Solar Farm as an Ideal Test Bed for Satellite Surface Emissivity and Temperature Retrieval Algorithms

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Introduction

R_S – Shortwave radiation; S – Sensible heat flux; R_L – Longwave radiation; C – Soil heat conduction; L – Latent heat flux; E – Electricity from solar panels

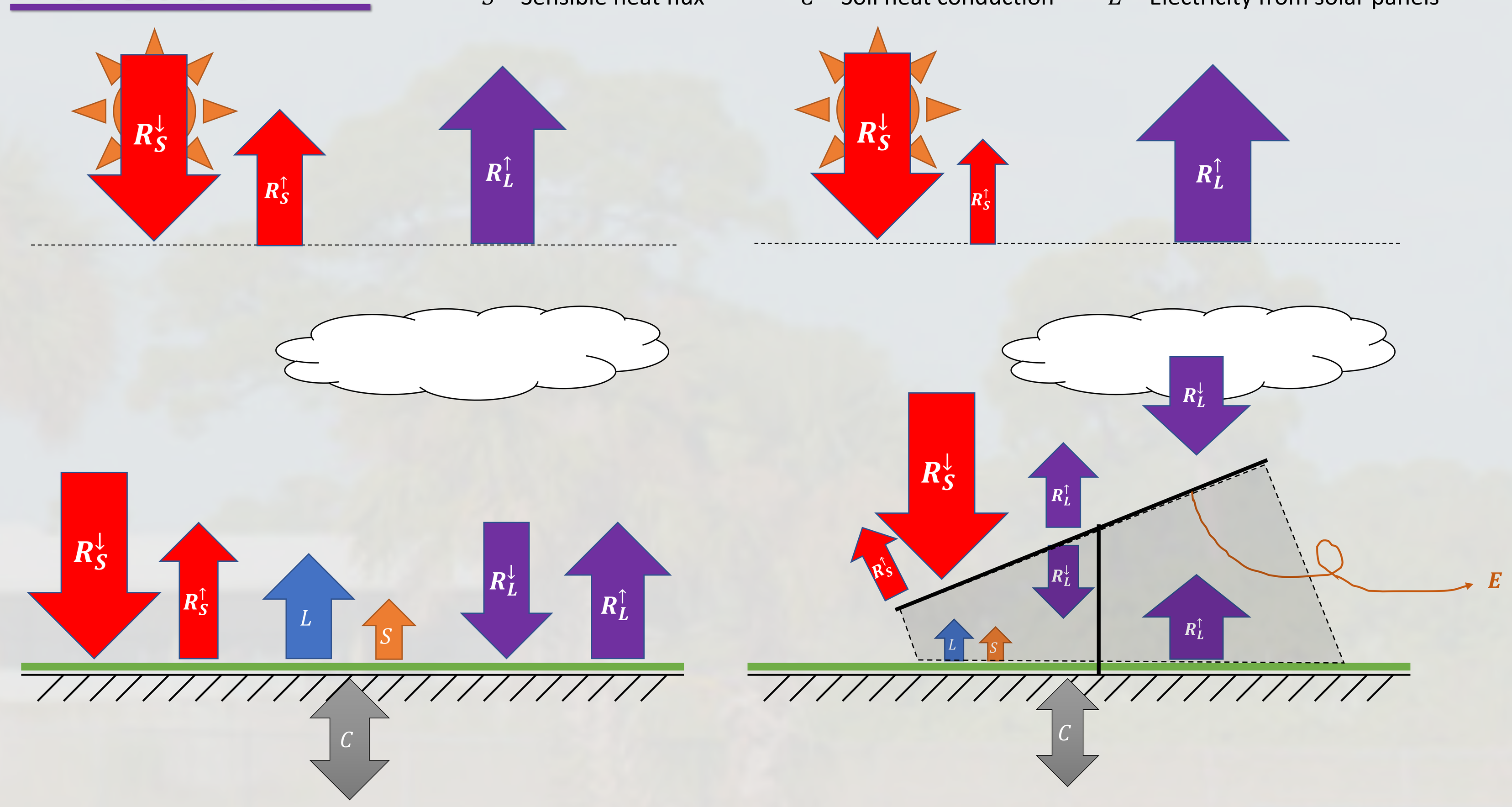


Figure. Schematic diagram of Surface energy budget over natural barren ground (left) and solar farm (right).

