Space Weather Impact on GPS

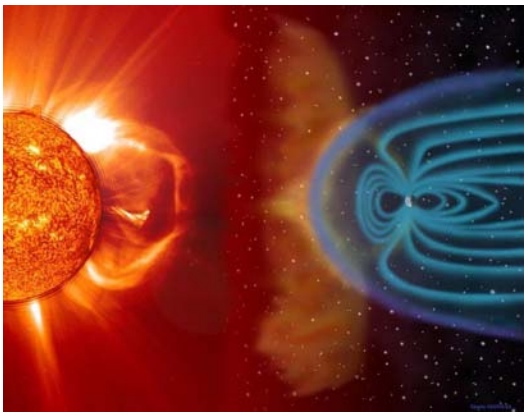
2025 Risk & Profit, Kansas State University
Manhattan, Kansas, 22 August 2025

TERRY GRIFFIN, PH.D.
AMIR BAHADORI , PH.D.

AgManager.info

Kansas State University | Agricultural Economics

What is space weather?



- Interaction among many phenomena
  - Solar events
  - Interplanetary magnetic field
  - Geomagnetic field
  - Radiation from outside of our solar system
- The Sun is really far away— 1 AU ~ 93 million miles– but significantly impacts life on Earth

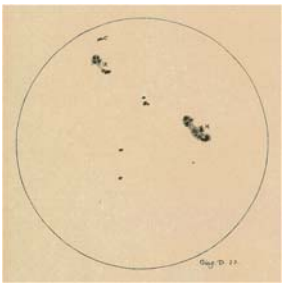
Blue lines represent the shield created by Earth's magnetic field. Notice how the solar wind shapes the magnetic field. Credit: SOHO (ESA & NASA)

AgManager.info

Kansas State University | Agricultural Economics

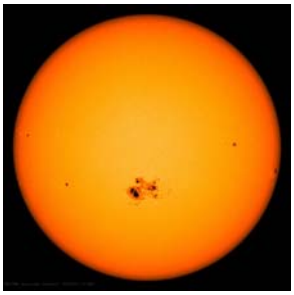
Space Weather Terms

Sunspot: dark spot on the Sun's surface, indicating reduced surface temperature; magnetic field anomaly that has the potential to cause space weather changes



Galileo's sunspot drawings (1612)

https://galileo.library.rice.edu/sci/observations/sunspot_drawings.html



Very large sunspot (2014)

Credit: NASA Goddard Space Flight Center and NASA/SDO

Space Weather Terms

Solar flare: burst of radiation from Sun's surface, measured by x-ray intensity

M-class solar flare (2019)

Credit: NASA/SDO

Space Weather Terms

Coronal mass ejection (CME): large ejection of mass from Sun; made up of plasma and often distorts the interplanetary magnetic field

CME coronagraph (27 May 2024)

