Impacts of large-scale Sahara solar farms on global climate, vegetation cover and solar potential

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FORMAS a Swedish Research Council for Sustainable Development
MERGE

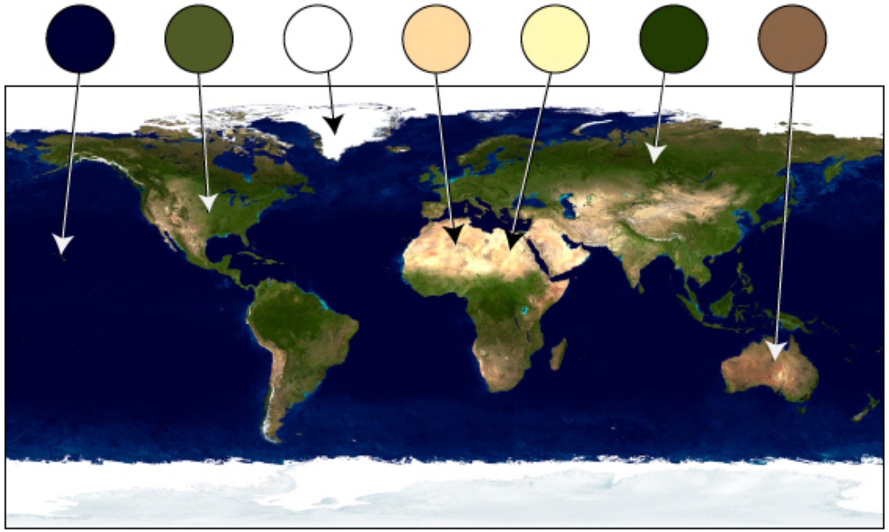
- Fossil fuels (coal, oil, and natural gas) supply about 80 percent of the world's energy
- Solar power is the most abundant renewable energy source in the world
- Massive-scale solar farms in the world's deserts and semi-arid regions have the potential to meet increasing energy demand for the globe

Some numbers of the largest solar farms in the world

- Bhadla Solar Park (Northwest India), 2.245 GW, 57 km^2
- Hainanzhou Solar Park (Northwest China), 2.2 GW, 40 km^2, 7million solar panels
- Stockholm 188 km^2, Lund 25.75 km^2 (from Wikipedia)

Solar farm in Morocco. Photo by Mohamed Atani/UN Environment

Background: energy balance disturbed by PV solar panels

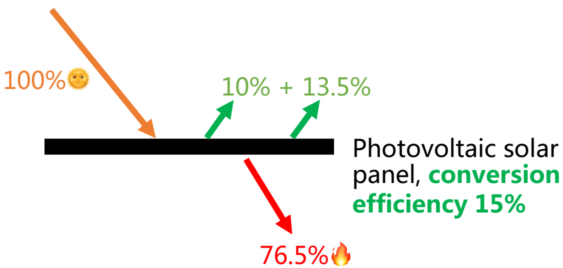


A sampling of Earth's colors, NASA image

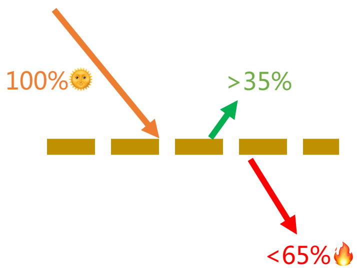
PV panels

Deserts

effective albedo **of PV panels** ***~0.235*** **(reflectance** ***~0.1*****)**



albedo **of bare soil in the deserts** ***0.3 - 0.4***



Question: What are the global impacts of *massive* solar farms in the largest desert in the world?
(Clue: Green Sahara conditions in the geological past…)

Model and simulations

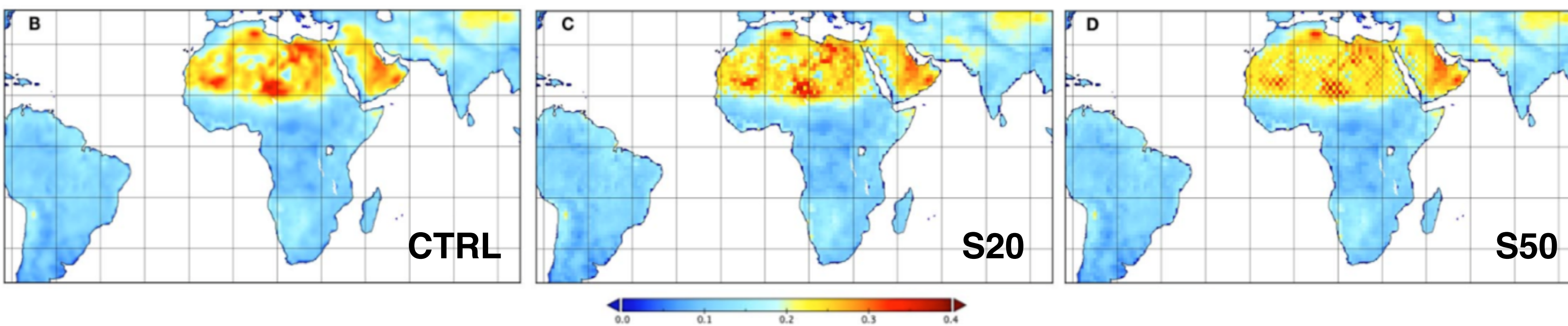
EC-Earth 3 model (http://www.ec-earth.org)

- Developed by 30 research institutes from 12 European countries
- Earth system model (atmosphere + ocean + sea-ice + vegetation; spatial resolution: T159L62/~1º + ORCA1L75/~1º)
- Land-use, nitrogen, pCO_2, etc. were kept as 1990 values

