What are the changes in climate trends in the 1950s and 2000s?

Comparing PVPot, SSRD, and temperature between these decades

Introduction

Our group wanted to answer the following questions:

- Is it possible to see climate change signal in the difference in PVPot from 1950-1959 and 2000-2009?
  - What if we look only at Austria?
  - What if we look only at Greenland?

- What could explain the relationship between temperature and PVPot, and SSRD (radiation) and PVPot that we found? What has other research found to explain this relationship?

Data\Variables

- Surface short-wave (solar) radiation downwards (ssrd): J m**-2
- 2 metre temperature (t2m) : K
- Valid time: YYYY-MM-DD hh:mm:ss
- Latitude
- Longitude

⇨ Windspeed

⇨ PV potential

Formulas

$$P_R(t) = 1 + \gamma\,(T_{cell}(t) - T_{STC})$$

$$T_{cell}(t) = c_1 + c_2 \cdot TAS + c_3 \cdot RSDS + c_4 \cdot VWS$$

$$c_1 = 4.3°\mathrm{C}, \quad c_2 = 0.943, \quad c_3 = 0.028°\mathrm{C\ m^2W^{-1}}, \quad c_4 = -1.528°\mathrm{C\ sm^{-1}}$$

$$PVpot(t) = P_R(t) \cdot \frac{RSDS(t)}{RSDS_{STC}}$$

$$RSDS_{STC} = 1000\,\mathrm{W\ m^{-2}}$$

Jerez, Sonia, Isabelle Tobin, Robert Vautard, Juan Pedro Montávez, Jose María López-Romero, Françoise Thais, Blanka Bartok, et al. 2015. “The impact of climate change on photovoltaic power generation in Europe.” Nat. Commun. 6 (1): 10014. https://doi.org/10.1038/ncomms10014.

Saving the data

```python
def fetch_monthly_data(path, new_data, year):
    months = [f"{month:02}" for month in range(1, 13)]
    ds2_dict = {}

    if new_data:
        Path(f"era5-{year}-monthly").mkdir(parents=True, exist_ok=True)
        for month in months:
            ds2 = xr.open_mfdataset(path + f"era5-{year}-{month}.nc", chunks={"valid_time":1e5} )
            ds2["wspd"] = core.windspeed(ds2)
            ds2["pvpot"] = core.pv_pot(ds2).groupby(ds2.valid_time.dt.month).mean("valid_time").compute()
            ds2[["pvpot", "longitude", "latitude"]].to_netcdf(f"era5-{year}-monthly/era5-{year}-{month}.nc")

            ds2_dict[f"{year}-{month}"] = ds2
    else:
        for month in months:
            ds2 = xr.open_dataset(f"era5-{year}-monthly/era5-{year}-{month}.nc")

            ds2_dict[f"{year}-{month}"] = ds2

    return ds2_dict
```