SOHO (ESA & NASA), NASA/SDO/AIA, JHelioviewer/D. Müller

Carrington Event - 1859

September 1, 1859:
- observed white-light flare
- Carrington and Hodgson

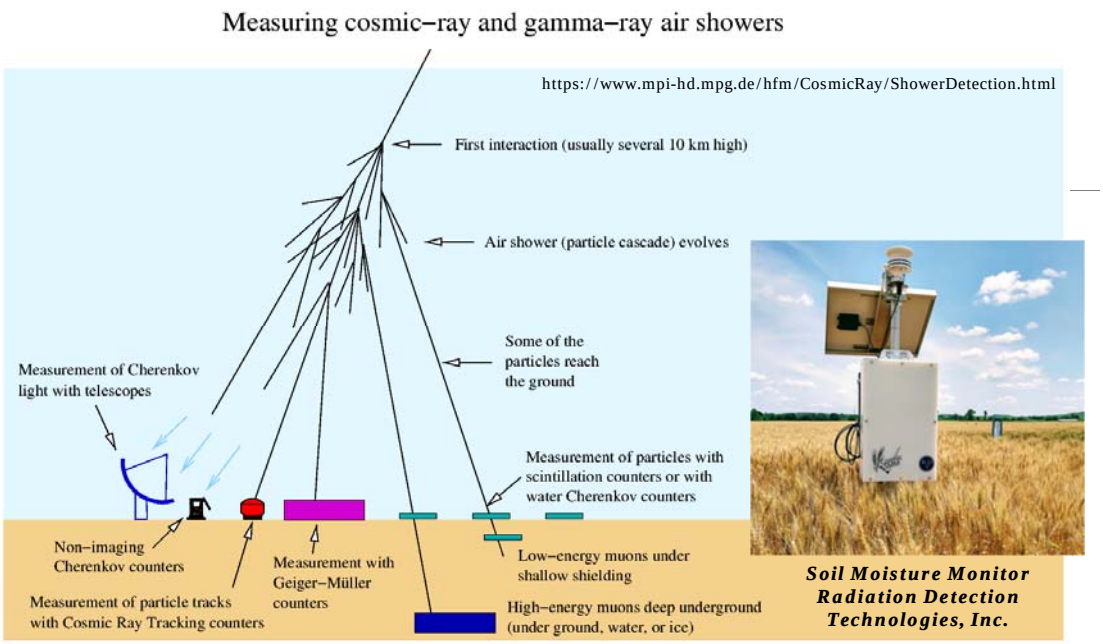
18 hours later: aurora observed from the Caribbean
- Telegraphs functioned w/o batteries, caught fire, shocked operators

Estimated to occur once every 150-200 years

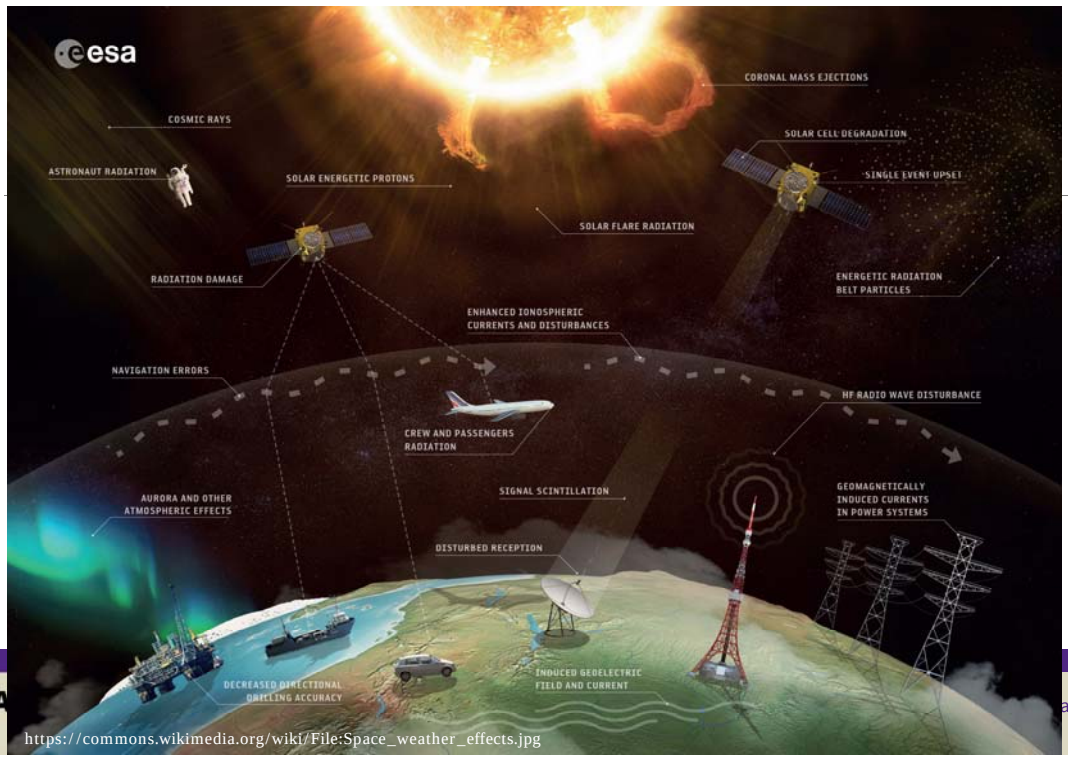
Today it would bring down the electrical grid, disable satellites