R_S Shortwave radiative flux. Reflected shortwave flux **reduced** due to solar panels absorbing solar energy and producing **electricity *E***.

- **Satellite observations (e.g., Fan et al., 2020)** – 20%~25% reduction of surface spectral reflectances at seven MODIS bands => 23% decrease in surface upward shortwave flux and a 14~18% decrease in TOA clear-sky reflected shortwave flux => Strong local effect but limited global effect (<1.1 W/m^2 of radiative forcing even if all bright deserts were converted to solar farms)
- **Climate modeling** – Global cooling (Hu et al., 2016) or local warming only (Li et al., 2018) due to different assumptions on surface effective albedo

R_L Longwave radiative flux. Not well understood.

- **Satellite observations (e.g., Zhang & Xu, 2020)** – Daytime and nighttime land surface temperature (LST) measured from MODIS over the solar farm **decreased**, due to energy conversion and enhanced convective heating
- **In-Situ measurements (e.g., Broadbent et al., 2019)** – Solar module **hotter** than the reference site ground, and upward longwave radiative flux **reduced** due to lower emissivity of solar panels

Scientific Questions

- **Surface emissivity and temperature differences** from satellite retrievals over solar farms?
- **Understanding of longwave radiation transfer** in solar farms?
- **Uncertainty** of surface retrieval algorithm?

Methodology

- **Six solar farms** in the southwest U.S. (Fan & Huang, 2020)
- New retrieval product (MYD21A2) that can **dynamically retrieve surface emissivity and temperature**
- Synthesis of **satellite retrievals** and **in-situ measurements** for better interpretation

Name	Location	Commission	Site Area	Power
Solar Star	34N, 118W (CA)	2011-2015	13 km^2	579 MW$_{AC}$
Topaz Solar Farm	35N, 120W (CA)	2011-2014	19 km^2	550 MW$_{AC}$
Desert Sunlight Solar Farm	33N, 115W (CA)	2011-2015	16 km^2	550 MW$_{AC}$
Copper Mountain Solar Facility	35N, 114W (NE)	2010-2016	16 km^2	552 MW$_{AC}$
California Valley Solar Ranch	35N, 119W (CA)	2011-2013	8 km^2	250 MW$_{AC}$
Agua Caliente Solar Project	32N, 113W (AR)	2011-2014	10 km^2	290 MW$_{AC}$

