additional, cost-effective land-based
mitigation potential represents approximately -8 to -13.8 $GtCO_2$-eq yr^{-1}

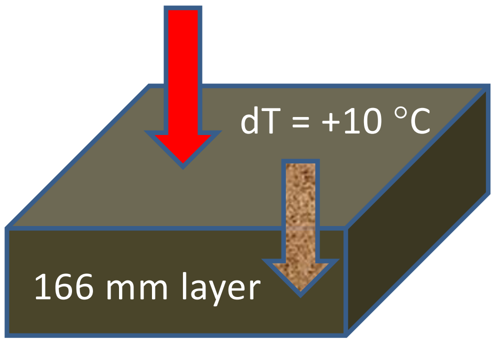
Restoring a significant share of historically lost forest cover
could likewise have a significant impact,
from -8.3 to -12.5 $GtCO_2$-eq yr^{-1}

C A R B O N

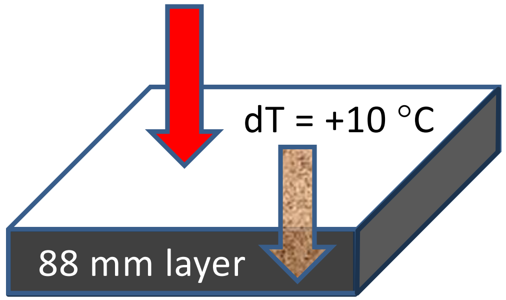
(Bader, Ungvari and Ellison, work-in-progress)

The Consequences of Albedo on Different Kinds of Surfaces

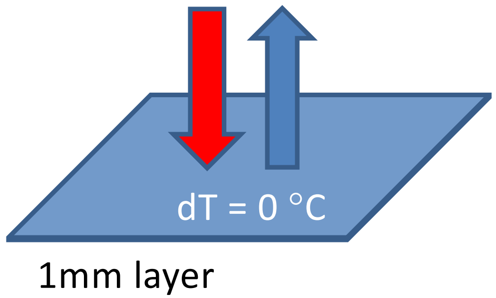
2,480 kj of energy will warm a 1 m^2, 288 kg block of dark-colored concrete by 10°C. The energy remains stored on the surface.



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 1mm of water from a 1 m^2 surface. The surface temperature does not change.