Standard for other storms to be compared: “Carrington-class event”

AgManager.info
KANSAS STATE UNIVERSITY | Agricultural Economics



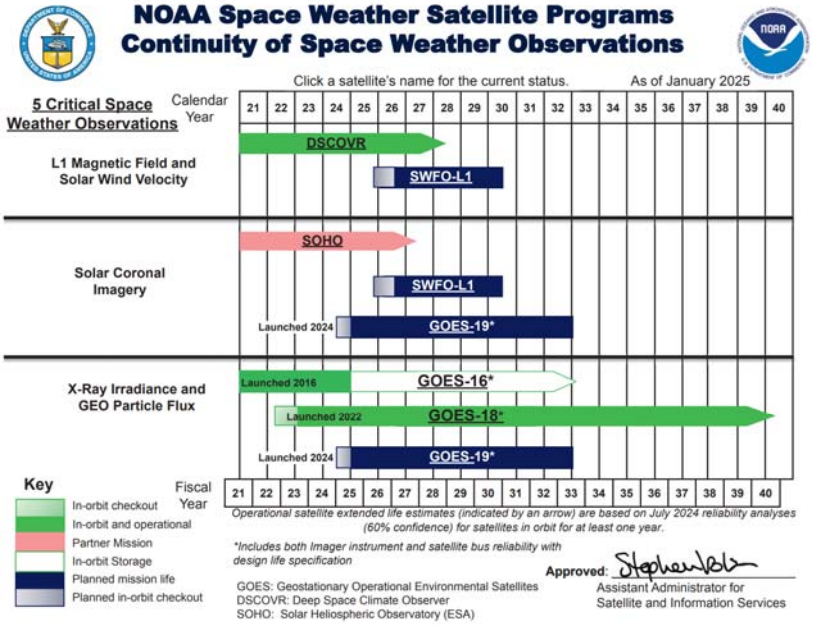
Soil Moisture Monitor Radiation Detection Technologies, Inc.



https://commons.wikimedia.org/wiki/File:Space_weather_effects.jpg

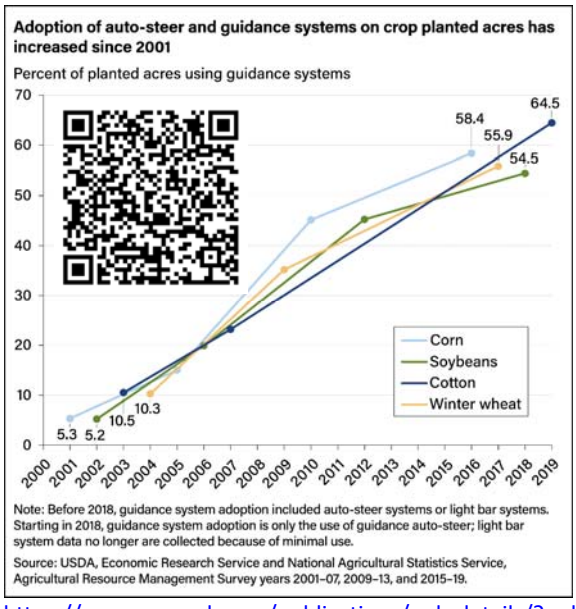
Credit: NASA


Heliophysics Missions
IBEX
EUVST (JAXA)
HERMES (Gateway)
ICON
SunRISE (6)
TRACERS (2)
AWE (ISS)
Solar Orbiter (ESA)
ACE
SDO
THEMIS-ARTEMIS (2)
SOHO (ESA)
IMAP
HelioSwarm (9)
Parker Solar Probe
GDC (6)
Wind
GOLD (SES-14)
Carruthers Geocorona Observatory
EZIE (3)
THEMIS (3)
STEREO
TIMED
MMS (4)
MUSE
Hinode (JAXA)
PUNCH (4)
IRIS
RAD (Curiosity)
Voyager (2)
ESCAPADE (2)