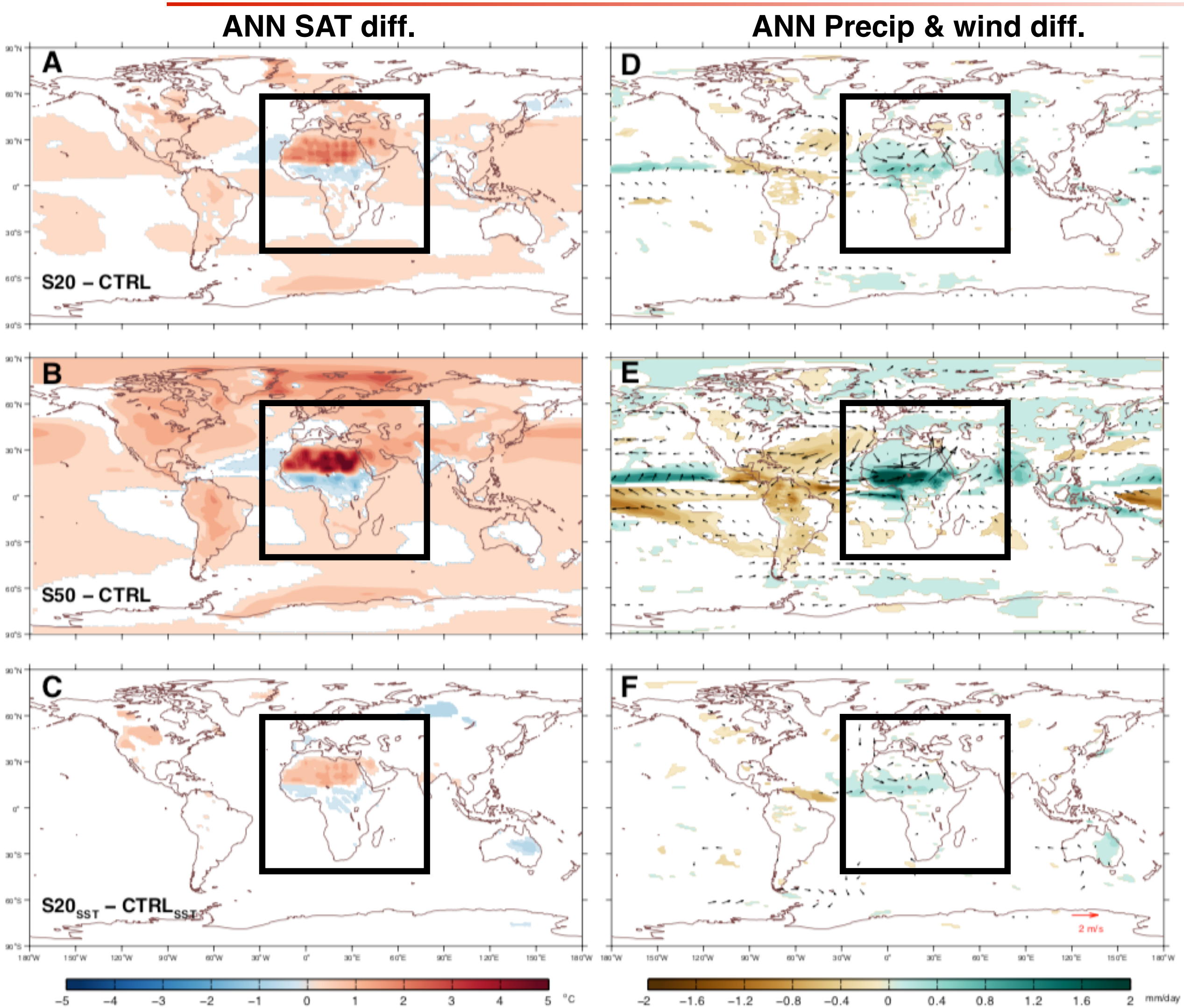
Simulations

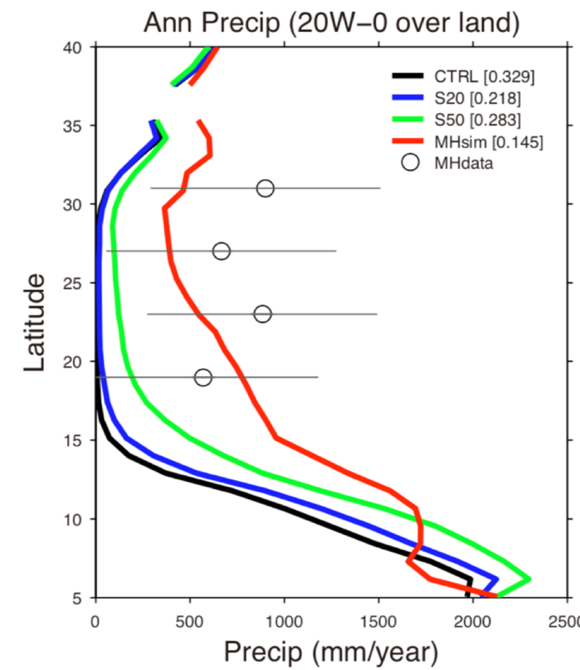
- *Control experiment **CTRL*** (current climate)
- *Solar farm experiments **S20** & **S50*** (20%, 50% of the area in Sahara covered by solar panels)
- ***CTRL**$_{SST}$ & **S20**$_{SST}$* (**Atmos+Veg**, prescribed SST climatology)