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

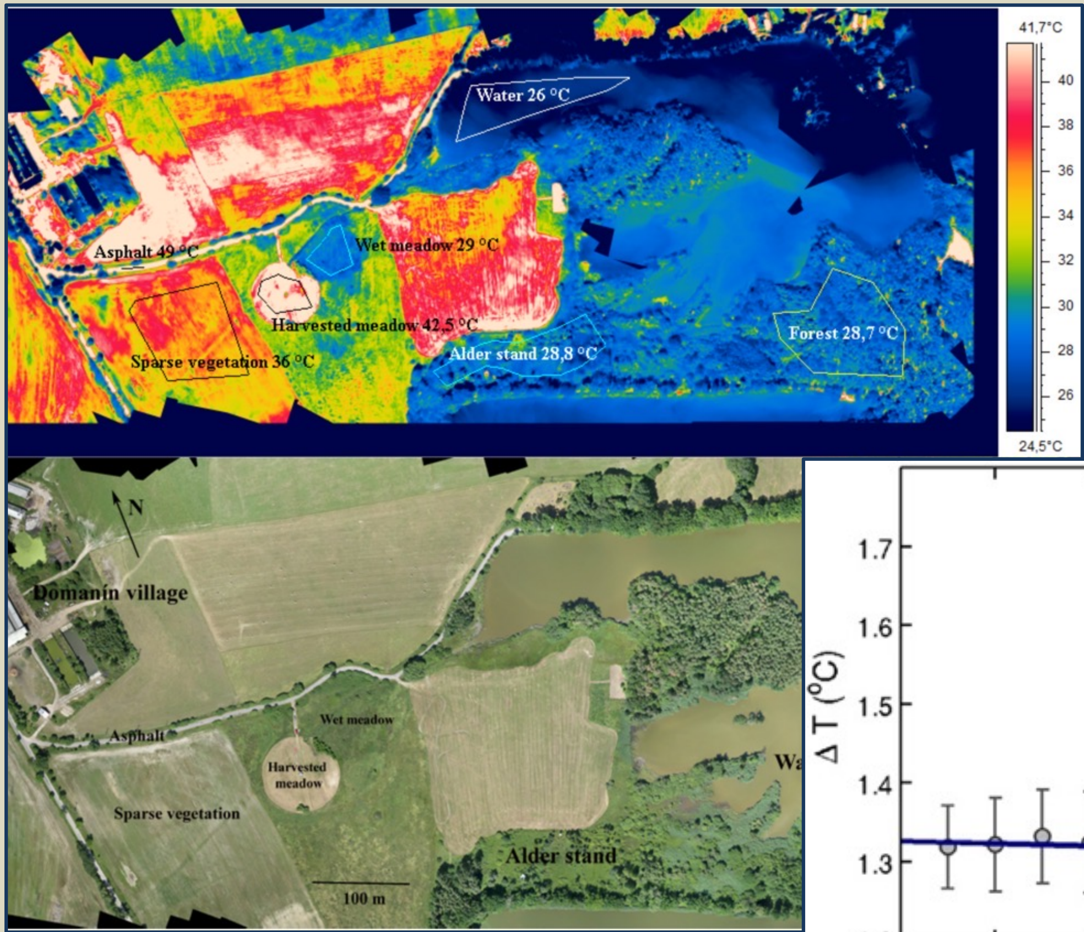
1) Store water on the land surface

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

E V A P O T R A N S P I R A T I O N

(ET)

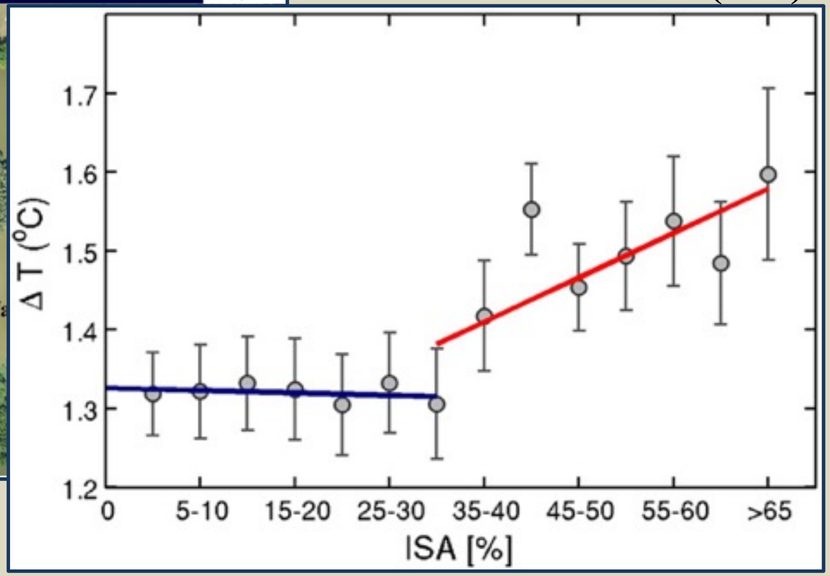
We Know ET Cools the Land Surface, But What does Albedo Tell Us?



(Pokorny, Hesslerova et al., 2013)

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

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



(Bounoua et al., 2015)

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(ET)

Evidence suggests E/ET are "*vegetation-dependent*"

On terrestrial surfaces, very little E/ET is produced without the presence of vegetation and/or wetlands.

⇒ The previously dominant paradigm suggested that E/ET can occur in areas without vegetation (TFVC).

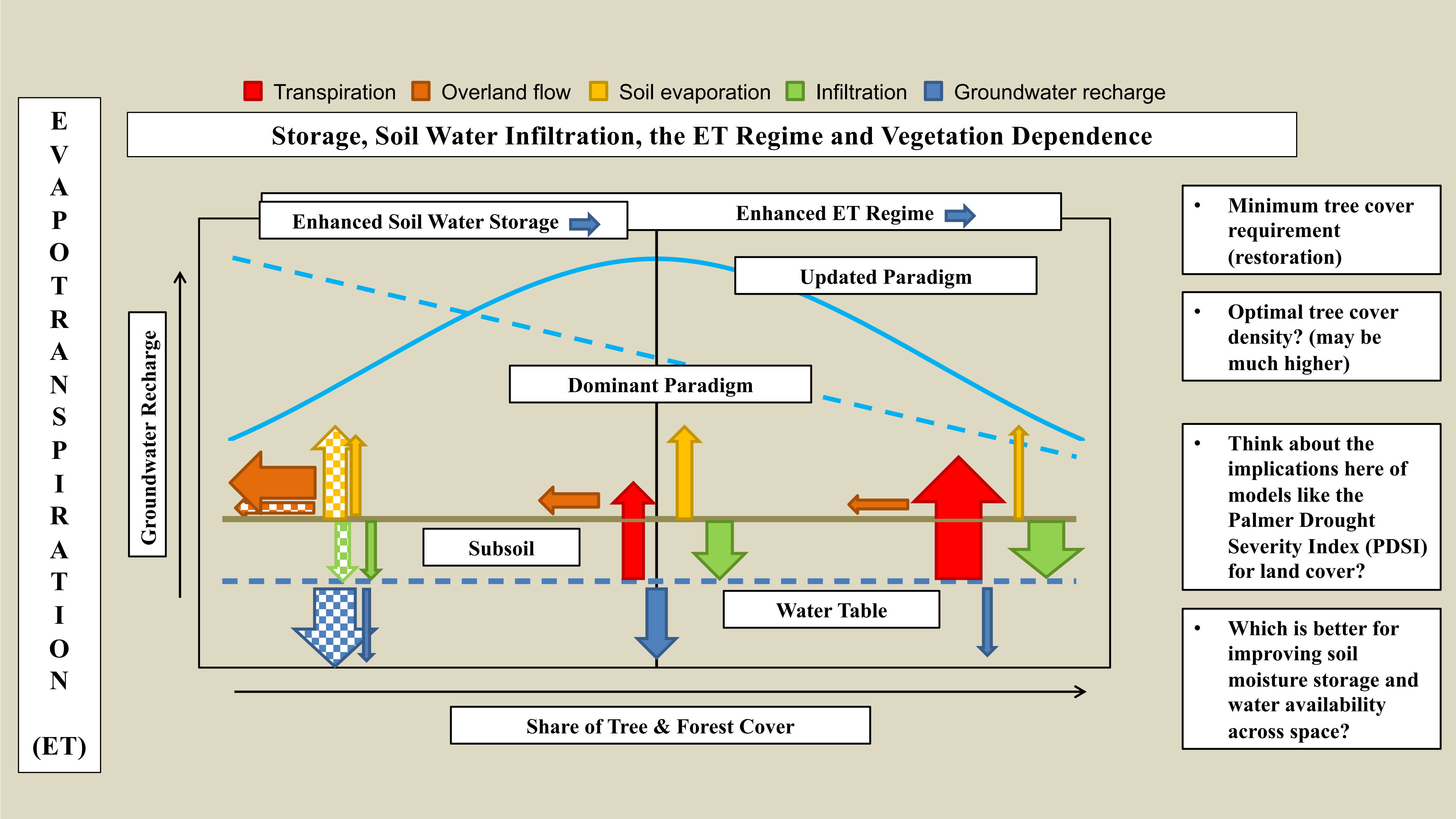
If we comb the literature on Transpiration, Interception, Soil Moisture Evaporation, we come to a different conclusion:

- Transpiration: 60 – 64% (of terrestrial E)
- Interception: 18 – 25%
- Soil Moisture E: 10%

Vegetation-Dependent E: 88 – 99% (of terrestrial E)
E from barren surfaces: 1 – 12% (of terrestrial E)

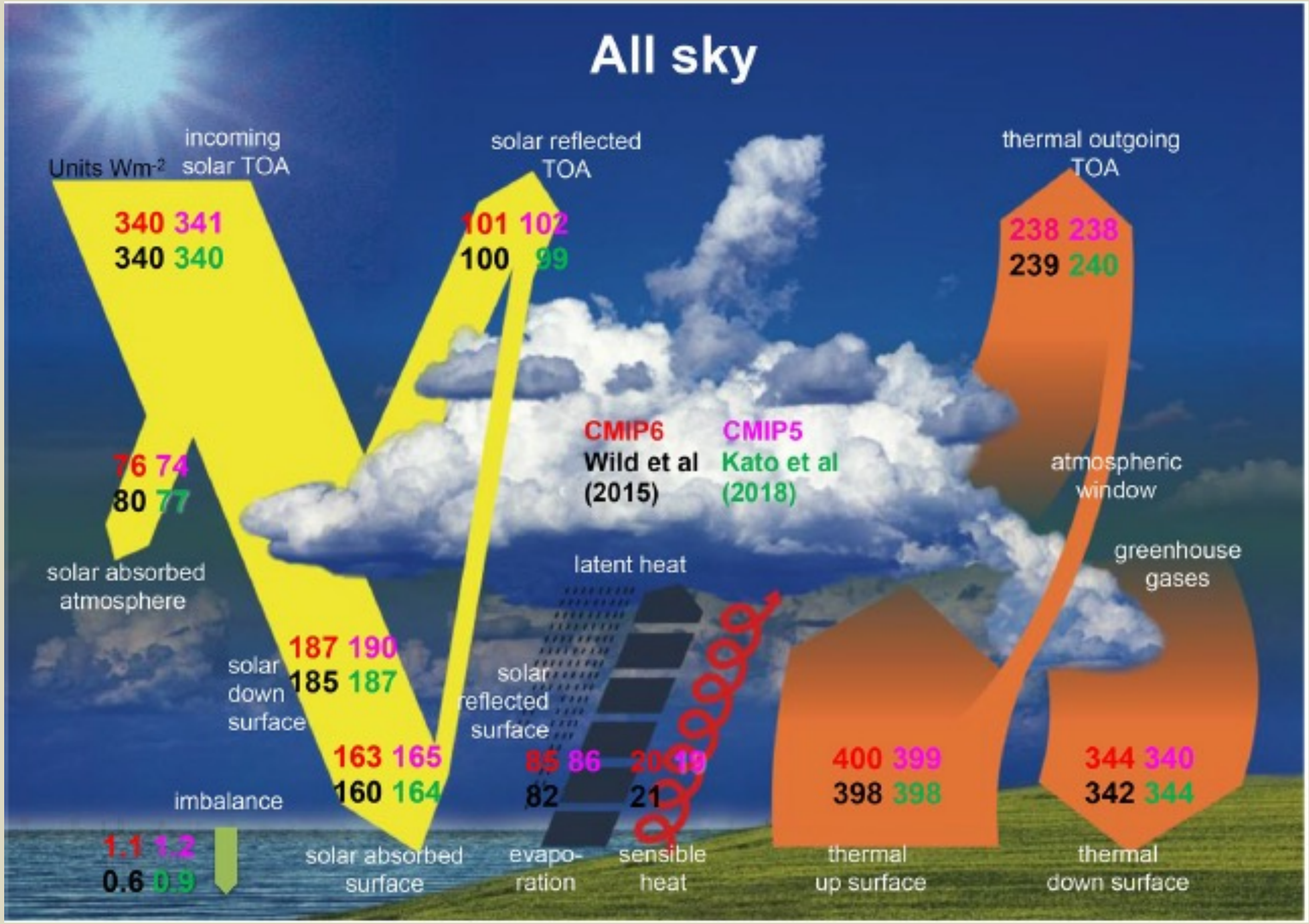
(Most overland flow => will end up as river runoff. Tree and Vegetation cover loss promotes soil degradation and overland flows).