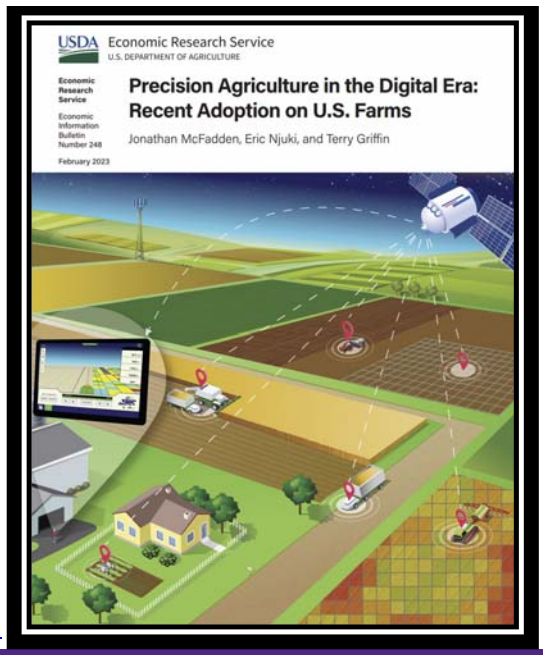

NOAA Space Weather Satellite Programs
Continuity of Space Weather Observations
Click a satellite's name for the current status.
As of January 2025
5 Critical Space Weather Observations
Calendar Year
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
L1 Magnetic Field and Solar Wind Velocity
DSCOVR
SWFO-L1
Solar Coronal Imagery
SOHO
SWFO-L1
Launched 2024
GOES-19*
X-Ray Irradiance and GEO Particle Flux
Launched 2016
GOES-16*
Launched 2022
GOES-18*
Launched 2024
GOES-19*
Key
In-orbit checkout
In-orbit and operational
Partner Mission
In-orbit Storage
Planned mission life
Planned in-orbit checkout
Fiscal Year
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Operational satellite extended life estimates (indicated by an arrow) are based on July 2024 reliability analyses (60% confidence) for satellites in orbit for at least one year.
*Includes both Imager instrument and satellite bus reliability with design life specification
GOES: Geostationary Operational Environmental Satellites
DSCOVR: Deep Space Climate Observer
SOHO: Solar Heliospheric Observatory (ESA)
Approved:
Assistant Administrator for Satellite and Information Services

