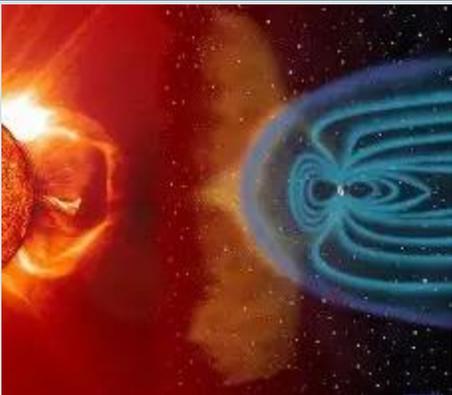


**Rotary**  **Club of Calgary  
at Stampede Park**

**“Solar Physics & You”**  
December 11, 2025



# Introduction

## Jim Fitzowich

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- I. 67<sup>th</sup> Club President 2022-23
- II. 30 yrs in Rotary, husband to Kathy & father of 4
- III. Engineer, Energy Executive & Entrepreneur
- IV. Background in energy conversion physics & economics
  - I. Gas, coal, wind, solar ▶ electricity ▶ H<sub>2</sub>, plasma, etc.
- V. Educated at University of Alberta in Electrical Engineering, and former student of Dr. Steven Chute & Dr. Frederick Vermullen, experts in electromagnetic wave theory and advisors to NRC at Dominion Radio Astrophysical Observatory (DRAO), near Penticton BC.
- VI. Amateur astronomer with interest in astrophysics, amongst other eccentric hobbies.



# Today's Topics

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## I. Solar Physics

- I. Dominion Radio Astrophysical Observatory
- II. Solar Flares, sunspots, Coronal Mass Ejections “CME’s”, Solar wind
- III. Earth effects on health, communications, temperatures, climate, etc

## II. Earth's magnetic fields

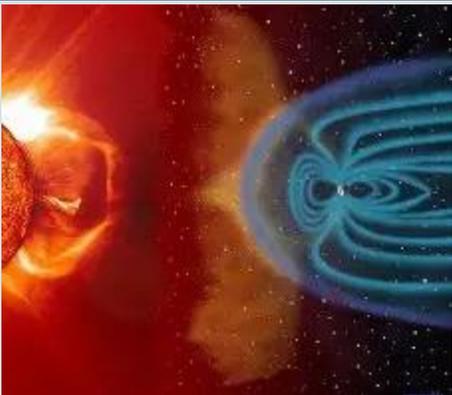
- I. Why does it matter?
- II. Field strength, anomalies and relation to solar activity
- III. Earth effects

## III. Solar Physics & Climate Change

- I. Does it matter?
- II. Thermodynamics of temperature rise.



## Solar Physics Overview

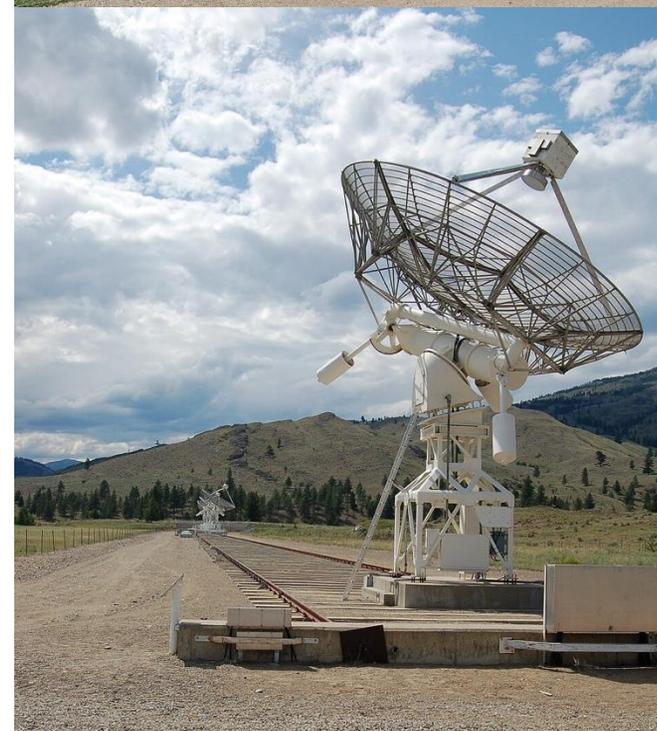


# Dominion Radio Astrophysical Observatory (DRAO)

Kaleden, British Columbia

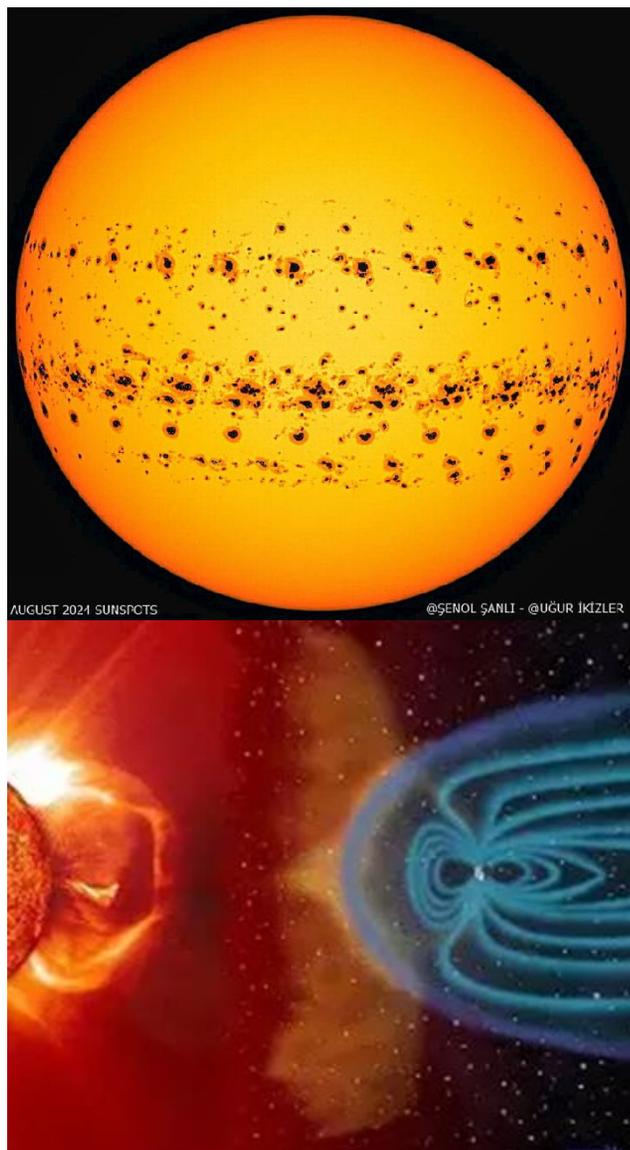


- The **Dominion Radio Astrophysical Observatory** is a [research](#) facility founded in 1960 and located at [Kaleden](#), British Columbia, Canada.<sup>[1]</sup>
- The site houses four [radio telescopes](#): an [interferometric](#) radio telescope, a 26-m single-dish [antenna](#), a [solar flux](#) monitor, and the [Canadian Hydrogen Intensity Mapping Experiment](#) (CHIME).
- **Measuring Solar Flux since 1947.**
- The DRAO is operated by the [Herzberg Institute of Astrophysics](#) of the National Research Council of the [Government of Canada](#). The observatory was named an [IEEE Milestone](#) for first [radio astronomical](#) observations using [VLBI](#).<sup>[2]</sup>



# Sunspots, Solar Flares, CME's and Solar Wind

## Summary of "Space Weather"



### What are Sunspots?

- Sunspots = **dark, cooler regions** on the Sun from magnetic activity.
- Solar cycles ~ **11 years**. **Solar Maxima = peak activity**
- **Solar cycles occur due to magnetic pole reversals on the sun every 11 yrs**
- Sunspots are **birthplaces of solar flares and CMEs**.
- **CME's or Coronal Mass Ejections** are massive bursts of solar plasma.
- CMEs can cause **geomagnetic storms**, disrupt power grids, satellites, and enhance **Joule heating** in the ionosphere.