Composite Analysis

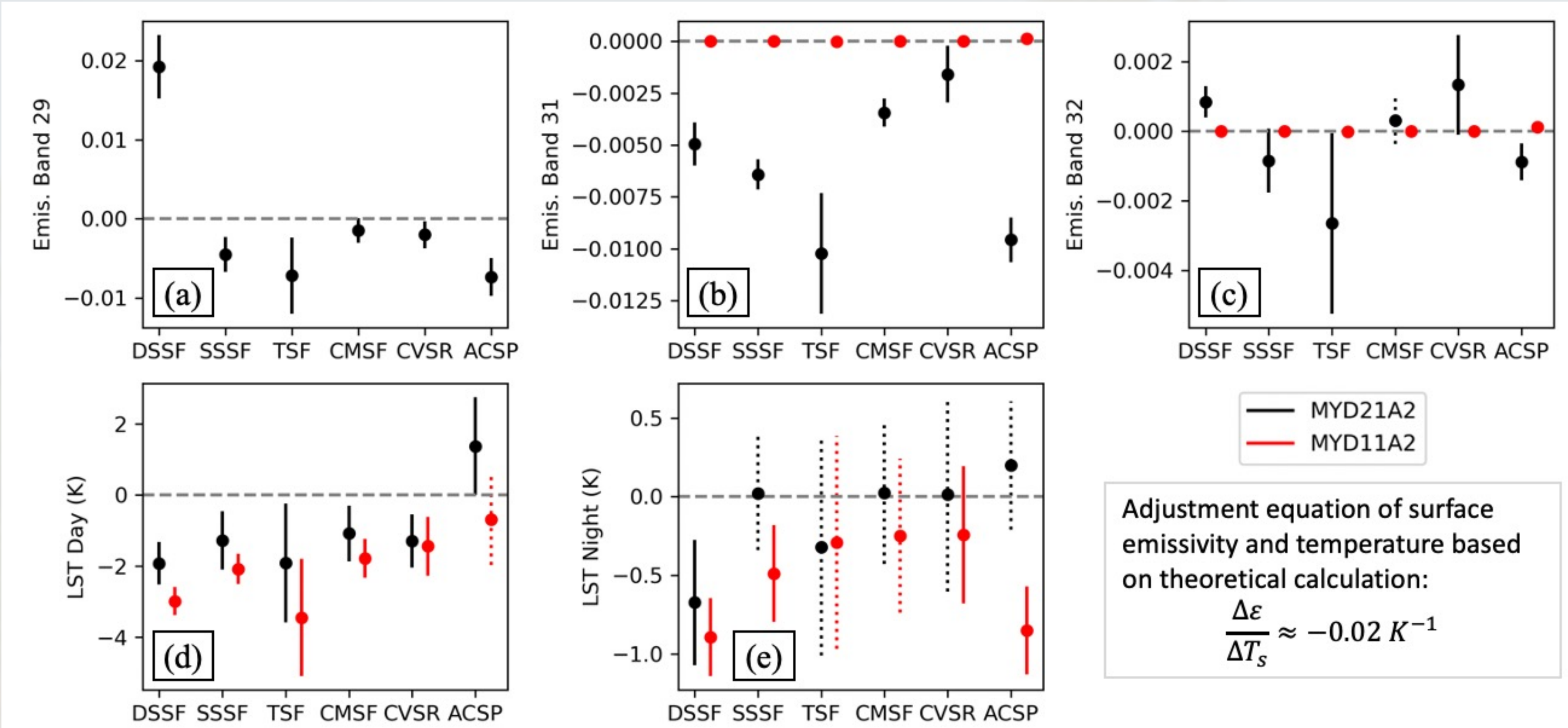


Figure. Differences of Longwave Radiation Properties before and after the Construction of Six Solar Farms. *Band 29 emissivity not available for MYD11A2. Calculated by subtracting the change over the solar farm by the mean change over the control fields. Bar length = the standard deviation of seasonal variation of changes. Solid bar => passing 5% significance test.*

- MYD11A2 surface emissivities over Bands 31 and 32 are **constant**.
- MYD11A2 LST for both day and night across all the six sites is **reduced**.
- MYD21A2 surface emissivities: Band 29 ▼ **except DSSF**; Band 31 ▼; Band 32 **small difference**.
- MYD21A2 LST: daytime **smaller decreases except ACSP**; nighttime **small difference except DSSF**.