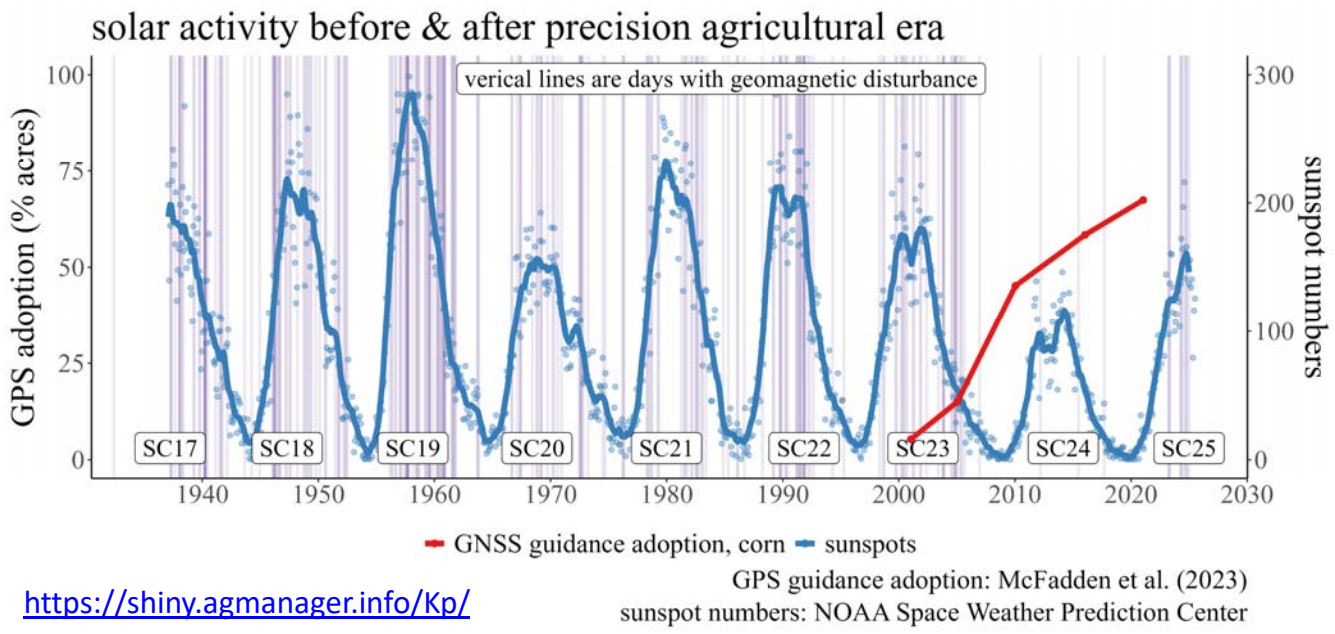
October 10, 2024
St. George, Kansas

June 1, 2025
St. George, Kansas



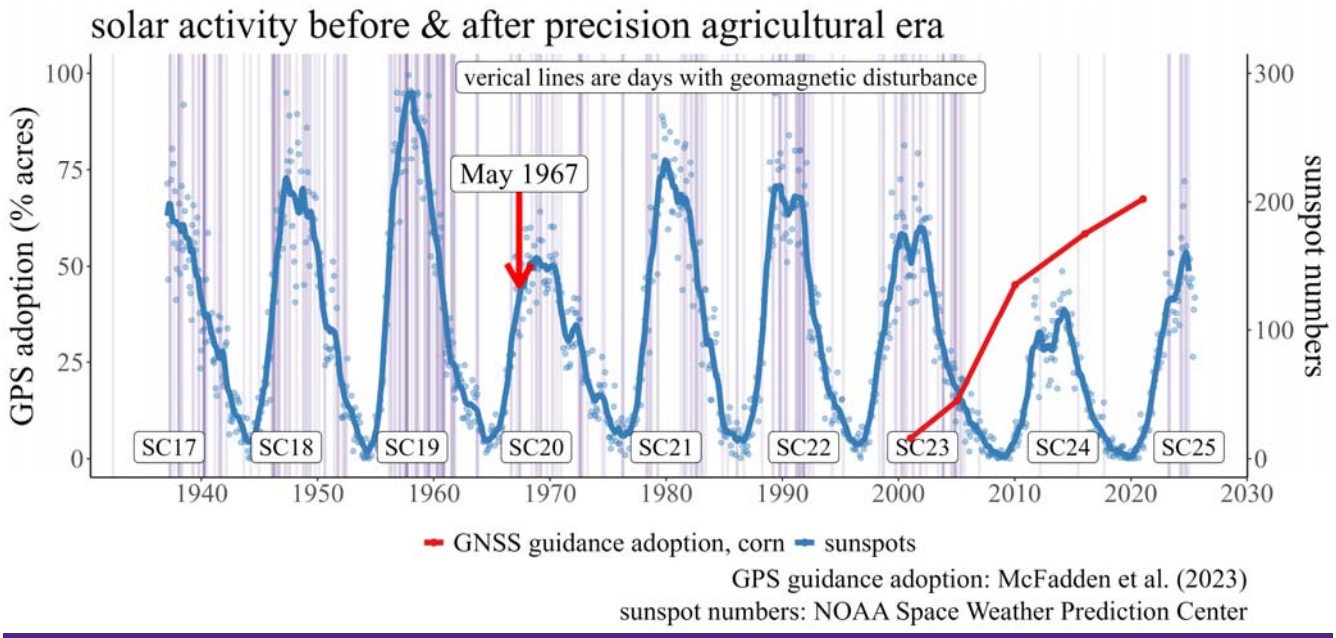
https://www.ers.usda.gov/publications/pub-details/?pubid=105893