### What Is Solar Flux?

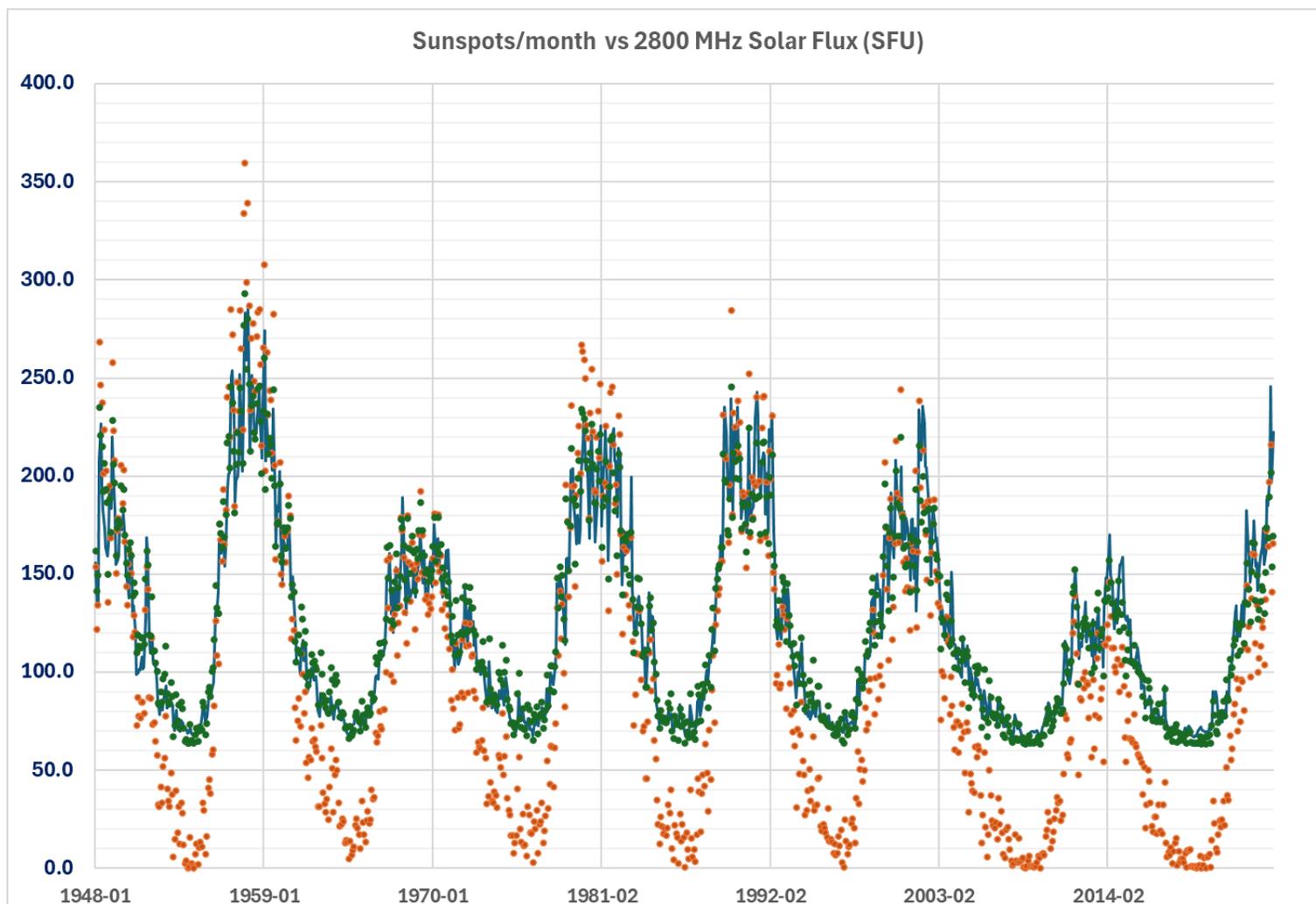
- Solar flux at **2800 MHz (10.7 cm wavelength)** is a measure of Solar radiation.
- It is reported in **solar flux units (s.f.u.)**, where **1 s.f.u. =  $10^{-22} \text{ W}\cdot\text{m}^{-2}\cdot\text{Hz}^{-1}$** .
- The **F10.7 index** is measured daily since 1947 by DRAO observatory.
- During **solar minimum: ~50–70 s.f.u.** During **solar maximum: ~200–300 s.f.u.**

### Sunspots, CMEs, and Solar Flux

- **More sunspots → more magnetic activity → more solar flares and CMEs.**

# Solar Flux & Sunspots

As Measured by DRAO since 1947\*



## Sunspots:

- Are “Dark Spots” on the sun is the area where solar flares “CME’s”) originate

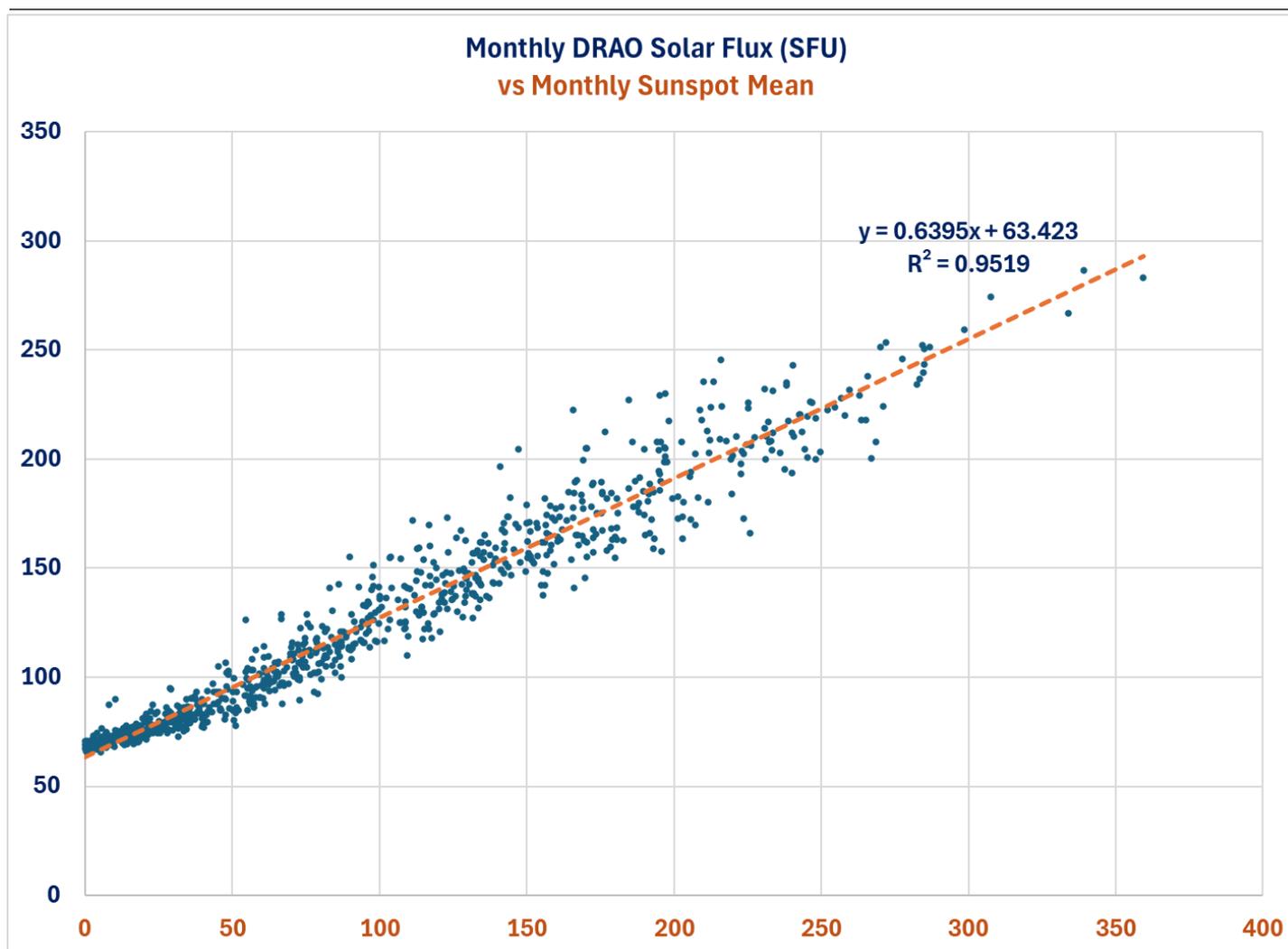
## Solar Flux:

- High frequency ionized particle energy measures at 2800 MHz
- Microwave oven frequency is ~2400MHz.

The DRAO Observatory near Penticton BC is considered the “Gold Standard” in Solar Flux Measurement.

# Solar Flux & Sunspots

Are they related to each other?



## Solar Flux Key Point

- Has been measured *reliably every day at DRAO since 1947*, and is used by NASA for space weather forecasting

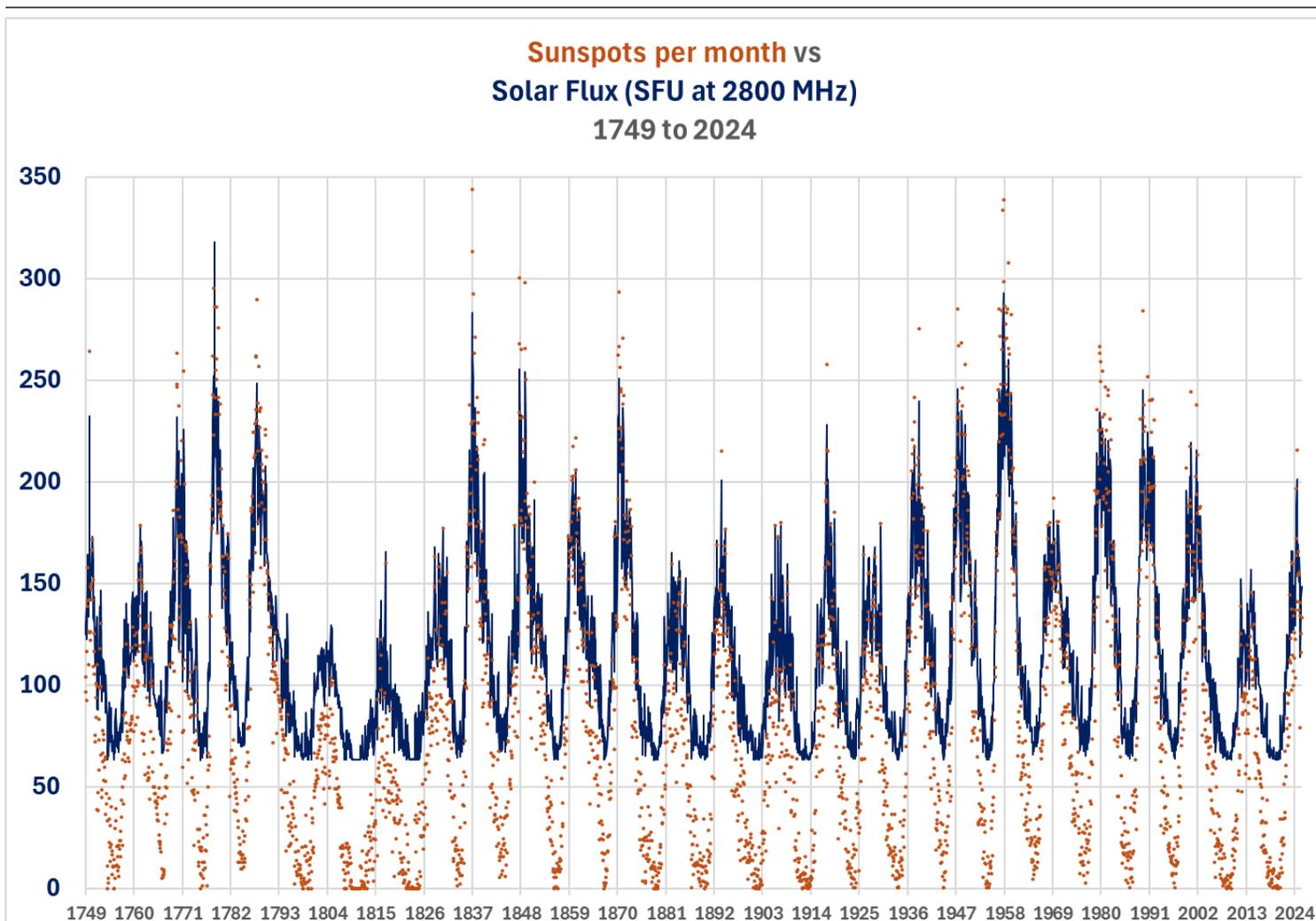
## Sunspots Key Point

- Has been measured at the Royal Belgium Observatory (SILSO) *continuously since 1750*.

Solar Flux and Sunspots are highly correlated to each other. Important for Climate history and forecasting.

# Solar Flux & Sunspots

## Historical relationships & use for forecasting\*



### Uses of Sunspot Data

#### a) Scientific Curiosity

- sunspot cycles correlated to **climate anomalies**.

#### b) Agricultural Planning

- Farmers and agronomists used sunspot cycles to anticipate **seasonal variability**