Albedo is an evolutionary principle…!!!


Transpiration
Overland flow
Soil evaporation
Infiltration
Groundwater recharge
Storage, Soil Water Infiltration, the ET Regime and Vegetation Dependence
EVAPOTRANSPIRATION (ET)
Groundwater Recharge
Enhanced Soil Water Storage
Enhanced ET Regime
Updated Paradigm
Dominant Paradigm
Subsoil
Water Table
Share of Tree & Forest Cover
• Minimum tree cover requirement (restoration)
• Optimal tree cover density? (may be much higher)
• Think about the implications here of models like the Palmer Drought Severity Index (PDSI) for land cover?
• Which is better for improving soil moisture storage and water availability across space?

Global Energy Budget under Skies with Clouds

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



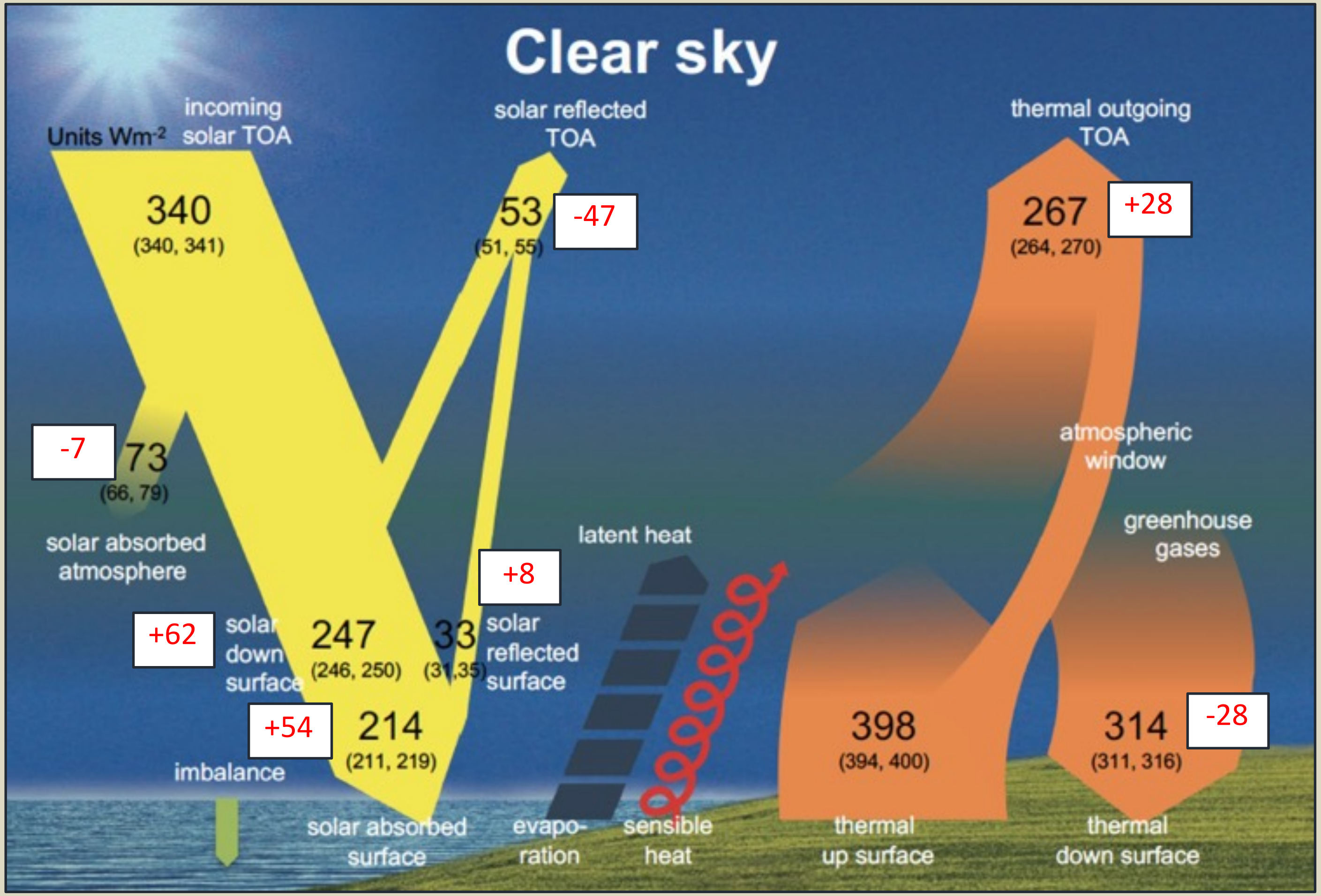
Wild et al., (2020)