Surface albedo prescribed in the simulations



Local & global climate response



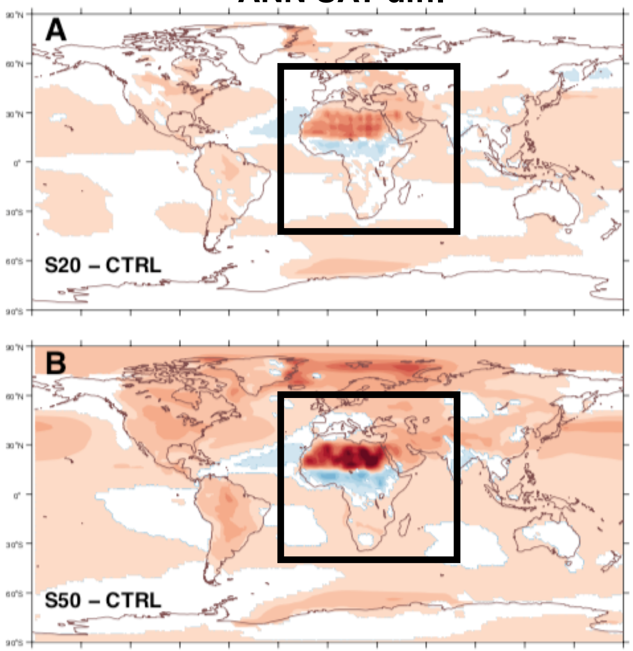


— Pausata et al., 2015

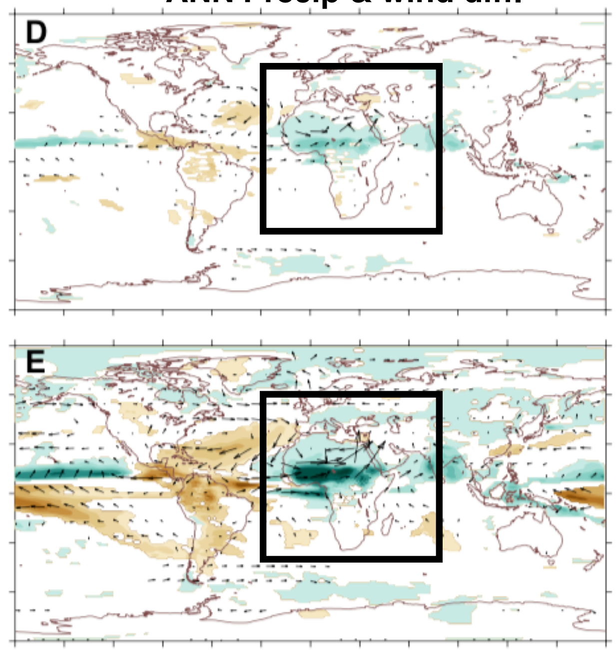
o Tierney et al., 2017

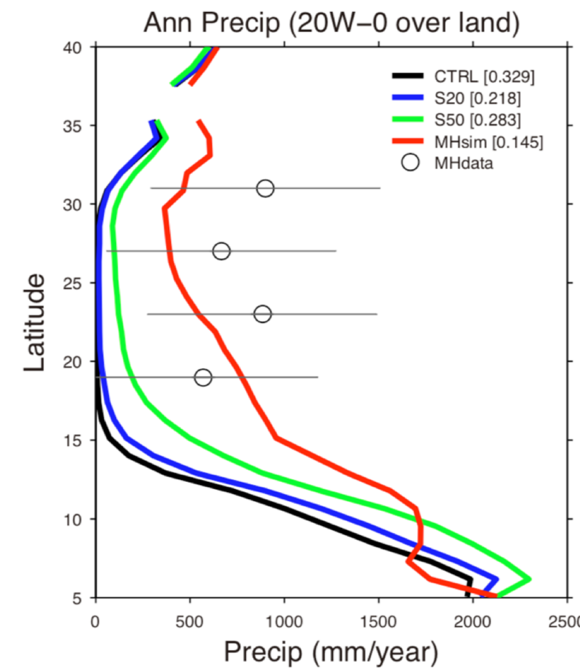
Local & global climate response

ANN SAT diff.



ANN Precip & wind diff.





Local response

robust *atmosphere-land/vegetation feedbacks*

S20: +1.5°C, +0.1mm/d,

S50: +2.5°C, +0.4mm/d

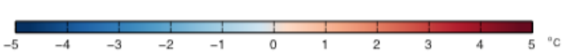
Remote response

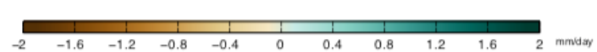
- Global and Arctic warming;
- Arctic sea-ice loss (-0.7% for S20, -5.3% for S50)
- Amazon droughts
- Polarward equatorial rainfall belt shift

