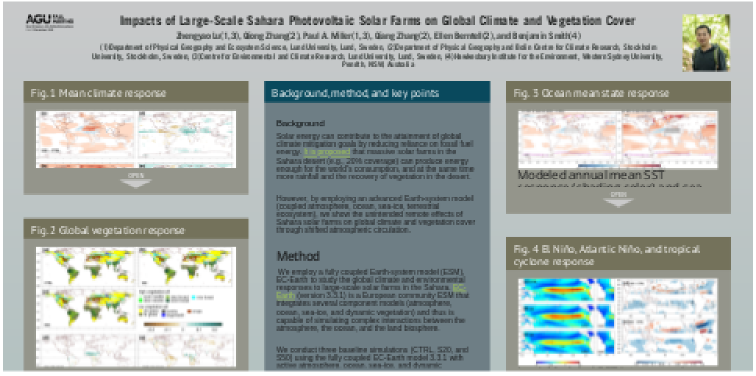
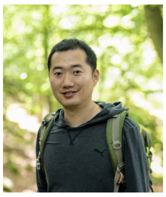
Impacts of Large-Scale Sahara Photovoltaic Solar Farms on Global Climate and Vegetation Cover



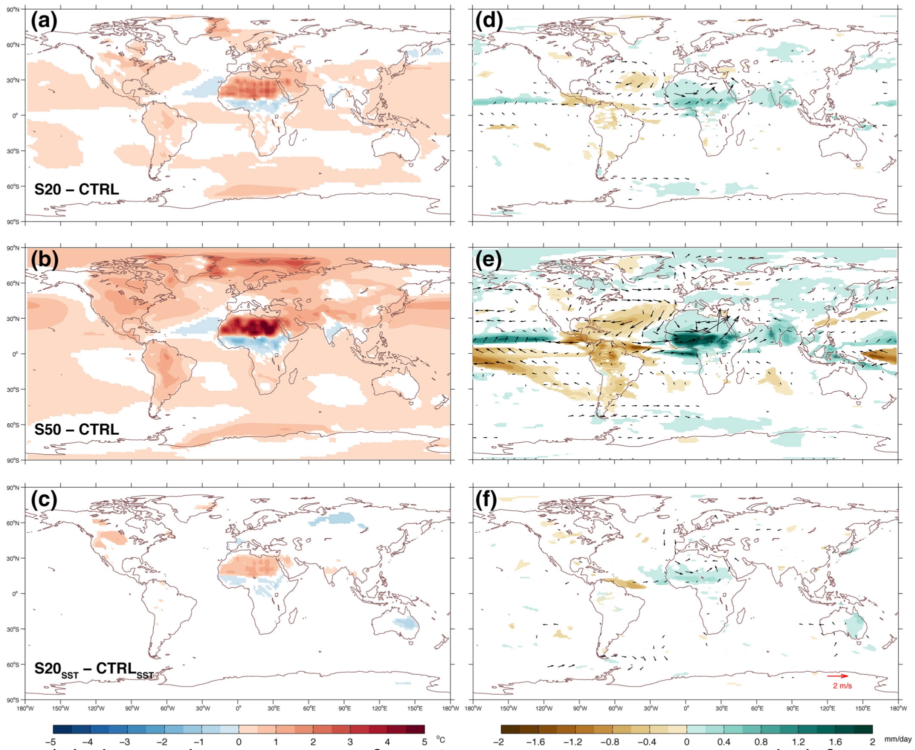
Zhengyao Lu(1,3), Qiong Zhang(2), Paul A. Miller(1,3), Qiang Zhang(2), Ellen Berntell(2), and Benjamin Smith(4)

(1)Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden, (2)Department of Physical Geography and Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden, (3)Centre for Environmental and Climate Research, Lund University, Lund, Sweden, (4)Hawkesbury Institute for the Environment, Western Sydney University, Penrith, NSW, Australia



PRESENTED AT:

FIG. 1 MEAN CLIMATE RESPONSE



Modeled annual mean (a–c) surface air temperature response, and (d–f) precipitation and 925 hPa wind response. From top to bottom, the results are for S20−CTRL, S50−CTRL, and S20SST−CTRLSST. All anomalies shown exceed 95% significance level based on two-sample *t-test*.