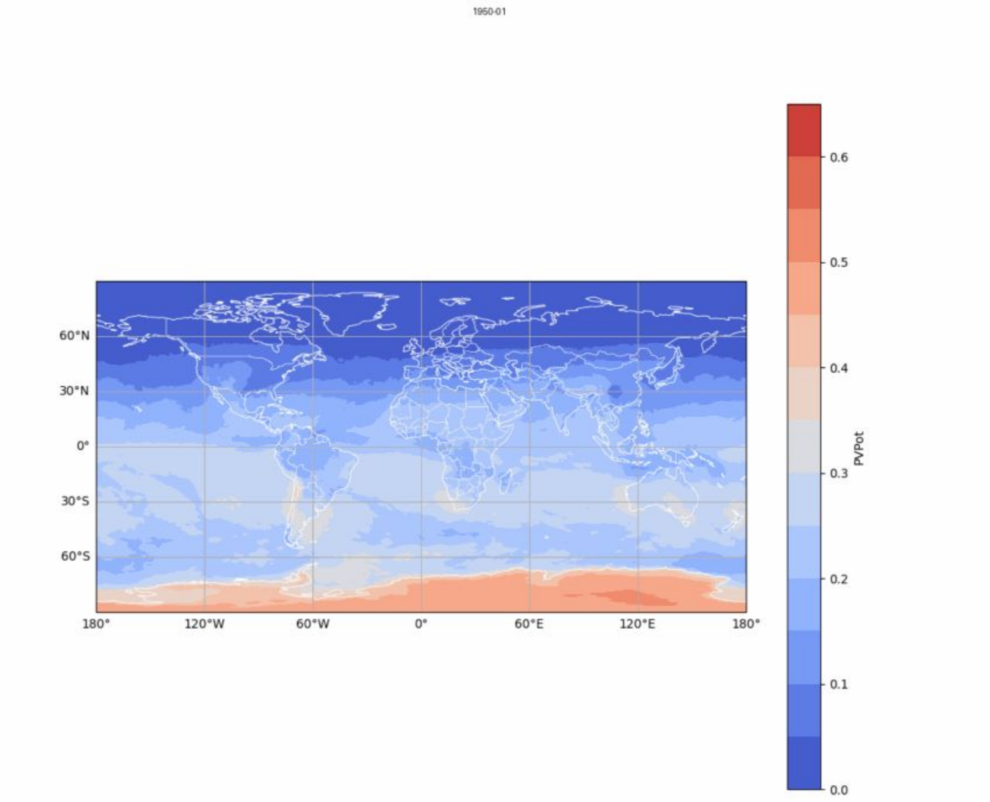
```
4.0M Dec 10 09:15 era5-1950-01.nc
4.0M Nov 26 10:31 era5-1950-02.nc
4.0M Nov 26 10:34 era5-1950-03.nc
4.0M Nov 26 10:36 era5-1950-04.nc
4.0M Nov 26 10:37 era5-1950-05.nc
4.0M Nov 26 10:39 era5-1950-06.nc
4.0M Nov 26 10:41 era5-1950-07.nc
4.0M Nov 26 10:44 era5-1950-08.nc
4.0M Nov 26 10:46 era5-1950-09.nc
4.0M Nov 26 10:48 era5-1950-10.nc
4.0M Nov 26 10:50 era5-1950-11.nc
4.0M Nov 26 10:52 era5-1950-12.nc
```

How did we compute the mean PVPot etc.?

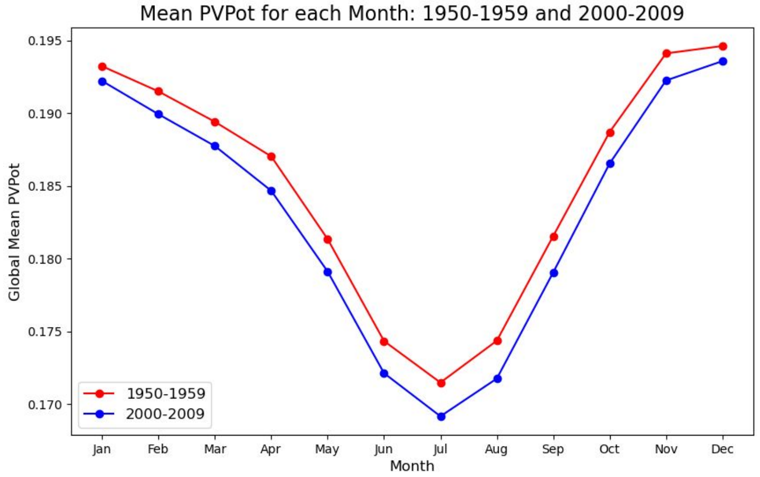
→ Climate Data Operator (cdo)