— Pausata et al., 2015

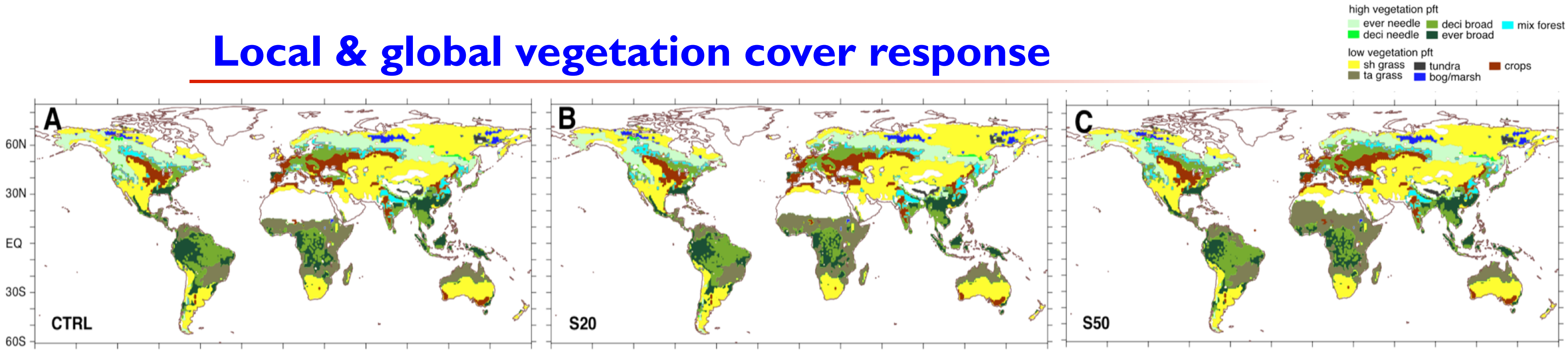
o Tierney et al., 2017

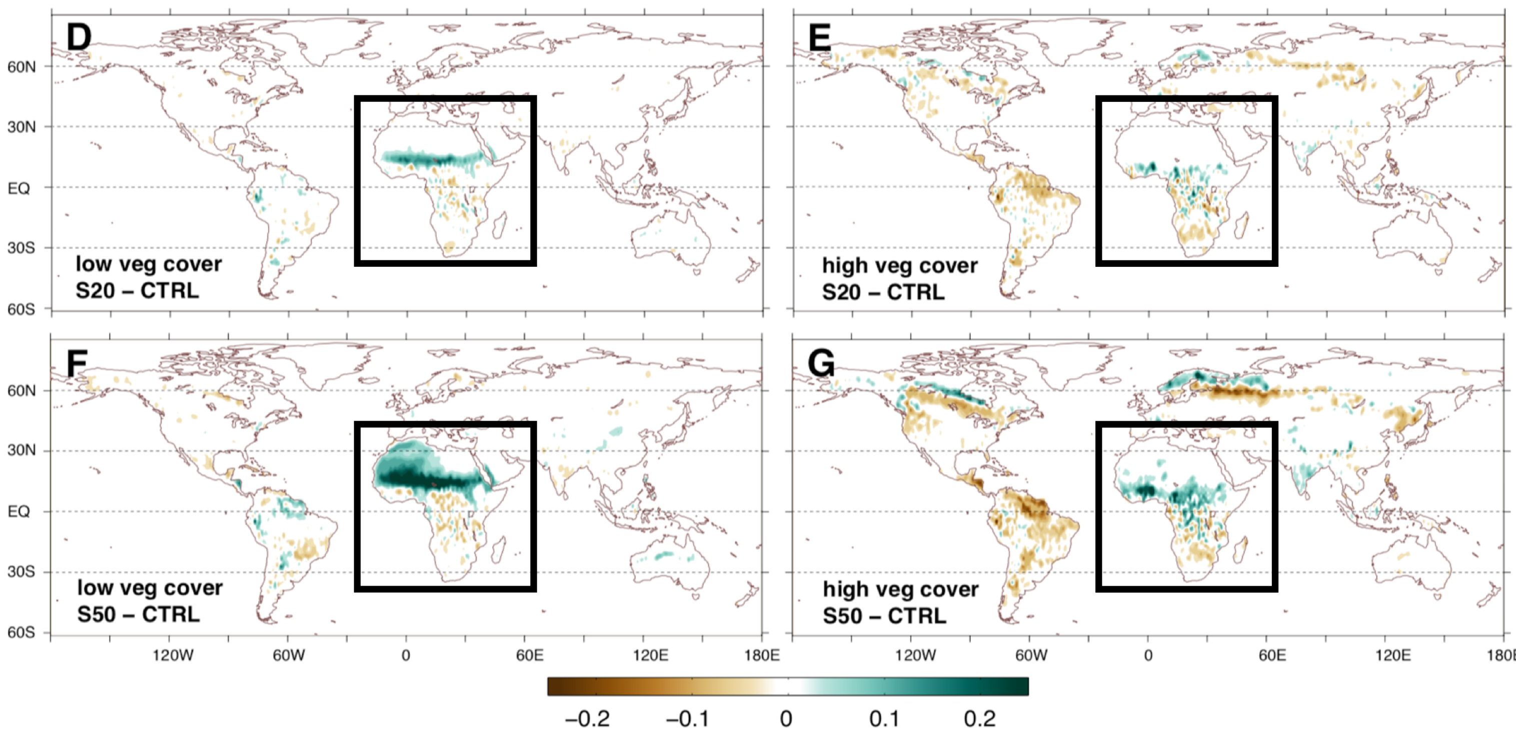
Consistent with Li et al. 2018 *Science*