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

- Perhaps not, reduces outgoing LW radiation.
- **But ET does lead to cloud formation!**
- **And this increases top-of-cloud reflectivity (albedo)**

Global Energy Budget under Clear Skies

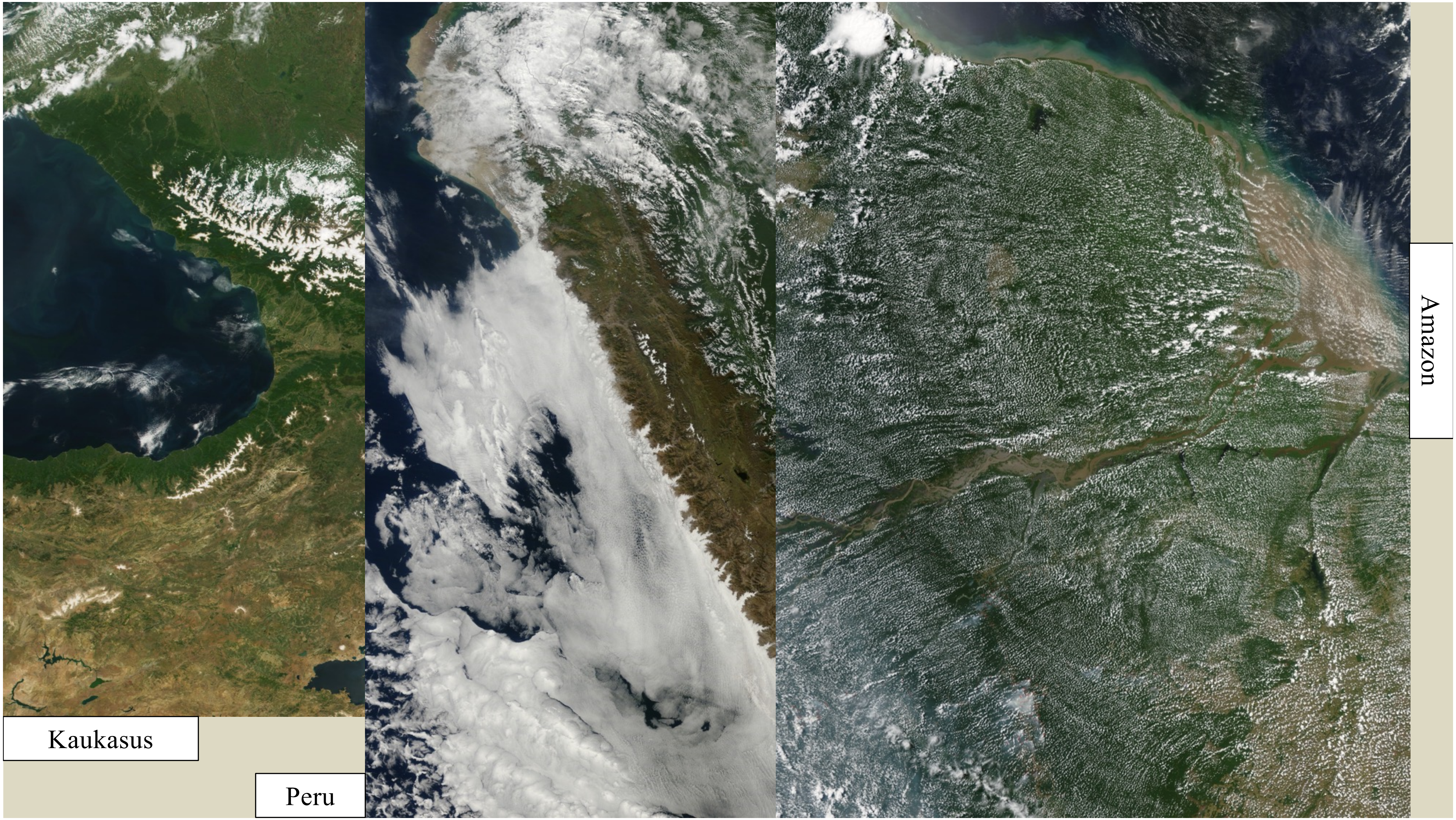
CLOUD FORMATION



- **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 Wm^2 (+5.8 Wm^2 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)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Amazon