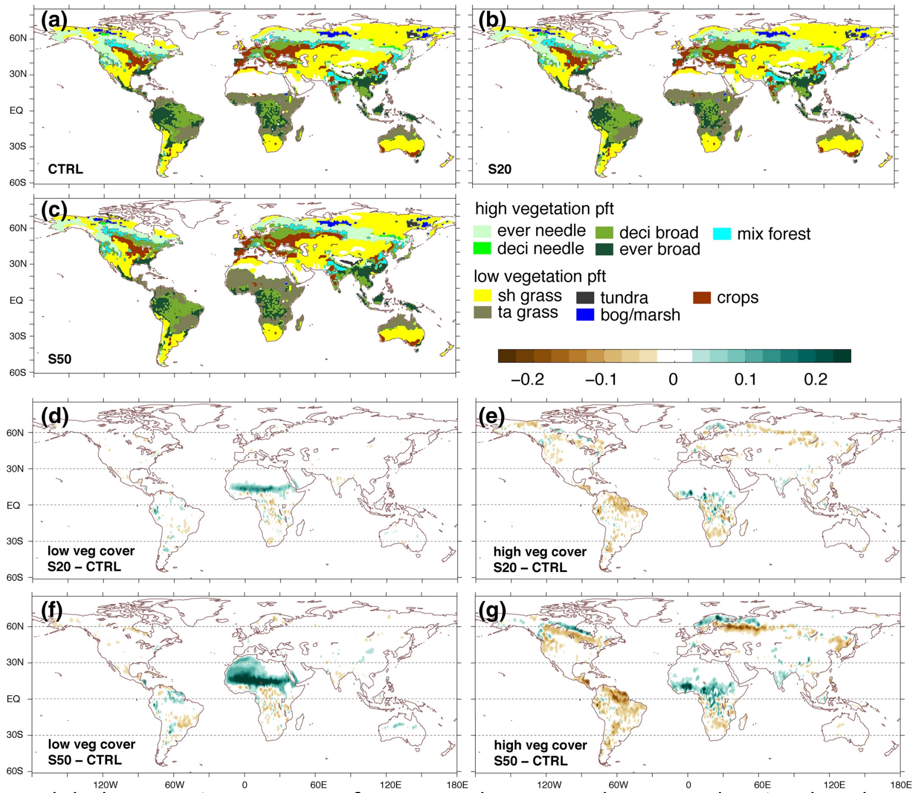
Local response (Sahara region)
More vegetation cover & rainfall in North Africa w/ enhanced Western African Monsoon, robust atmosphere-land/vegetation feedbacks

- S20: +1.5C, +0.1mm/d
- S50: +2.5C, +0.4mm/d

Remote response

- Global and Arctic warming
- Amazon droughts
- Polarward ITCZ shift
- Atmospheric and oceanic meridional heat transport (and AMOC strength) increase

FIG. 2 GLOBAL VEGETATION RESPONSE



Modeled vegetation pattern of (a) CTRL, (b) S20, and (c) S50. The simulated plant functional type (PFT) is shown where the vegetation cover is larger than 15%. Modeled annual mean vegetation cover (fraction) differences for (d, f) low vegetation and (e, g) high vegetation.

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

BACKGROUND, METHOD, AND KEY POINTS

Background

Solar energy can contribute to the attainment of global climate mitigation goals by reducing reliance on fossil fuel energy. It is proposed (https://www.science.org/doi/full/10.1126/science.aar5629) that massive solar farms in the Sahara desert (e.g., 20% coverage) can produce energy enough for the world's consumption, and at the same time more rainfall and the recovery of vegetation in the desert.

However, by employing an advanced Earth-system model (coupled atmosphere, ocean, sea-ice, terrestrial ecosystem), we show the unintended remote effects of Sahara solar farms on global climate and vegetation cover through shifted atmospheric circulation.

Method

We employ a fully coupled Earth-system model (ESM), EC-Earth to study the global climate and environmental responses to large-scale solar farms in the Sahara. EC-Earth (http://www.ec-earth.org/) (version 3.3.1) is a European community ESM that integrates several component models (atmosphere, ocean, sea-ice, and dynamic vegetation) and thus is capable of simulating complex interactions between the atmosphere, the ocean, and the land biosphere.

We conduct three baseline simulations (CTRL, S20, and S50) using the fully coupled EC-Earth model 3.3.1 with active atmosphere, ocean, sea-ice, and dynamic vegetation components.

The S20 and S50 ("solar panels") represent the "Sahara solar farm" scenarios in which 20% and 50% of all the grid points in the North African region are prescribed reduced bare soil albedo. They are compared with a modern climate (1990CE) control simulation (CTRL).

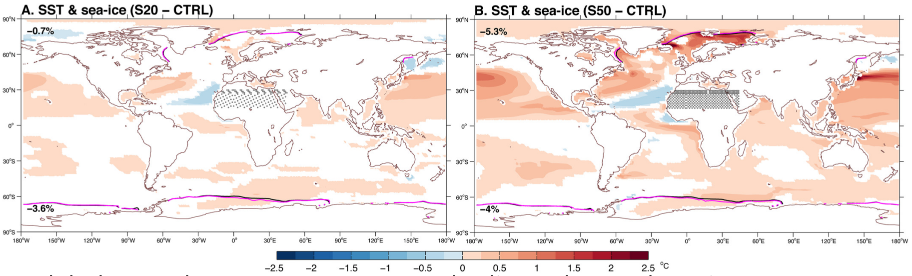
Key Results

The hypothetical solar farms increase local rainfall and vegetation cover through positive atmosphere–land(albedo)–vegetation feedbacks.