#### c) Navigation

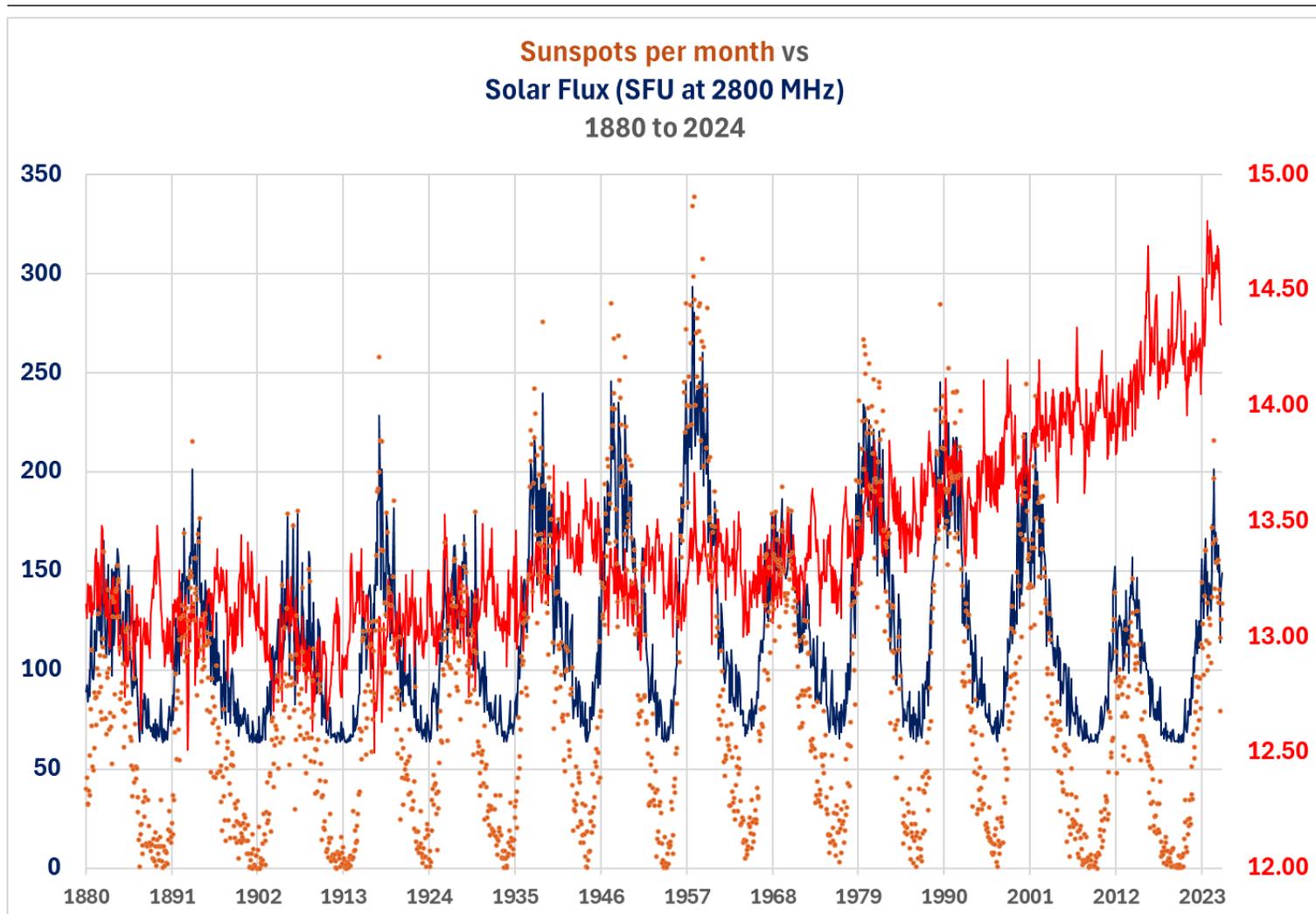
- geomagnetic compasses & GPS Satellites** can be affected by solar storms.

Sunspot history & high correlation to Solar Flux allows scientist to calculate suns energy back to 1750

\*Source: Authors analysis of SILSO and DRAO public data

# Solar Flux & Sunspots

Does it impact temperature & climate change\*



**“Yes”**

- Within 11 solar cycle, sunspots & solar flux is used for weather forecasts (e.g. NOAA)

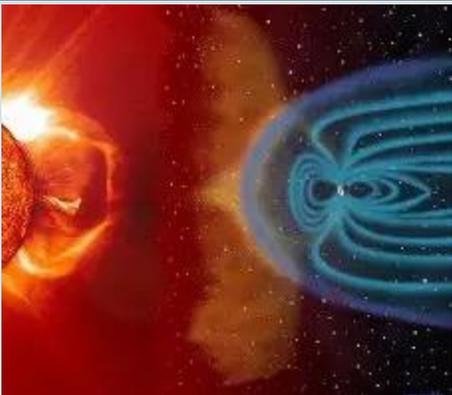
**“No”**

- High sunspots and solar activity preceded recent temperature increase.
- Not obvious it is directly linked to long term climate change since 1880.

Likely, but not intuitively obvious when compared to long term temperature trends.