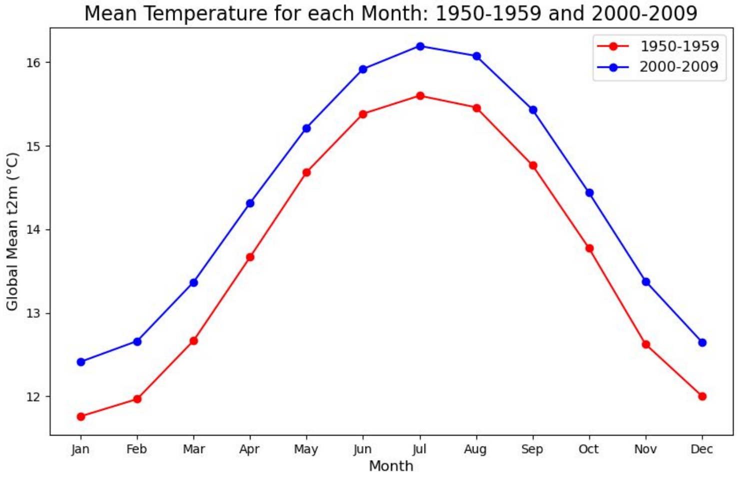
```
cdo mergetime input output

    yearmean
    ymonmean
    fldmean
    zonmean
    -fldmean -sellonlatbox,9,17,46,49
```

PVPot (monthly) for 1950



Global Mean PVPot Monthly





Formulas