Conveyed by atmospheric teleconnections, the Sahara solar farms can induce remote responses in global climate and vegetation cover:

1. A redistribution of precipitation causing Amazon droughts and forest degradation
2. Global surface temperature rise
3. Sea-ice loss, particularly over the Arctic due to increased polarward heat transport
4. Northward expansion of deciduous forests in the Northern Hemisphere
5. Reduced El Niño-Southern Oscillation and Atlantic Niño variability
6. Enhanced tropical cyclone activity

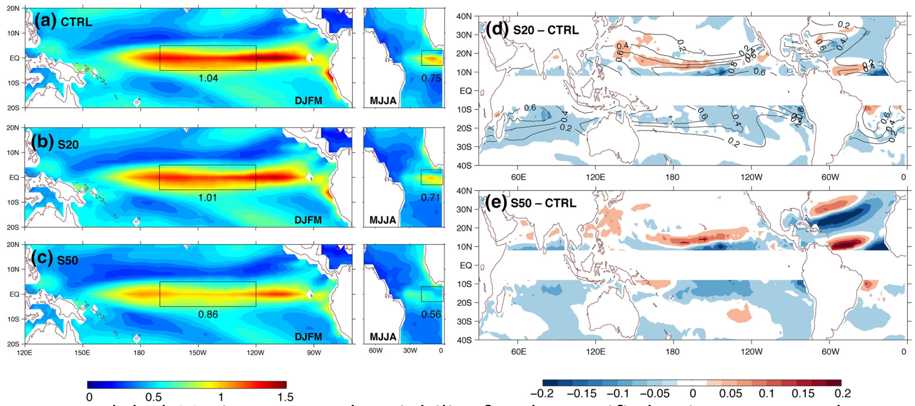
FIG. 3 OCEAN MEAN STATE RESPONSE



Modeled annual mean SST response (shading color) and sea-ice extent (>50% sea-ice concentration) in CTRL (black curve) and solar farm simulations (purple curves) for (a) S20−CTRL and (b) S50−CTRL. The hemispheric sea-ice extent changes are also shown in the corner of the map. Black dots depict the locations of solar panels for S20 and S50 ("checkerboard"). All anomalies shown exceed 95% significance level based on two-sample *t-test*.

- Global and Arctic warming
- Arctic sea-ice loss (-0.7% for S20, -5.3% for S50)

FIG. 4 EL NIÑO, ATLANTIC NIÑO, AND TROPICAL CYCLONE RESPONSE



(a–c) Modeled SST interannual variability for the Pacific basin (DJFM) and Atlantic basin (MJJA). Black boxes are Niño3.4 and Atlantic3 regions with the region averaged value shown below. (d, e) Modeled CGI index change (shading color) with mean CGI index of CTRL shown in (d) as black contour. The CGI is set to zero between 5°S and 5°N due to zero Coriolis vorticity at the equator. CGI, Cyclone Genesis Index.

- El Niño-Southern Oscillation & Atlantic Niño variability are suppressed
- Tropical cyclone activities (coastal regions) are enhanced.

AUTHOR INFORMATION

Zhengyao Lu(1,3), Qiong Zhang(2), Paul A. Miller(1,3), Qiang Zhang(2), Ellen Berntell(2), and Benjamin Smith(4)

(1)Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden, (2)Department of Physical Geography and Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden, (3)Centre for Environmental and Climate Research, Lund University, Lund, Sweden, (4)Hawkesbury Institute for the Environment, Western Sydney University, Penrith, NSW, Australia

Contact: zhengyao.lu@nateko.lu.se

ABSTRACT

Solar energy, if carefully planned, can contribute to the attainment of global climate mitigation goals by reducing reliance on fossil fuel energy. It has been suggested that large-scale photovoltaic solar farms envisioned over the Sahara desert would reduce surface albedo, leading to increased rainfall and vegetation cover that would benefit the regional environment while meeting the world's energy demand. However, adverse remote effects resulting from atmospheric teleconnections could offset such regional benefits. We use state-of-the-art Earth-system model simulations to evaluate the global impacts of Sahara solar farms. Our results indicate a redistribution of precipitation causing Amazon droughts and forest degradation, and global surface temperature rise and sea-ice loss, particularly over the Arctic due to increased polarward heat transport, and northward expansion of deciduous forests in the Northern Hemisphere. We also identify reduced El Niño-Southern Oscillation and Atlantic Niño variability and enhanced tropical cyclone activity. All these remote effects are in line with the global impacts of the Sahara land-cover transition ~6,000 years ago when Sahara desert was wetter and greener. The improved understanding of the forcing mechanisms of massive Sahara solar farms can be helpful for the future site selection of large-scale desert solar energy facilities.

REFERENCES

Lu, Z., Zhang, Q., Miller, P. A., Zhang, Q., Berntell, E., & Smith, B. (2021). Impacts of Large-Scale Sahara Solar Farms on Global Climate and Vegetation Cover. *Geophysical Research Letters*, *48*(2), e2020GL090789.

https://doi.org/10.1029/2020GL090789 (https://doi.org/10.1029/2020GL090789)