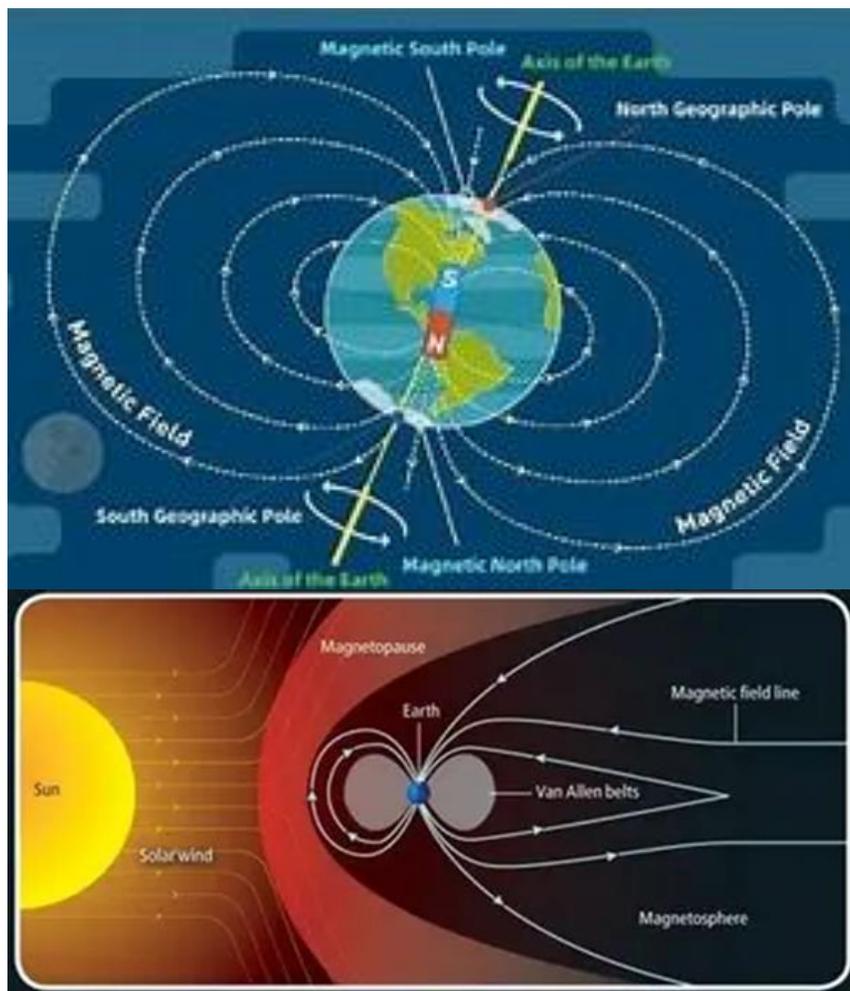


## Earths Magnetic Field Overview



# Earth's Magnetic Field

## Is the Earth's Magnetic Field important to Solar Physics?\*



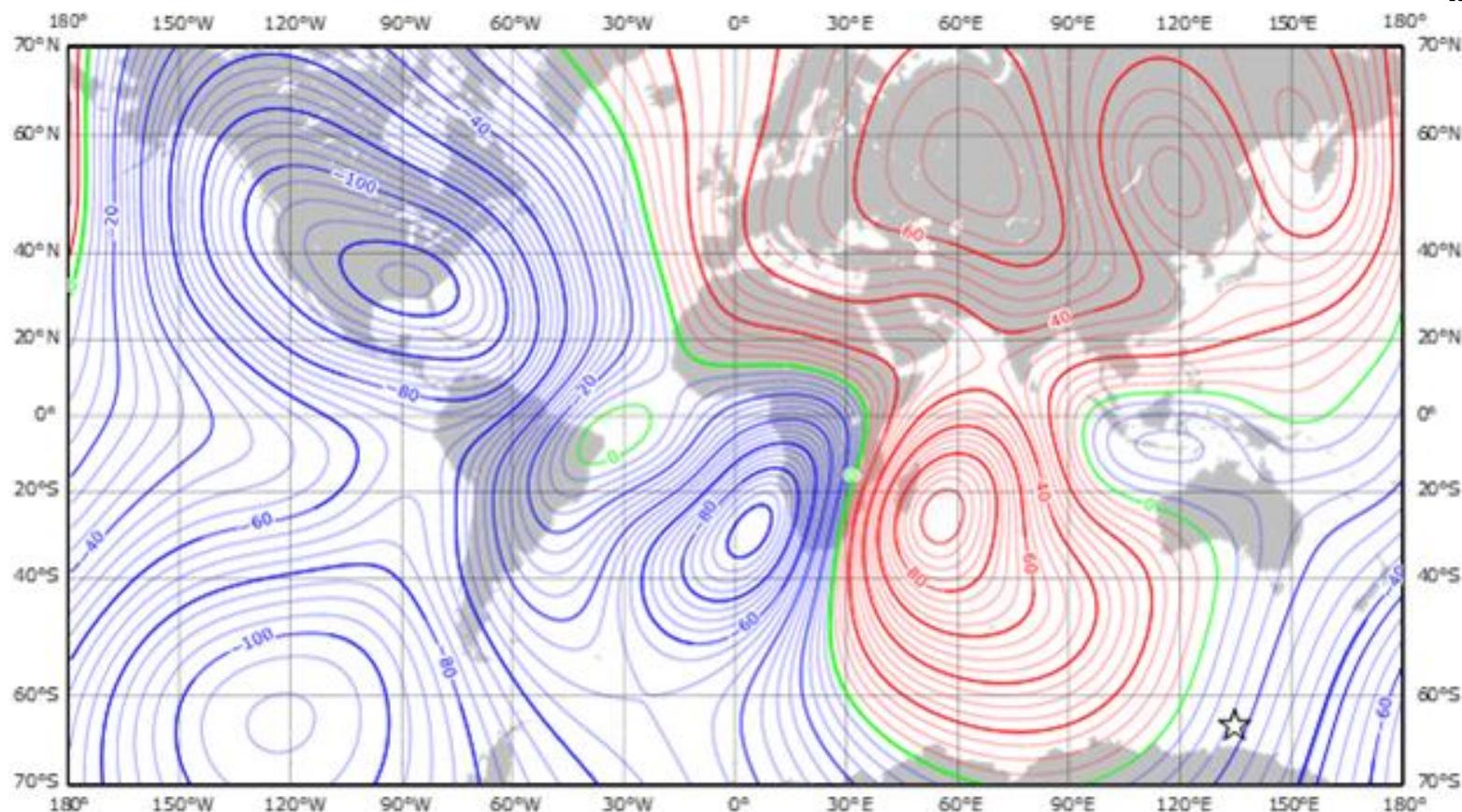
### “Yes”

- Magnetic field shields the planet from solar radiation
- Measured since 1880 at **Royal Belgium Observatory**
- Currently measured by **160 observatories worldwide**.
- “**Kp Index**” = 13 observatories average, includes 2 Cdn
- 2 Canadian Observatories at Ottawa and **Meanook, AB** 🍁
- ***Magnetic field strength falling since 1880***
- Due to shifts in the locations of the magnetic poles.
- **South Atlantic Anomaly “SOA”** , is a “hole” in the field
- ***As the magnetic field diminishes, more of the sun’s energy reaches the earths surface for heating.***

The Magnetic Field shields radiation from the sun’s ionized particles.

# Earth's Magnetic Field

Is the Earth's Magnetic Field important to Solar Physics impact?\*



Annual rate of change of total intensity at 2027.5 from the World Magnetic Model - High Resolution (WMMHR) 2025 (core component only). Red - positive change, blue - negative change, green - zero change. Contour interval is 5nT/year, white star is the location of a magnetic pole and the projection is Mercator. This is an example of an isoporic chart.  
British Geological Survey © UKRI 2024

## “Key Points”

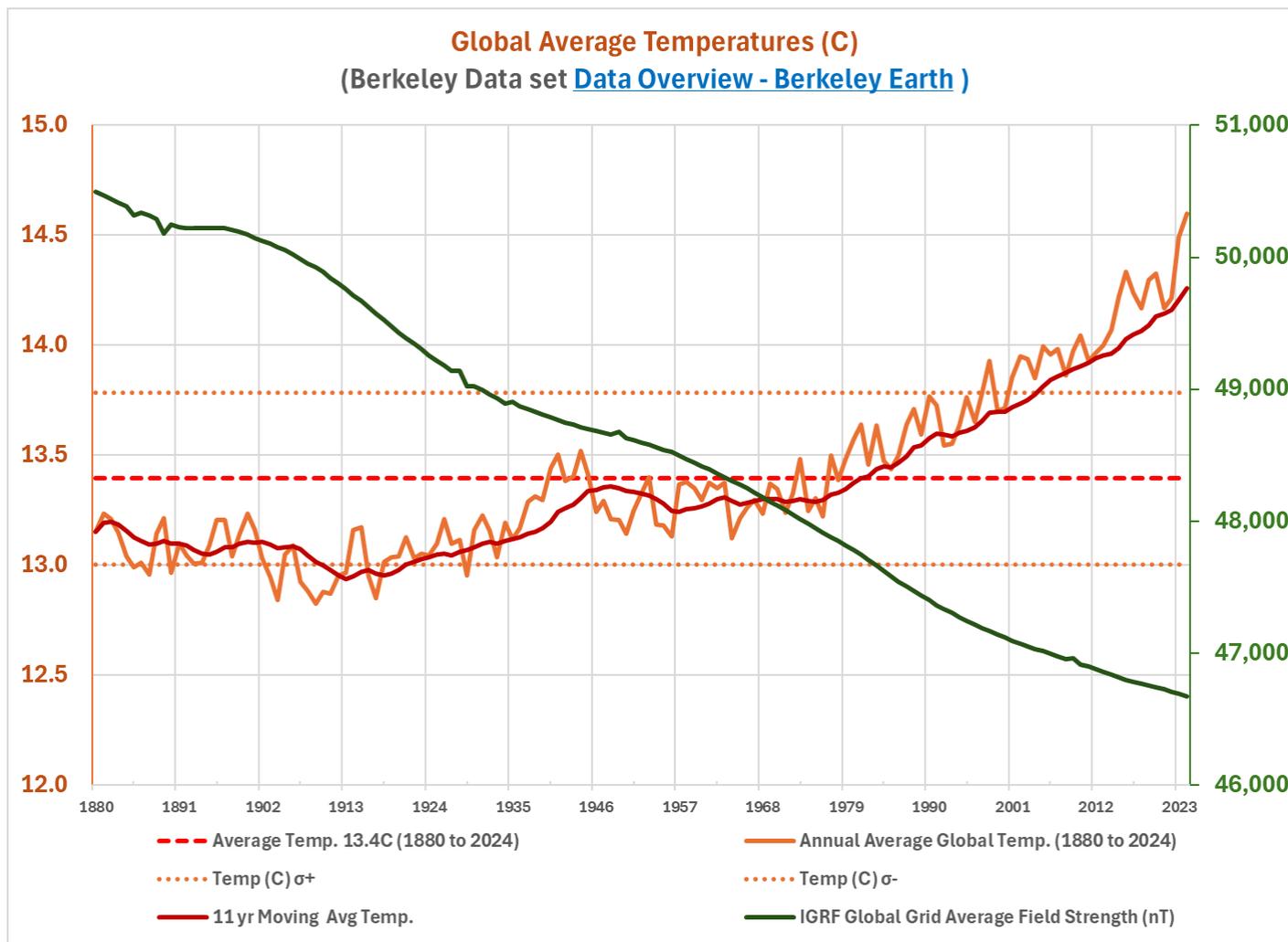
- Blue areas show reductions in field strength
- Red areas show increases in field strength
- Overall average field strength is diminishing since 1880.