Local & global vegetation cover response

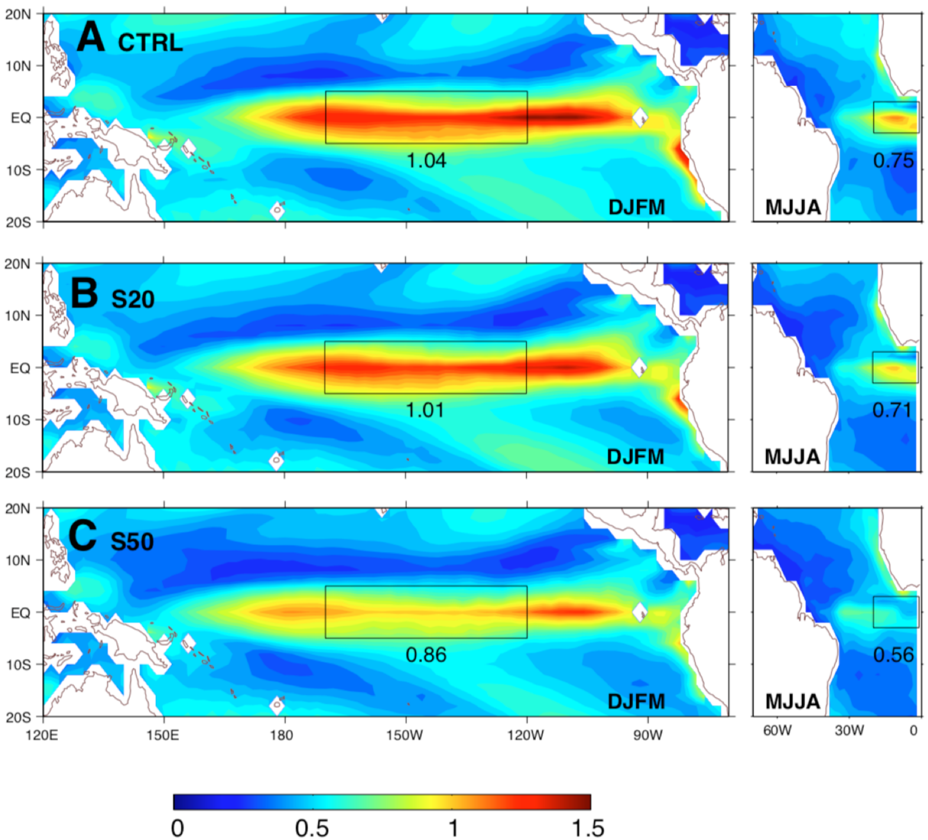




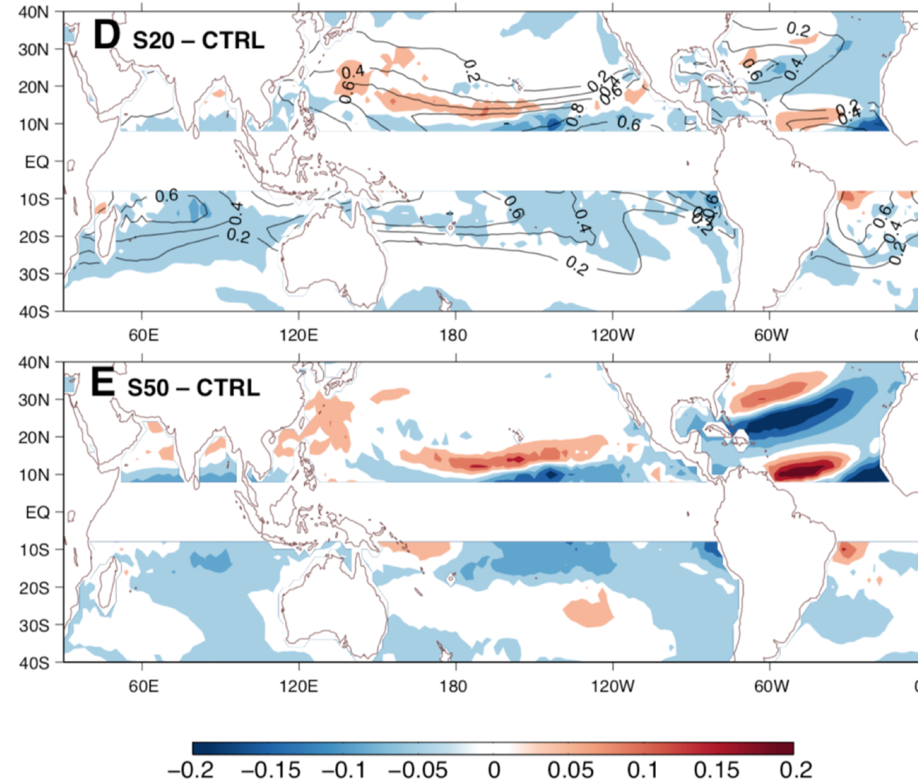
- Vegetation expansion in North Africa
- Amazon forest degradation
- Treeline northward shift in the Northern Hemisphere