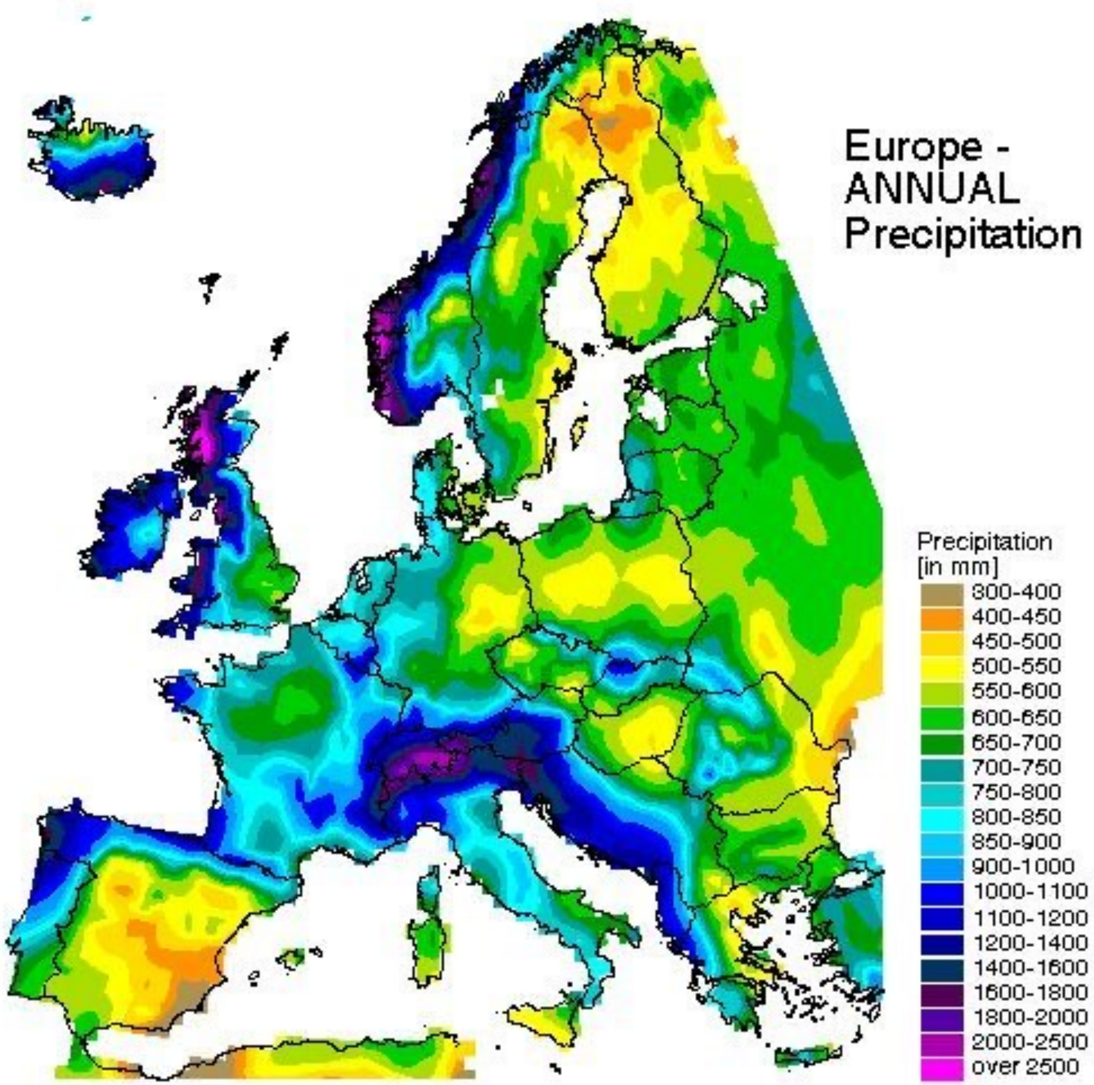
CLOUD FORMATION

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.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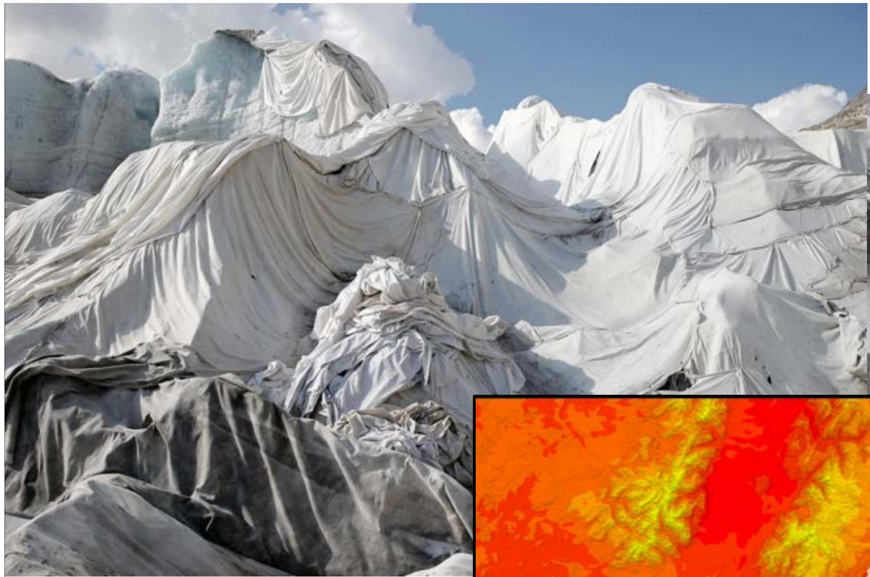


Figure 1: Examples of

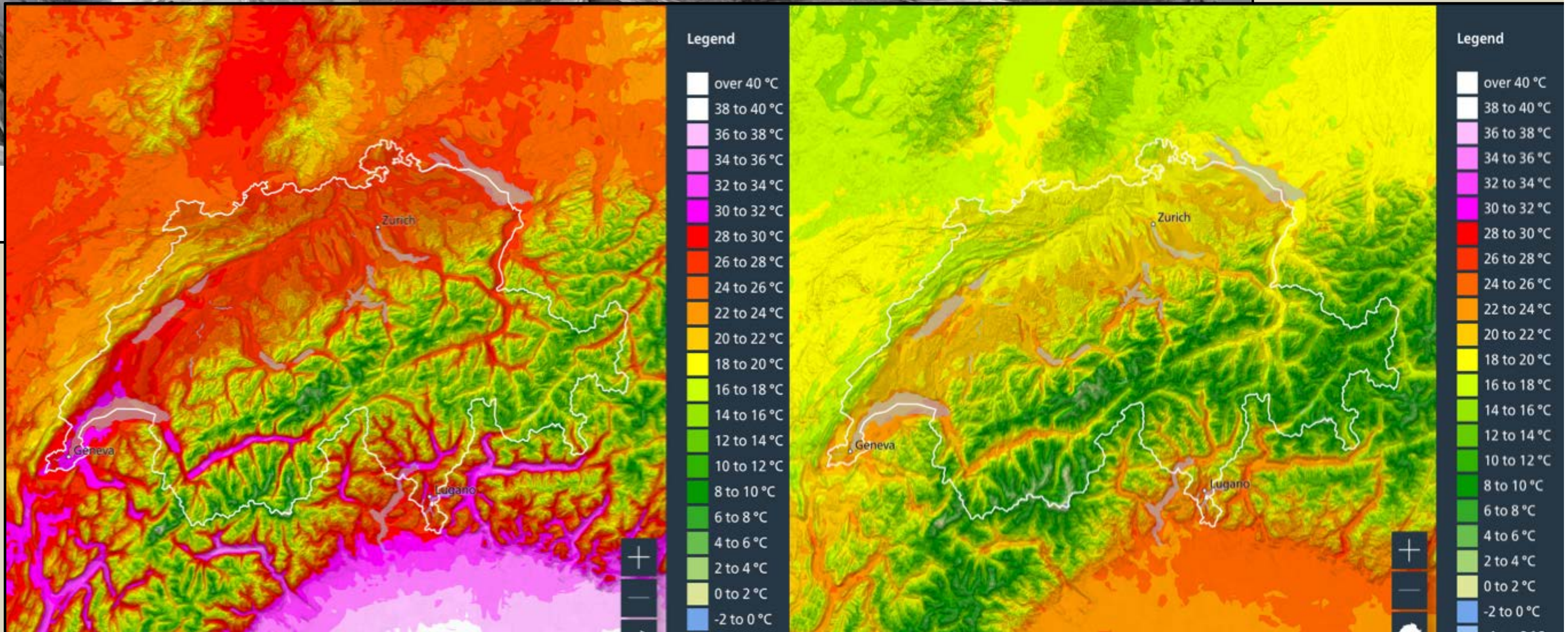


Figure 2: Day and night-time temperatures in Switzerland, mid-summer, July, 2023
Source: Produced using temperature estimates at MeteoSwiss.admin.ch.

Is the Role of Albedo Over-Emphasized?

Mother Nature is and has been far less concerned about albedo effects than we seem to be.

Prior to the current state of historical deforestation (and prior to all global warming and climate change impacts), existing tree and forest cover had no *negative,* potentially *climate-warming* consequences.

Thus, it is unlikely we need all the albedo-related cooling power of snow cover that would come with outer latitude deforestation
(though clearly, we must eliminate GHG's from industrial processes and the atmosphere).