[Historical Magnetic Declination Viewer](#)

Earth's magnetic field mapping and pole shift is well understood

# Magnetic Field Strength

## Relationship to Global Average Temperatures\*



### Magnetic Field Key Point

- Has been measured **reliably every day or over 100 years at 160 observatories**
- **Average field strength is diminishing**
- Data set available at SILSO and IPCC

### Temperature Key Point

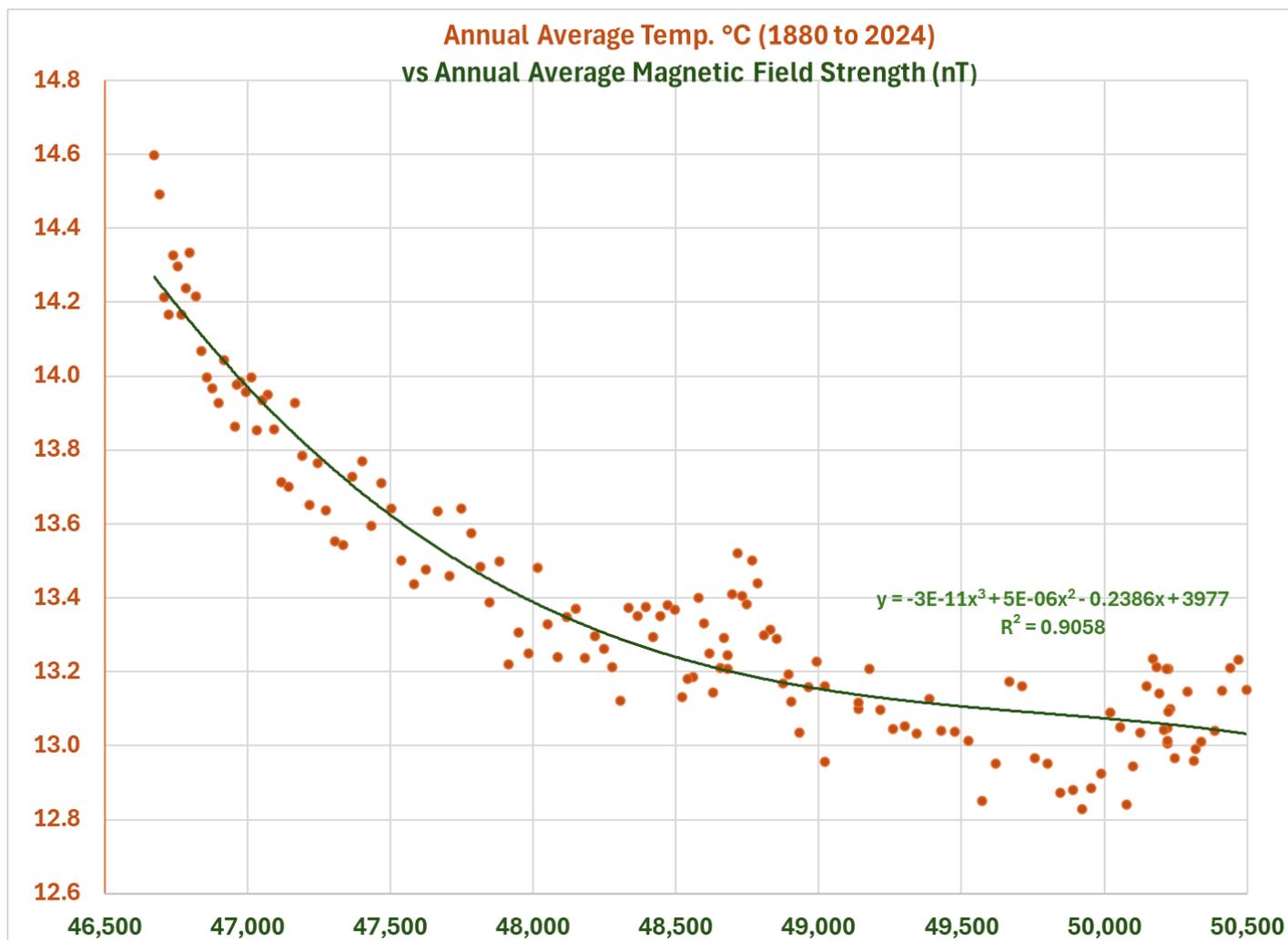
- Has been measured at global observatories **continuously since 1880** and is publicly available from the University of Berkeley

Global temperatures have been increasing as magnetic field has weakened since 1880.

\*Source: Authors analysis using data from [SILSO program](#) [Berkeley Earth – Global Temperature Dataset](#)

# Magnetic Field Strength

## Relationship to Global Average Temperatures\*



### Magnetic Field Key Point

- As, Field strength ▼, temperatures ▲
- More sun's energy reaches the earth's surface
- Regional effects are larger (eg. Polar ice caps)

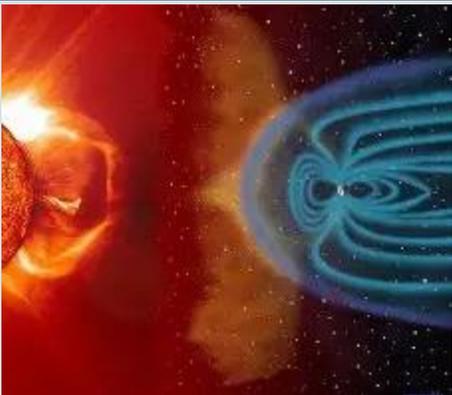
### Temperature Key Point

- Temperature rise is highly correlated to lower "shielding" effect of the the magnetic field,

The increase in temperatures is highly correlated to lower magnetic field strength due to pole shift.