ENSO and Tropical cyclone response

SSTA interannual variability



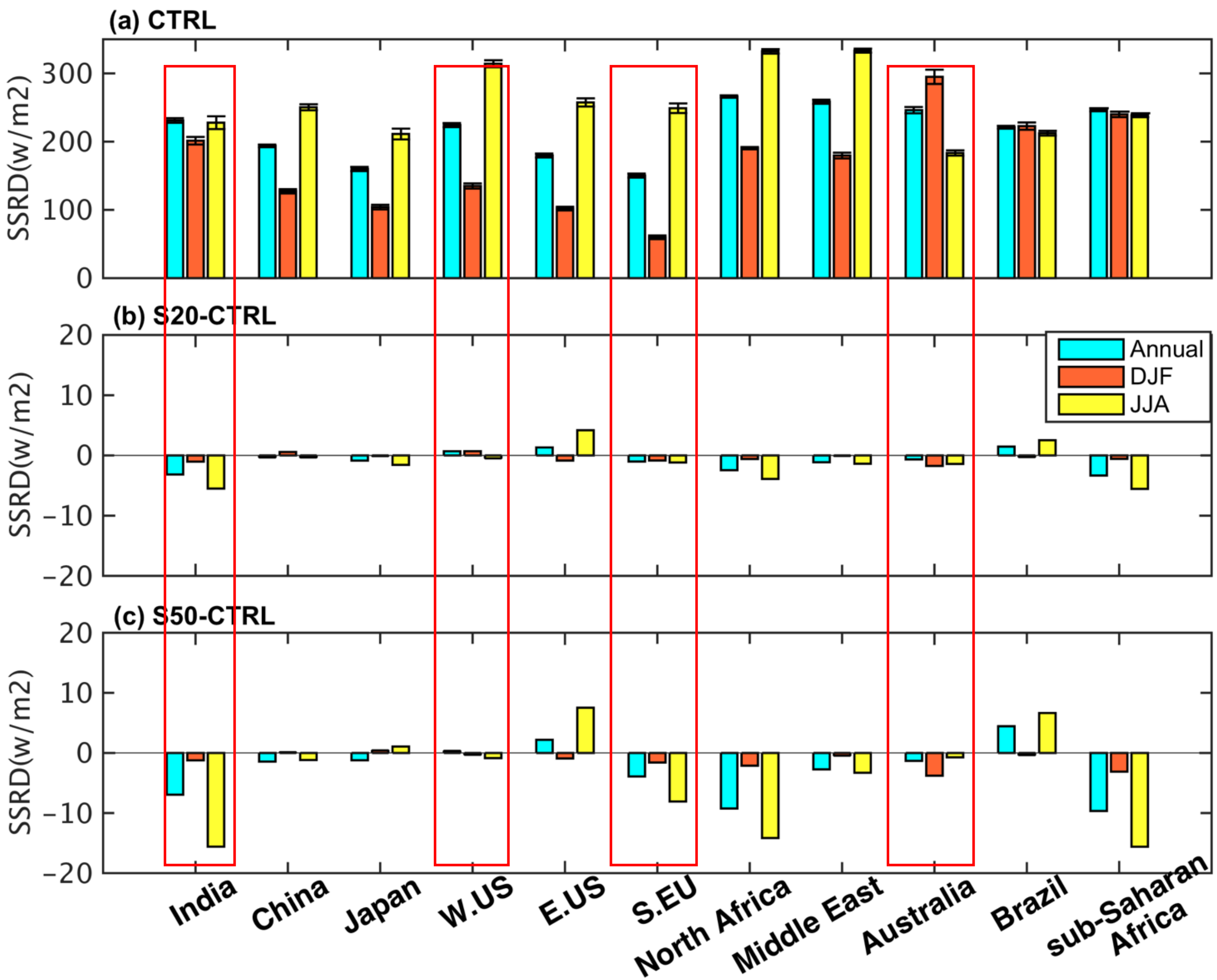
Cyclone genesis index diff.

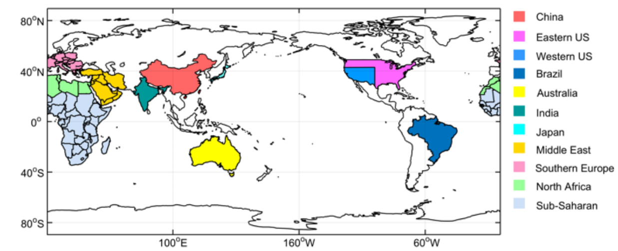


$$CGI = \left(\frac{V_{pot}}{70}\right)^3 (1 + 0.1V_{shear})^{-2}$$ Bruyère et al., 2012

- Suppressed El Niño-Southern Oscillation & Atlantic Niño variability
- Enhanced tropical cyclone activities (coastal regions)

Global solar potential changes





- Reduced solar power generation (more cloud, less SSRD) in many regions where energy transition to solar power is heavily promoted, such as Southern Europe, India, Southeast Asia, Eastern Australia, and Western US

Long, Lu et al. *In Prep.*

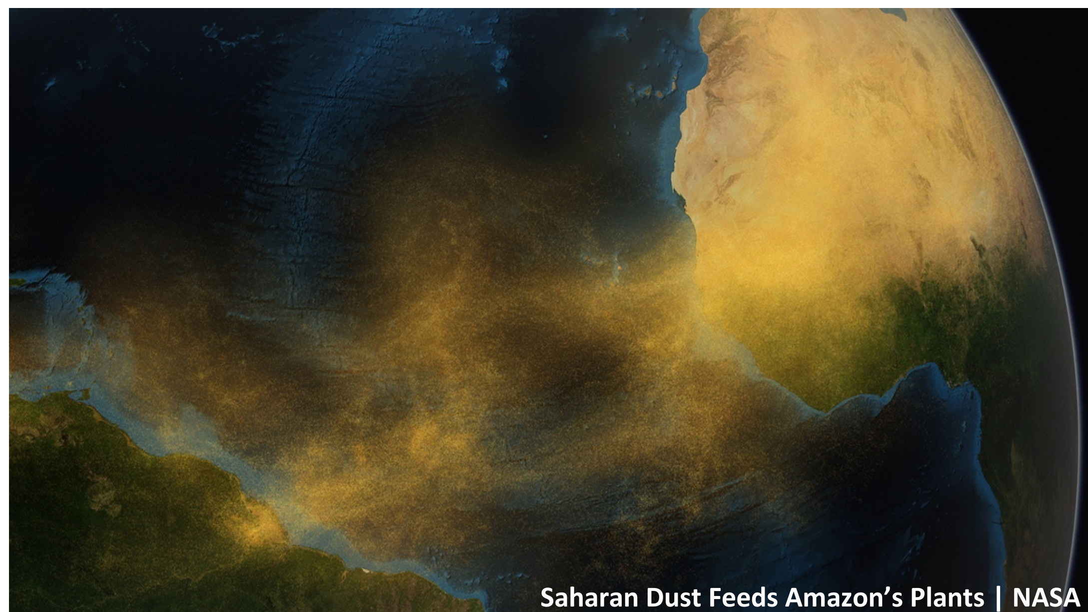
A preliminary assessment (electricity production, other potential effects)