Interpretation of Satellite Measurements

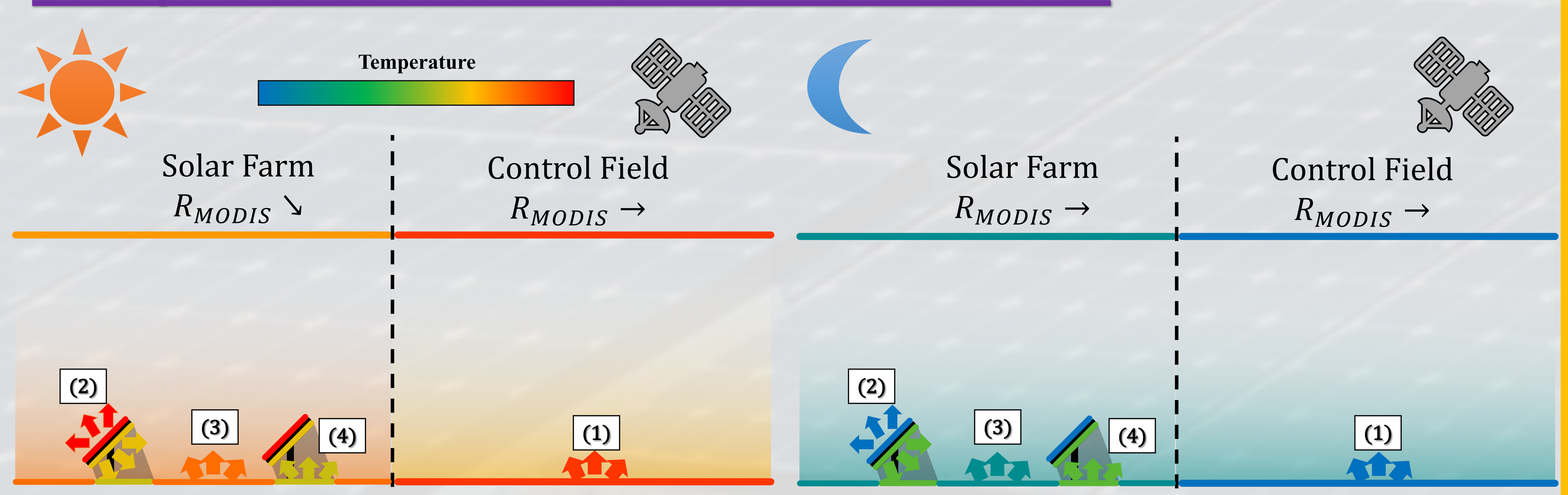


Figure. Proposed schematic diagram of understanding longwave radiation effects from solar farms during the day (left) and night (right), according to satellite observations and in-situ measurements (Broadbent et al., 2019).

[Daytime]

Upward longwave radiative flux reduced compared to control field.

- Solar panel front (2)-(1): hot but less emissive surface $\Delta\varepsilon \approx -0.09,\ \Delta T \approx 0$
- Exposed barren surface (3)-(1): cooler $\Delta\varepsilon = 0,\ \Delta T \approx -2.5\ K$
- Shaded barren surface (4)-(1): much lower temperature due to shading $\Delta\varepsilon = 0,\ \Delta T \approx -7.5\ K$