https://shiny.agmanager.info/Kp/

GPS guidance adoption: McFadden et al. (2023)
sunspot numbers: NOAA Space Weather Prediction Center

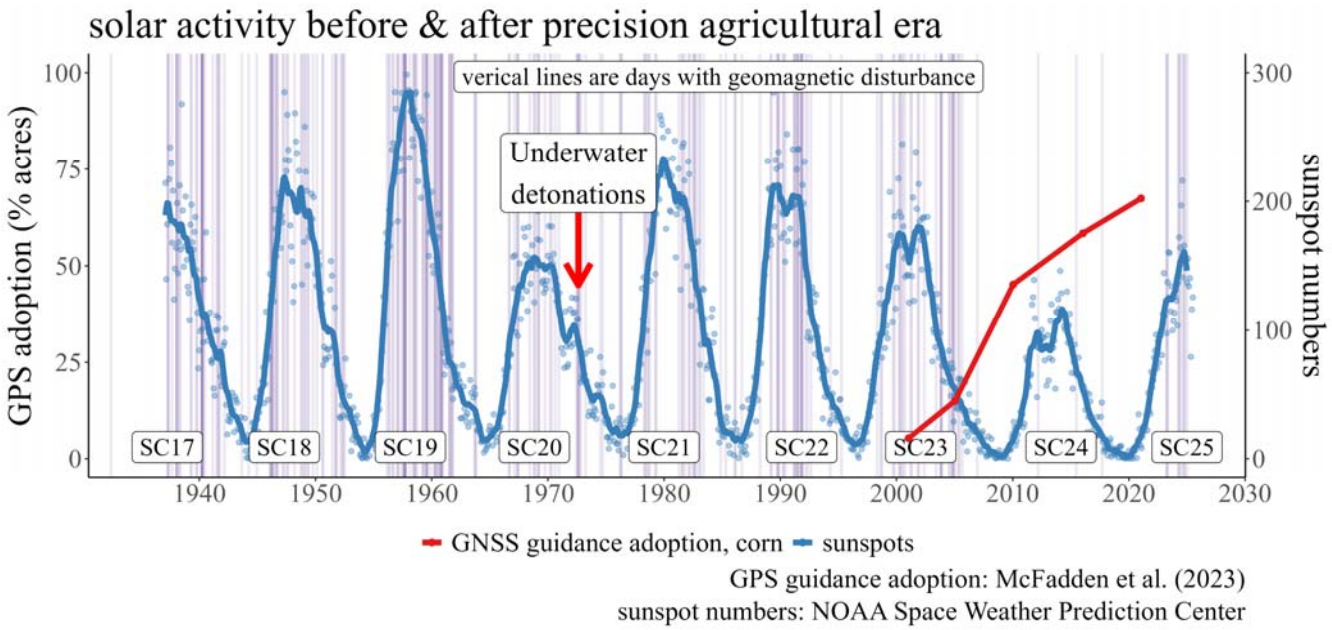


GPS guidance adoption: McFadden et al. (2023)
sunspot numbers: NOAA Space Weather Prediction Center