Simulation	Power generated (no vegetation shading)	Power generated (with max vegetation shading)	Global surface air temperature change
20% coverage	**91.2 TW**	86.3 TW	**+ 0.16^{o}C**
50% coverage	**218.1 TW**	188.9 TW	**+ 0.39^{o}C**

- Current world consumption: 18.4 TW (= 8000 Bhadla Solar Parks, each 2.245 GW)

Other processes may further amplify the impacts

- **Dust effects** are missing (changing albedo, fertilization)



Take-home message

Massive Sahara solar farms (20% or more coverage)

pros: energy enough for the world; increased local rain and vegetation, good for agriculture & pasture in one of the poorest and driest region in the world.

cons/other impacts:

- global warming (still less than fossil fuels), particular in the Arctic;
- droughts and deforestation in the Amazon;
- treeline northward shift in the Northern Hemisphere;
- polarward ITCZ shift;
- loss of Arctic sea-ice;
- enhanced tropical cyclone activities (coastal regions);
- suppressed El Niño-Southern Oscillation & Atlantic Niño variability;
- significantly disturbed global solar power generation

The importance of **an Earth-system analysis** when examining the future site locations of **large-scale solar energy facilities**.

Refs:
Lu et al. (2021). Impacts of large-scale Sahara solar farms on global climate and vegetation cover. *Geophysical Research Letters, 48, e2020GL090789.*
Lu & Smith (2021). Solar panels in Sahara could boost renewable energy but damage the global climate–here's why. *The Conversation*. (popular science)
Long, Lu et al. Global solar power generation disturbed by large-scale Sahara photovoltaic solar farms. *In Prep.*

Backup slide

Background: climate and environmental impacts of solar farms

Based on on-site measurements and satellite remote sensing…

- Large solar power plants **increase** local temperatures (“**solar heat island** effect”)
- The installation of the photovoltaic (PV) powerplants significantly **reduced** the daily mean surface temperature
- Solar photovoltaic panels significantly **promote vegetation recovery** by modifying the soil surface microhabitats in an arid sandy ecosystem
- The **negative effects** of solar energy development on the desert scrub plant community

Barron-Gafford et al., 2016; Grodsky & Hernandez, 2020; Liu et al., 2019; Zhang & Xu, 2020, …

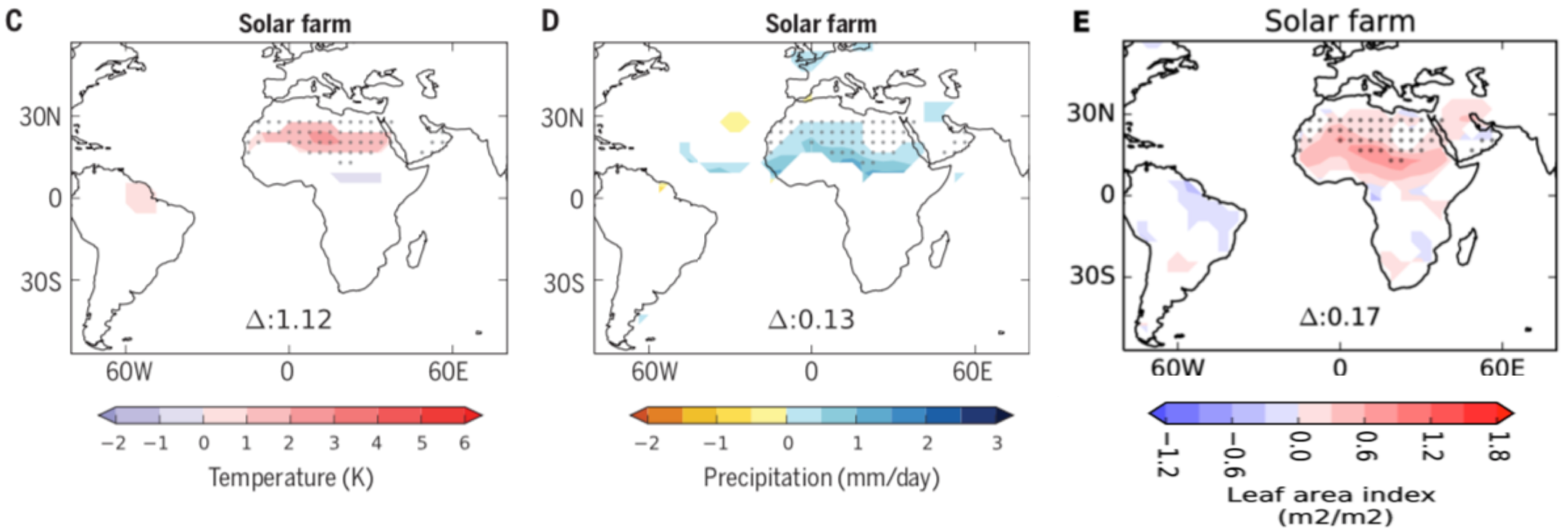
(a)

(b)

(c)

Background: Hypothetical large-scale Sahara solar farms

"large-scale solar farms in the Sahara increase rain and vegetation" Li et al., 2018