Deforestation has many other negative consequences that should likewise be considered: loss of precipitation recycling, loss of soil water infiltration and groundwater recharge, loss of hydrologic intensity, loss of terrestrial surface cooling potential, loss of natural water purification processes, etc. …

Thus, it is highly likely that albedo impacts are greatly *over-estimated* and other tree and forest cover impacts *neglected* and *under-estimated* (e.g., modeled data *misrepresents/under-estimates* the surface cooling power of forests and thereby *overstates* albedo impacts).

Some Conclusions:

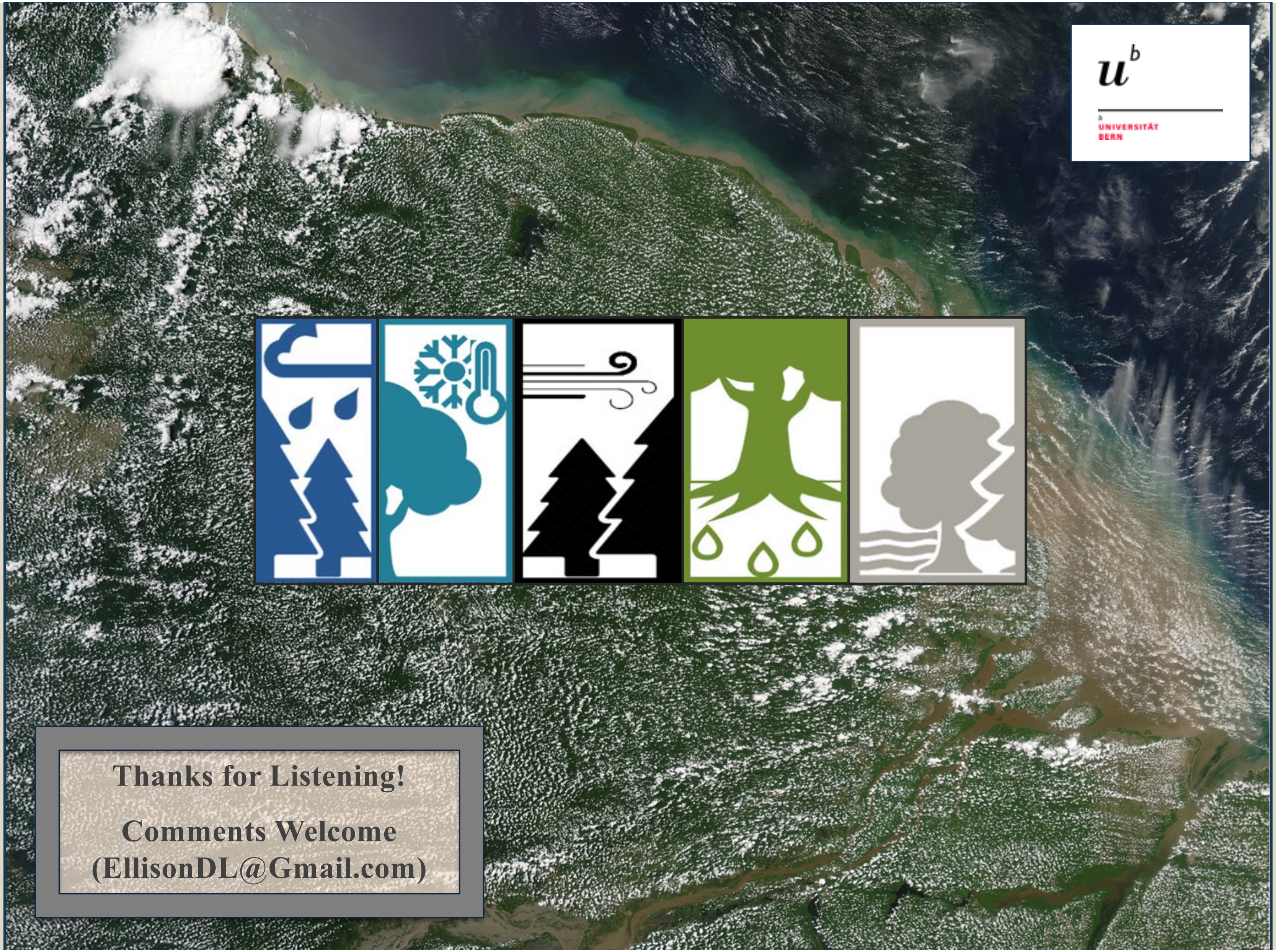
Wetland, tree, forest, and vegetation cover play an important role in providing the potential for increased ET production and thus hydrologic intensity across land surfaces.

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.

➢ The benefits of increased wetland, tree, forest and vegetation cover, irrespective of where they occur, should not be ignored.

➢ The Boreal is neither expendable, nor negotiable:
- Stores: 272 ± 23 Pg C; Annual flux removes: -3.4 to -4.4 $GtCO2^{-1}$



Thanks for Listening!

Comments Welcome (EllisonDL@Gmail.com)

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