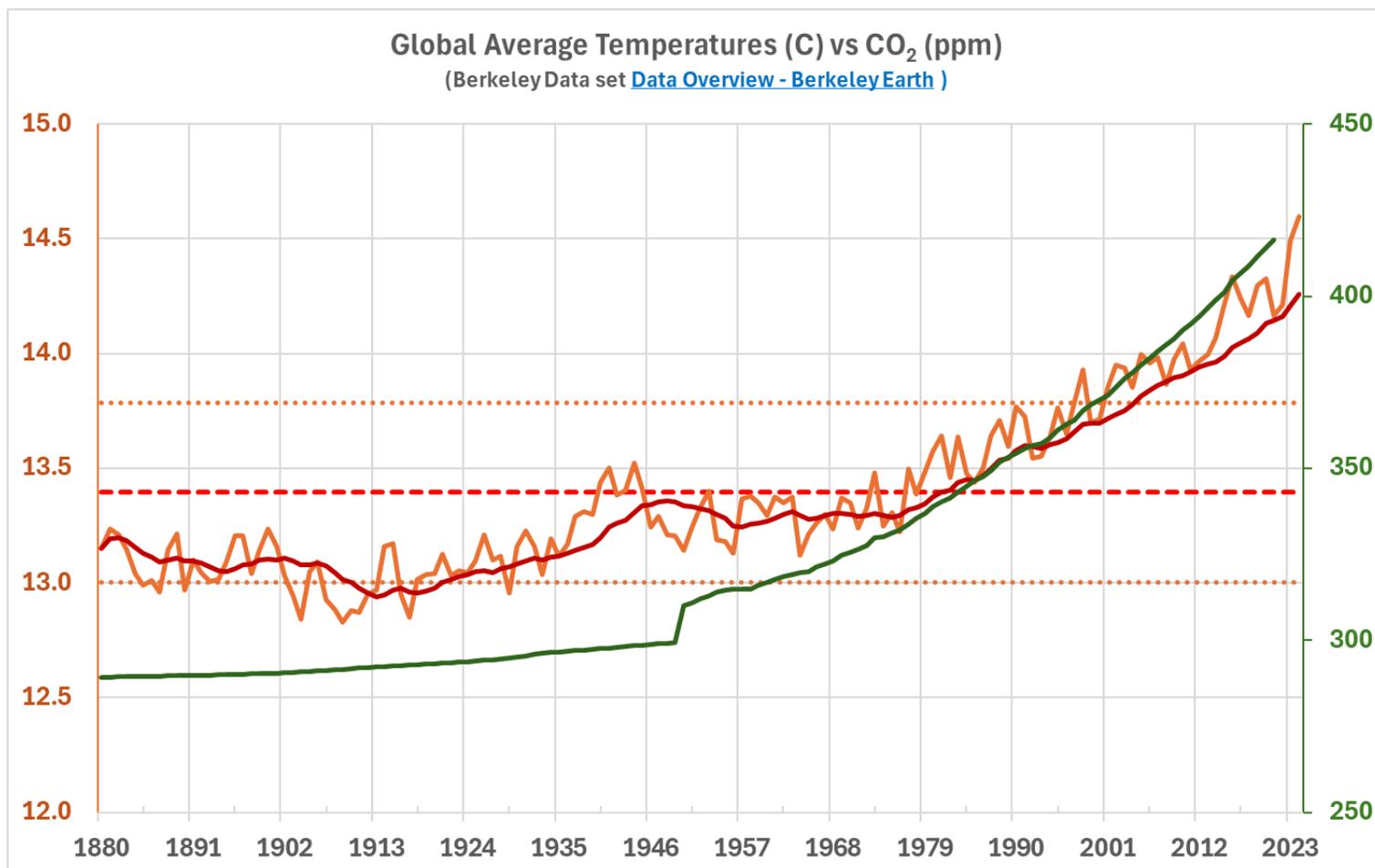


## Solar Physics & Climate Change Overview



# Solar Physics and Climate Change

Is there a link?



**“Yes”**

- Climate Change is based on how much of the sun’s energy is retained by the Earth..

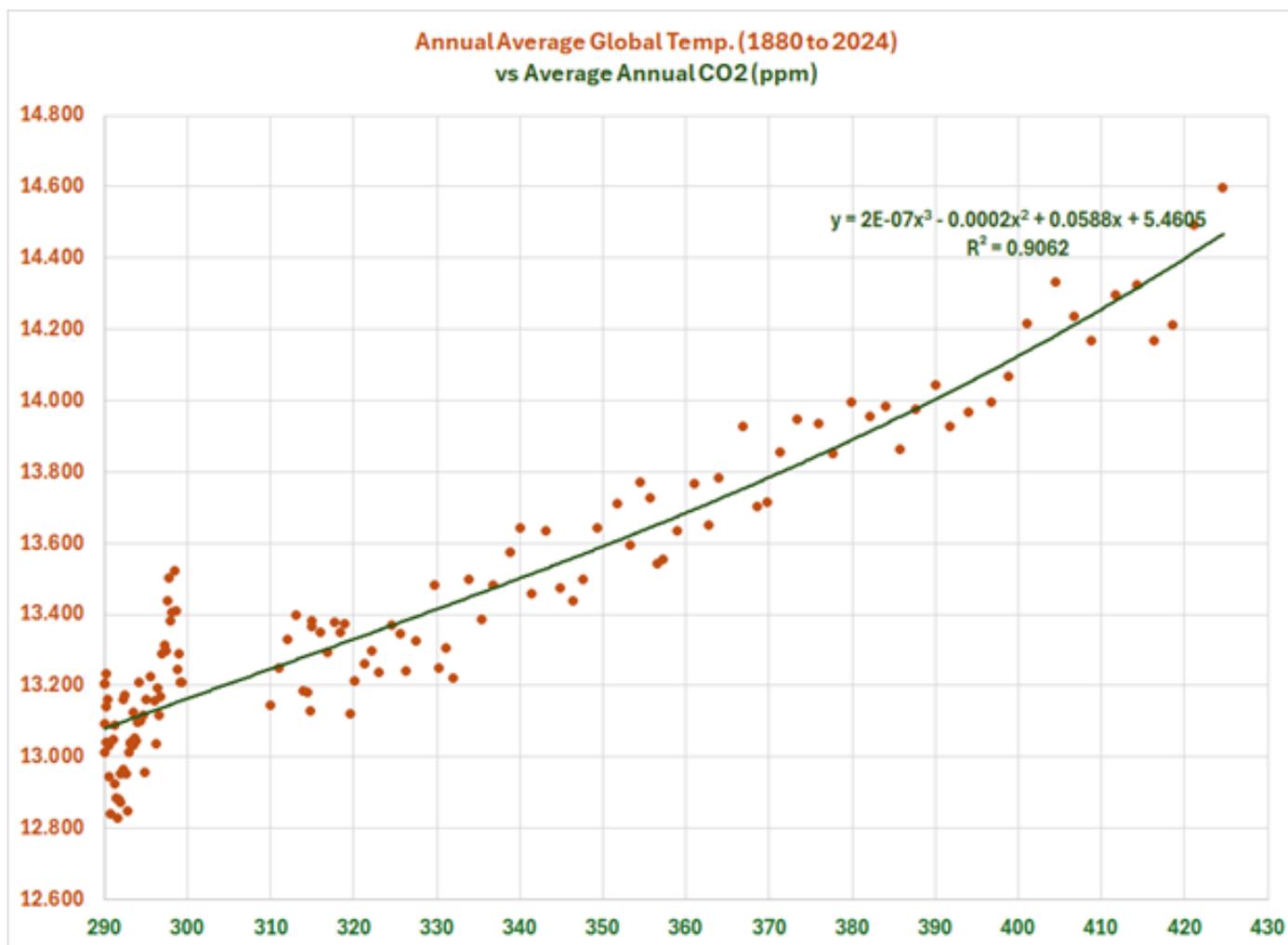
**“No”**

- The UN Intergovernmental Panel on Climate Change (“IPCC”) only reviews 3<sup>rd</sup> party studies on Anthropic CO<sub>2</sub> impacts on climate change.
- The IPCC remit does not include other related research such as Solar Flux and Magnetic Field effects, only CO<sub>2</sub>.

IPCC models are based on solar energy retention by the planet from CO<sub>2</sub> effects alone.

# Climate Change

## Relationship to CO<sub>2</sub>\*



### CO<sub>2</sub> Key Points

- Has been measured **at the Muana Loa observatory since 1958**
- Pre 1958 CO<sub>2</sub> levels are estimated by other means (e.g. ice cores)
- High correlation to temps since 1958.