When solar farms are deployed:

surface albedo↓ → local temperature↑ → local precip↑ → vegetation cover↑

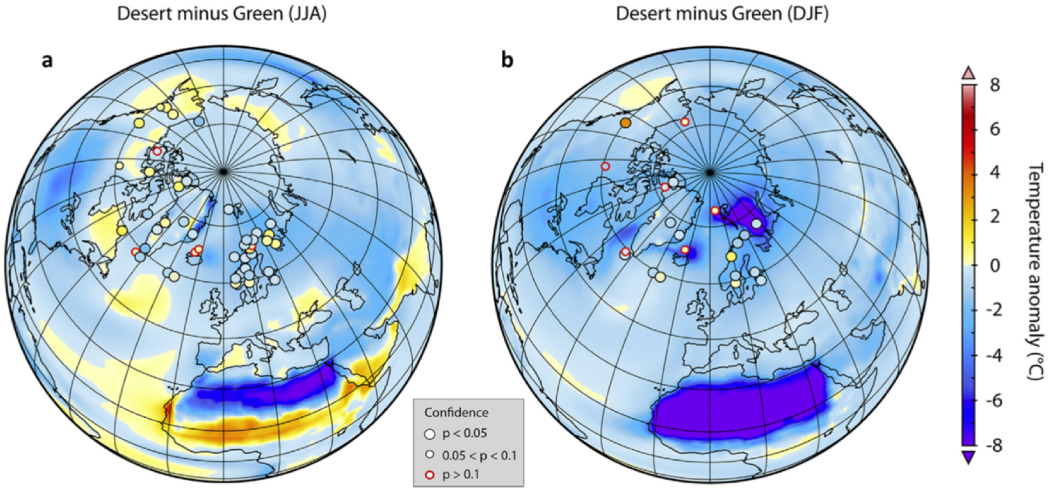
positive atmosphere-vegetation feedbacks

Overgrazing – Sahel droughts

Charney, 1975

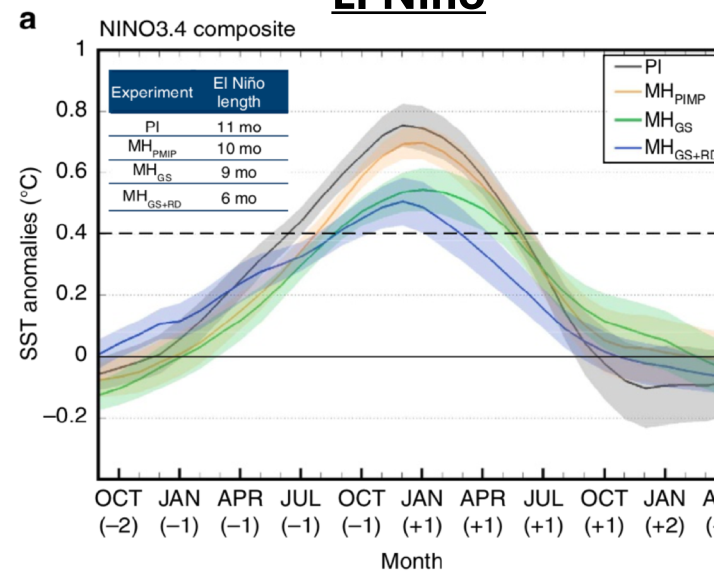
Background: Remote influences of the mid-Holocene Green Sahara

Arctic climate



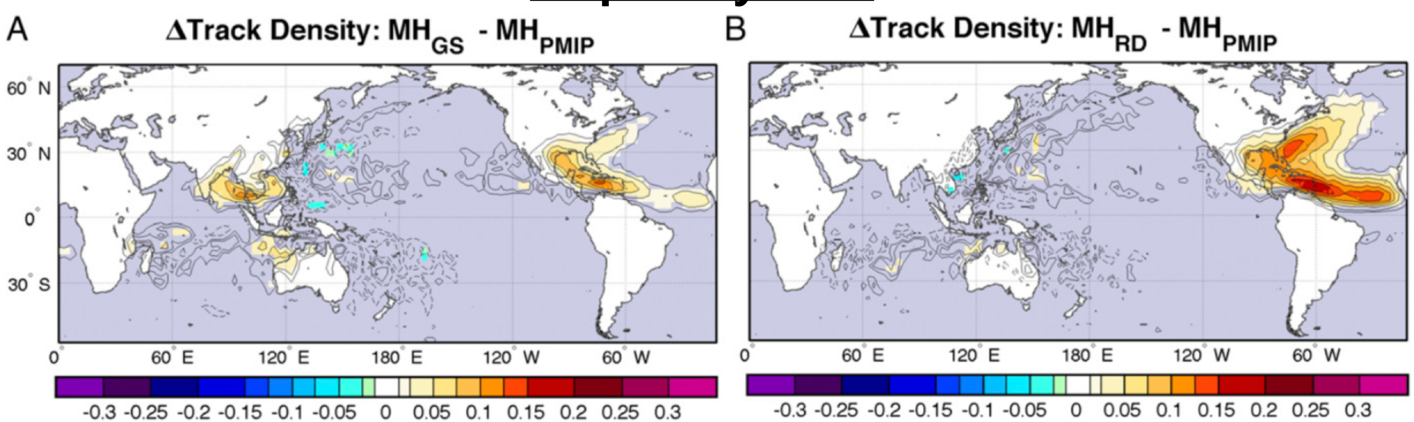
Muschitiello et al., 2015

El Niño



Pausata et al., 2017a

Tropical cyclone



Pausata et al., 2017b