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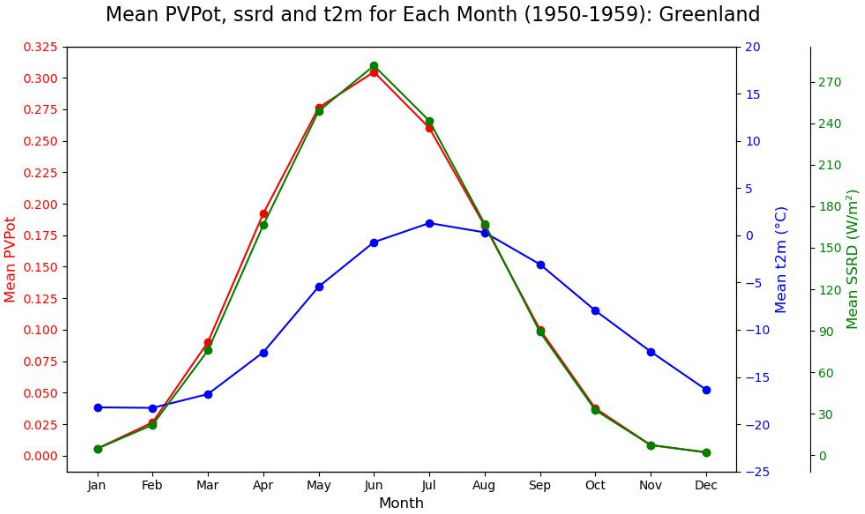
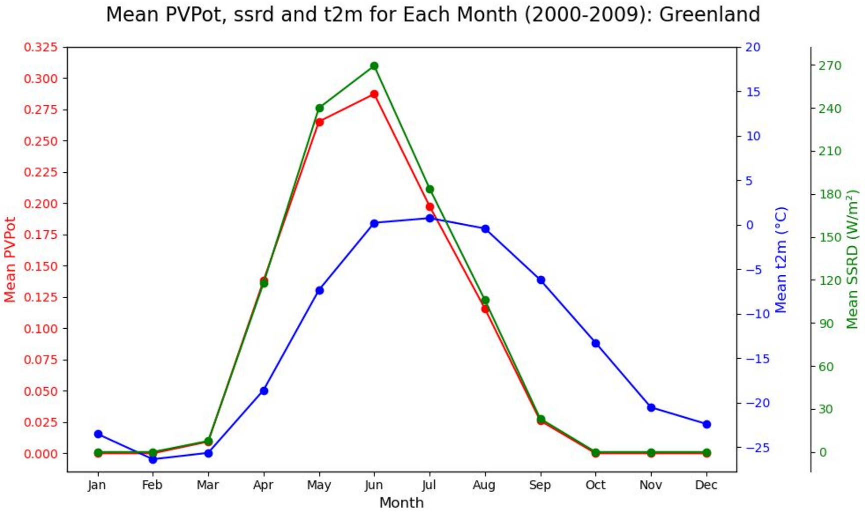
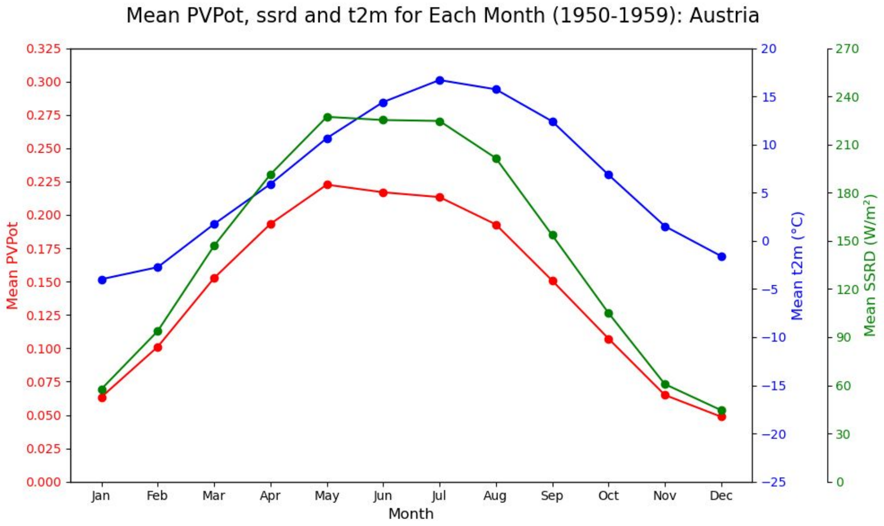
https://www.solarnplus.com/how-temperature-impacts-solar-cell-efficiency https://globalsolaratlas.info/global-pv-potential-study