### Temperature Key Point

- Has been measured **continuously since 1880** and is publicly available from the University of Berkeley

Good measured CO<sub>2</sub> data since 1958. Earlier values are estimated or inferred.

\*Source: Authors analysis using data from [IPCC — Intergovernmental Panel on Climate Change](https://www.ipcc.ch/)

# Climate Change

How much energy to increase average global temperatures by 1° C?

Climate Driver	Estimated Energy Contribution	Assumptions
Solar Flux (Joule Heating)	$\sim 1.6 \times 10^{23}$ joules	0.2 W/m <sup>2</sup> average
Geomagnetic Weakening	$\sim 8.2 \times 10^{22}$ joules	0.1 W/m <sup>2</sup> average
Anthropogenic CO <sub>2</sub>	$\sim 2.0 \times 10^{23}$ joules	0.25 W/m <sup>2</sup> average
<b>Total Required</b>	$\sim 4.1 \times 10^{23}$ joules	0.5 W/m <sup>2</sup> sustained

- To raise the Earth's surface temperature by 1°C over 50 years, we need to overcome the planet's thermal inertia.
- Based on published estimates:
- Earth's surface area:
  - **$5.1 \times 10^{14}$  m<sup>2</sup>**
- Duration:
  - **50 years  $\approx 1.6 \times 10^9$  seconds**
- Required energy imbalance:
  - **$\sim 0.3\text{--}0.6$  W/m<sup>2</sup> (\*)** sustained globally
- This is equivalent to the **entire U.S. energy consumption for 4 million years**

More than either IPCC CO2 models alone predict.

\*Source: (based on NASA Earth Energy Imbalance estimates)

# Key Takeaways

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## I. Solar Physics

- I. DRAO Observatory near Penticton is a world leader in solar research 
- II. Sunspots are dark areas on sun from Solar Flares and CME's
- III. 11 year cycles due to sun's magnetic pole reversals
- IV. More ionized energy impacts auroras, satellites, grids, temperatures

## II. Earths magnetic fields

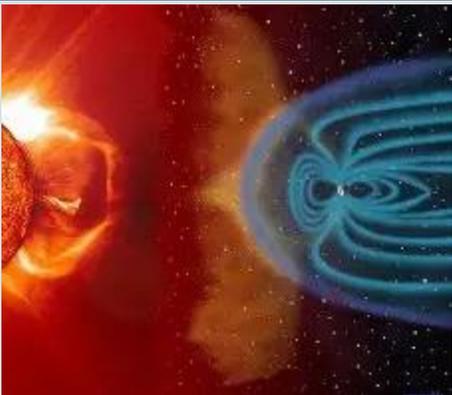
- I. Determines Solar Physics impact on earth
- II. Lower Field strength due to pole shift allows more sun's energy
- III. Some geographic areas are more impacted (e.g. SOA, polar icecaps)

## III. Solar Physics & Climate Change

- I. Temperature rise is impacted by magnetic field strength, solar flux & GHG's.
- II. Energy requirement for 1°C rise is likely greater than any one factor alone.

# Rotary Club of Calgary at Stampede Park

**Thank You**



# Further Information

## References and helpful websites

### References (with embedded links)

- [Robinson & Zanetti \(2021\) – Auroral Energy Flux and Joule Heating](#)
- [Rae et al. \(2007\) – Field Line Resonance Heating](#)
- [Fejer et al. \(2024\) – Low-Latitude Ionospheric Electrodynamics](#)
- [Campuzano et al. \(2018\) – Transfer Entropy and Sea Level Rise](#)
- [Berkeley Earth – Global Temperature Dataset](#)
- [NOAA Mauna Loa Observatory – CO<sub>2</sub> Records](#)
- [IPCC AR6 – Radiative Forcing Summary](#)
- [NASA Earth Energy Imbalance Estimates](#)
- [NCEI Geomagnetic Calculators](#)
- [Annual Means Data Request Form](#)
- [WMMHR Mercator Projections](#)
- [Dominion Radio Astrophysical Observatory - National Research Council Canada](#)
- [Royal Observatory of Belgium](#)
- [SILSO program](#)
- [IPCC — Intergovernmental Panel on Climate Change](#)

### Notes for References

- <sup>1</sup> Estimated global energy retention due to geomagnetic field weakening is based on modeling from Campuzano et al. (2018), which links field strength decline to increased sea level rise and inferred energy uptake.  
*Source:* [Campuzano et al., PLoS ONE, 2018](#) – see Section 3.2, Table 2.
- <sup>2</sup> Robinson & Zanetti (2021) estimate Joule heating rates during geomagnetic storms ranging from 0.1 to 10 W/m<sup>2</sup>, with global averages around 0.2 W/m<sup>2</sup>.  
*Source:* [NOAA Technical Report](#) – see page 12, “Auroral Energy Flux and Joule Heating.”
- <sup>3</sup> Fejer et al. (2024) review equatorial ionospheric electrodynamics and estimate energy deposition from electric field-driven currents at ~0.05–0.2 W/m<sup>2</sup>.  
*Source:* [Frontiers in Astronomy and Space Sciences](#) – see Section 4.1.
- <sup>4</sup> Rae et al. (2007) describe resonant waveguide heating via ULF waves, with localized energy deposition reaching 0.5 W/m<sup>2</sup>.  
*Source:* [Annales Geophysicae](#) – see page 2533, Figure 3.
- <sup>5</sup> Combined Joule heating estimate of ~0.2 W/m<sup>2</sup> is derived from averaging the mechanisms described in Robinson, Fejer, and Rae.  
*Source:* Synthesized from references <sup>2</sup>, <sup>3</sup>, and <sup>4</sup>.
- <sup>6</sup> Global average Joule heating contribution from solar flux is estimated at ~0.2 W/m<sup>2</sup>, consistent with Robinson and Fejer’s long-term modeling.  
*Source:* [NOAA Technical Report](#) and [Frontiers in Astronomy and Space Sciences](#)
- <sup>7</sup> Vares et al. (2016) found a near-perfect inverse correlation ( $r = -0.99$ ) between magnetic dipole strength and global temperature indicators, supporting an energy contribution of  $\sim 0.5 \times 10^{20}$  joules.  
*Source:* Vares, A., et al. (2016). *Geomagnetic Dipole Strength and Climate Correlation*. [Link unavailable—archived in conference proceedings]
- <sup>8</sup> NASA estimates Earth’s current energy imbalance at ~0.5 W/m<sup>2</sup>, which aligns with the total energy required for a 1°C rise over 50 years.  
*Source:* [NASA Climate News, 2021](#) – see paragraph 4.
- <sup>9</sup> Joule heating from solar flux interactions is estimated at ~0.2 W/m<sup>2</sup> based on long-term averages from Robinson, Fejer, and Rae.  
*Source:* See footnotes <sup>2</sup>, <sup>3</sup>, and <sup>4</sup>.
- <sup>10</sup> Geomagnetic field weakening contributes ~0.1 W/m<sup>2</sup> to global energy retention, based on Campuzano et al. and Vares et al.  
*Source:* See footnotes <sup>1</sup> and <sup>7</sup>.
- <sup>11</sup> IPCC AR6 estimates radiative forcing from CO<sub>2</sub> at ~2.3 W/m<sup>2</sup> since 1750. Adjusted for the past 50 years, the net contribution is ~0.25 W/m<sup>2</sup>.  
*Source:* [IPCC AR6 Chapter 7](#) – see Table 7.15 and Figure 7.19.