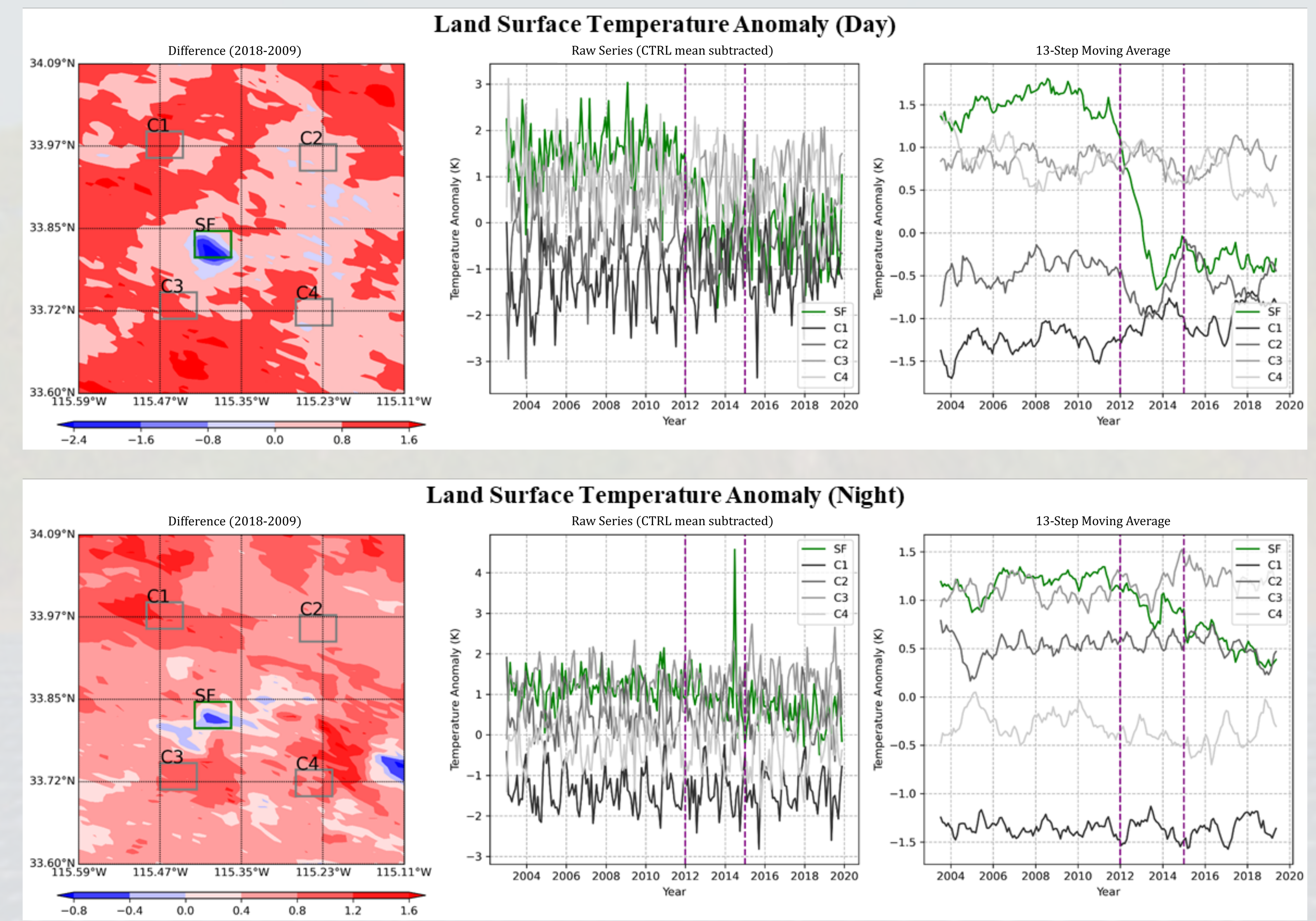
[Nighttime]

Upward longwave radiative flux change negligible

- Solar panel front (2)-(1): cold and less emissive $\Delta\varepsilon \approx -0.09,\ \Delta T \approx -5.0\ K$
- Exposed barren surface (3)-(1): warmer $\Delta\varepsilon = 0,\ \Delta T \approx +2.5\ K$
- Shaded barren surface (4)-(1): much warmer due to downward LW radiation $\Delta\varepsilon = 0,\ \Delta T \approx +3.5\ K$

Daytime air temperature is much colder than the surface. The 2m air temperature in the solar farm is warmer than the counterpart in the control site due to enhanced convective heating. Nighttime air temperature difference is subtle between the solar farm and the control site.

Case – Desert Sunlight Solar Farm (DSSF)



MODIS Retrieval Algorithms

MYD11A2 Generalized split-window algorithm (Wan et al., 2015)

- \+ Widely used in previous studies
- − Assumes that surface emissivities are stable and well known
- − Does not consider solar farm as a land cover type

MYD21A2 Temperature Emissivity Separation (TES) (Hulley & Hook, 2017)

- \+ Can dynamically retrieve surface emissivities
- − Relies on empirical relationship that may not hold on artificial surfaces
- − Retrievals on solar farms still differ from what in-situ measurements suggested

Take-Home Messages

- MODIS products and in-situ measurements agree on **reduced outgoing longwave radiation** over solar farms
- **Small and heterogeneous emissivity changes** and **lower surface temperature** from satellites
- Current retrieval algorithms have challenges with such "unconventional" surface type

Background Image from NASA

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