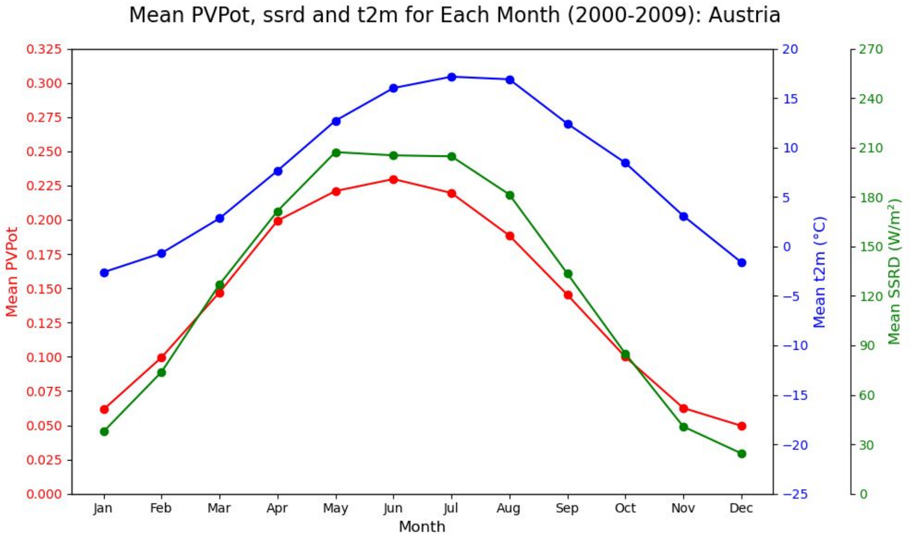
PVPot Comparison For Greenland



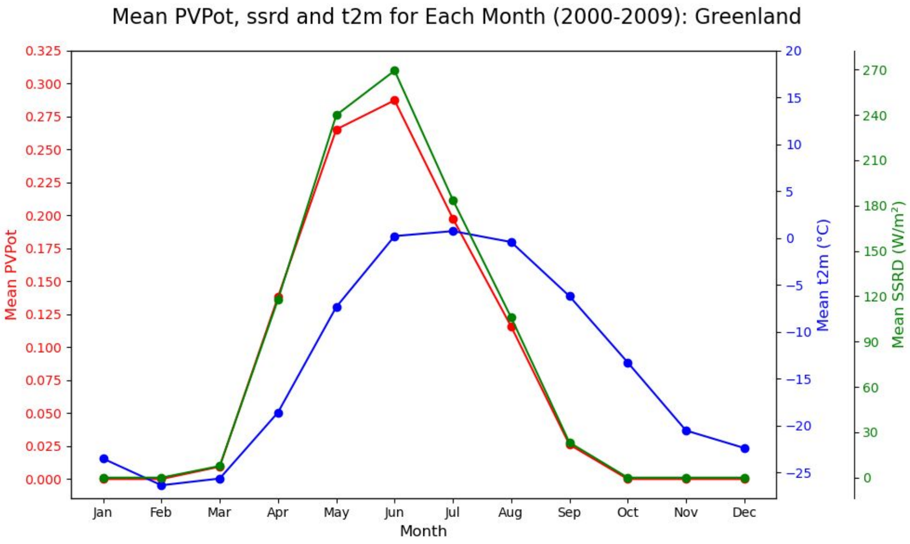


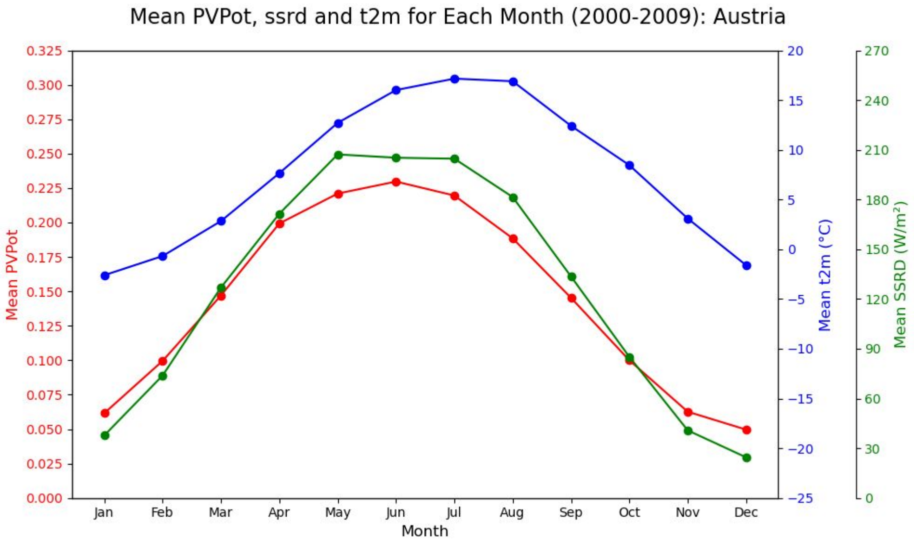
PVPot Comparison For Austria



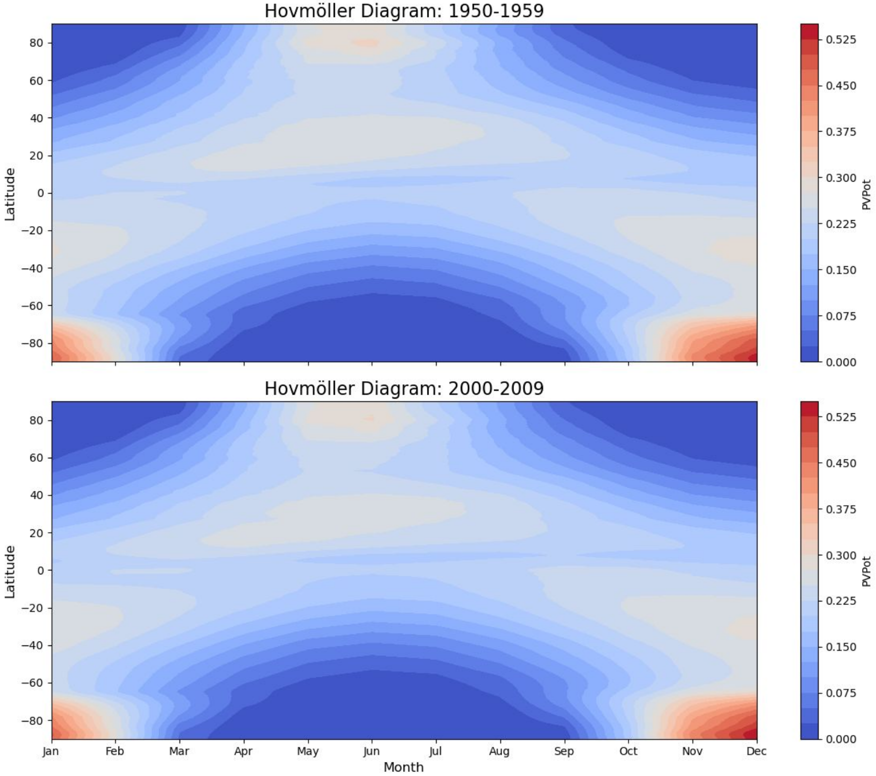


Comparison Of PVPot Between Austria And Greenland

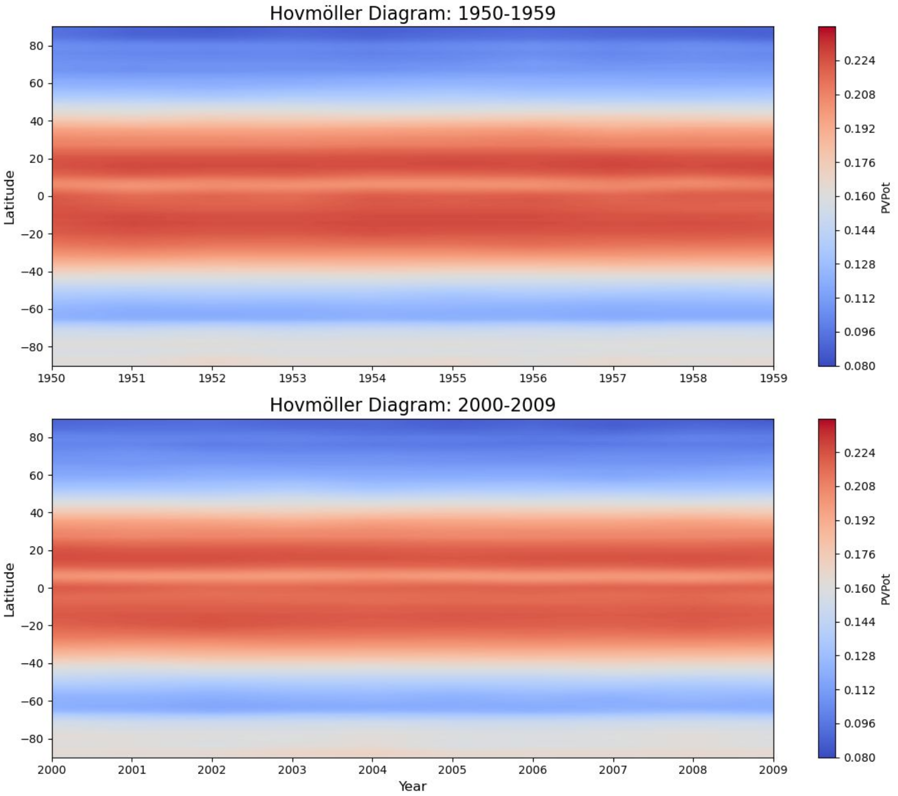




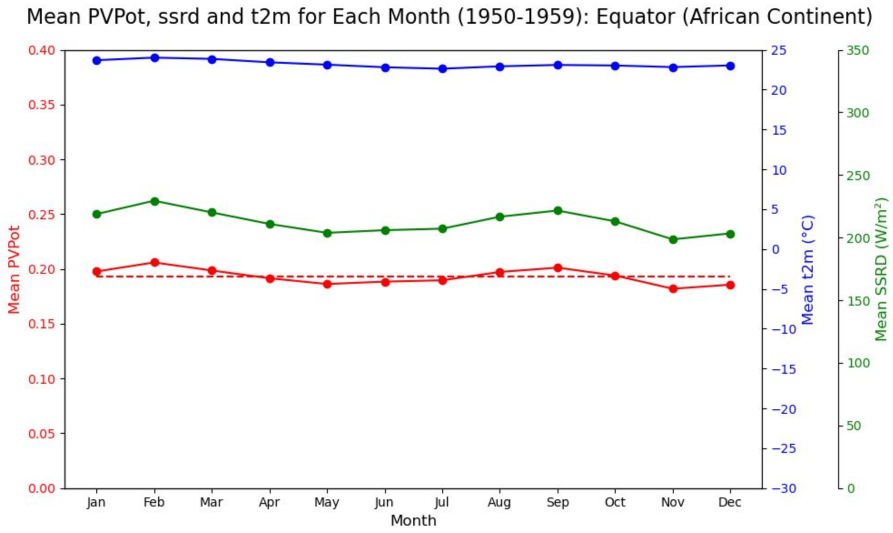
Change of Zonal Mean over a Year

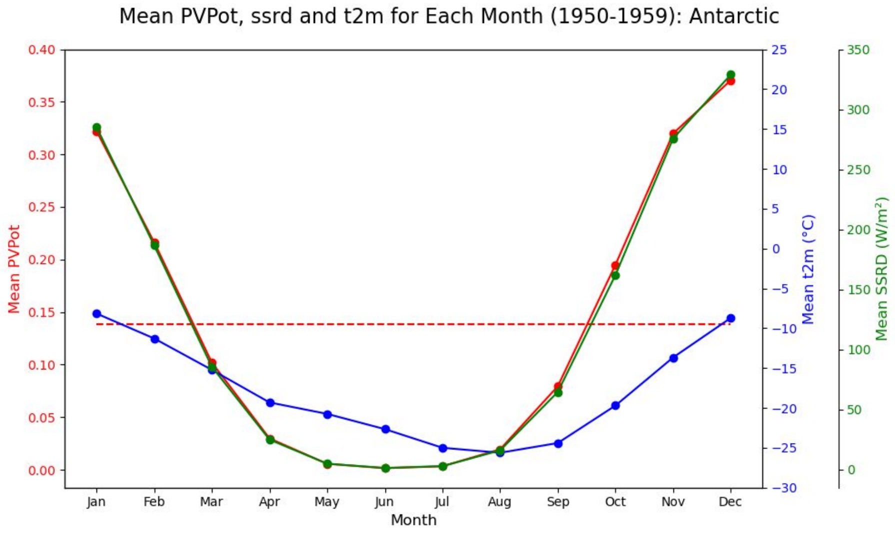


Change of Zonal Mean over 10 Years

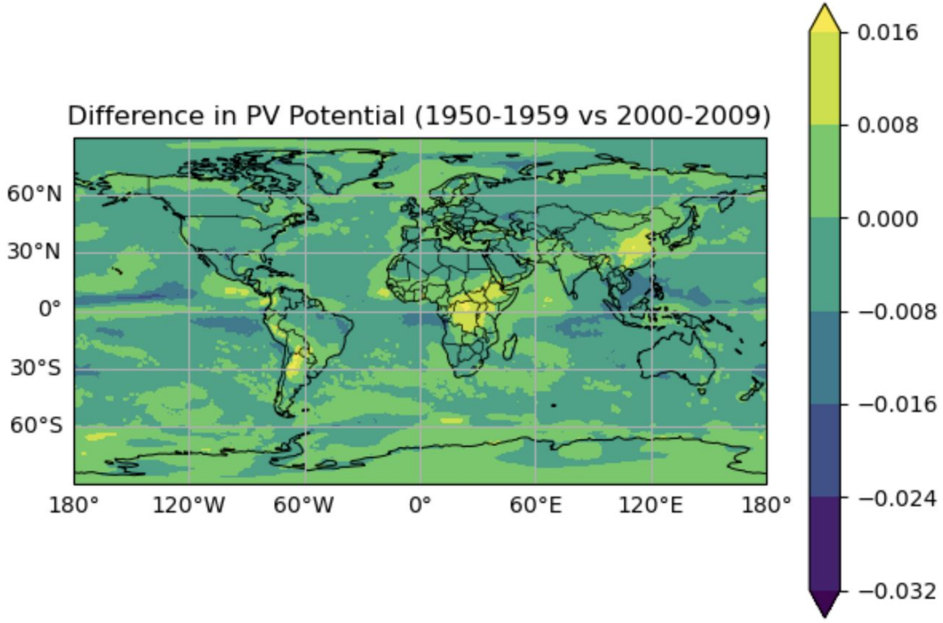


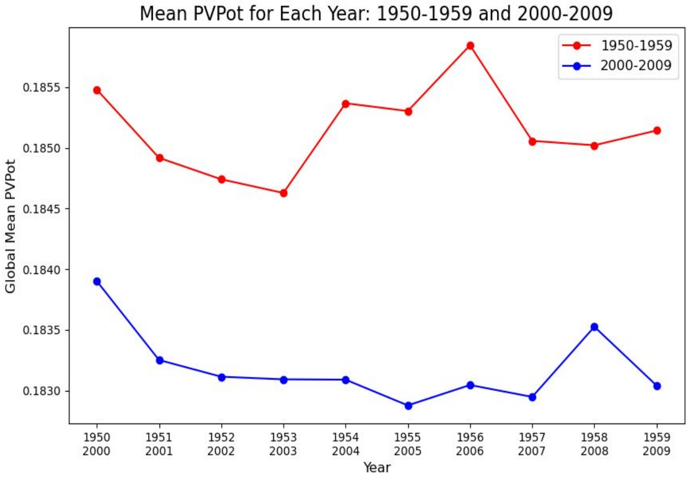
Mean PVPot: Equator and Antarctic





Conclusions - Difference in yearly PVPot





Conclusions

- The global mean PVPot of 1950-1959 was consistently higher than the mean PVPot in 2000-2009
- The global mean temperature of 2000-2009 was consistently higher than the mean PVPot in 1950-1959
- SSRD was relatively similar across these two time periods

"Solar cell performance decreases with increasing temperature, fundamentally owing to increased internal carrier recombination rates, caused by increased carrier concentrations. The operating temperature plays a key role in the photovoltaic conversion process. Both the electrical efficiency and the power output of a photovoltaic (PV) module depend linearly on the operating temperature."

- So, this relationship is consistent with what the research says

https://www.sciencedirect.com/science/article/pii/S1876610213000829#:~:text=https%3A//doi.org/10.1016/j.egypro.2013.05.072

Further Questions

- How would the results differ from ours if we used a land-sea mask?

- Can we train an ML model with hourly data and then use only daily mean data for testing and still get hourly PVPot predictions?

Machine Learning- What we tried

- Features: ssrd, t2m, windspeed, time, longitude and latitude
- Label: PVPot

- Model: Long Short-Term Memory (LSTM) Neural Network
  - Effective for time series: Can remember certain long-term dependencies

- Goal: Learning the times of day and the course of the year

Sepp Hochreiter, Jürgen Schmidhuber; Long Short-Term Memory. *Neural Comput* 1997; 9 (8): 1735–1780. doi: https://doi.org/10.1162/neco.1997.9.8.1735

Machine Learning - Challenges

- Pytorch cannot handle Netcdf files
    - Tried to save data in another format
    - Data is too large, not enough disk space

- We only tried with one month of data
    - Realistically, you would need to train with all data
    - Except one/two months for testing