The May 1967 great storm and radio disruption event: Extreme space weather and extraordinary responses

D. J. Knipp[1,2], A. C. Ramsay[3], E. D. Beard[3], A. L. Boright[3], W. B. Cade[4], I. M. Hewins[5], R. H. McFadden[5], W. F. Denig[6], L. M. Kilcommons[1], M. A. Shea[7], and D. F. Smart[7]

... **was nearly ultimate societal impact**, were it not for **United States Air Force** expanding terrestrial weather monitoring efforts into **space weather forecasting** ... during rapid rise and **intense Cold War**... events intersecting categories of **solar-terrestrial interactions and the political-military backdrop of the Cold War**. This was one of the "Great Storms" of the twentieth century ... warrant the attention of today's radio-reliant, **cellular-phone** and **satellite-navigation** enabled world.



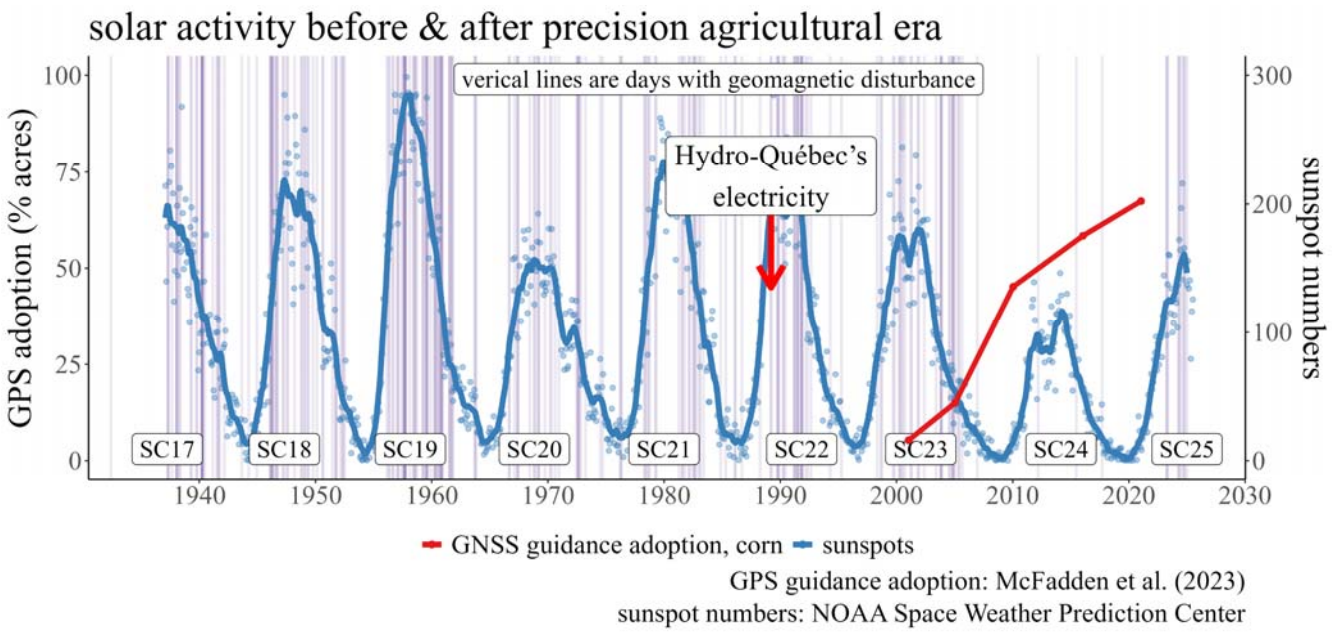
AgManager.info
KANSAS STATE UNIVERSITY | Agricultural Economics

Space Weather®

Commentary | Free Access

On the Little-Known Consequences of the 4 August 1972 Ultra-Fast Coronal Mass Ejecta: Facts, Commentary, and Call to Action

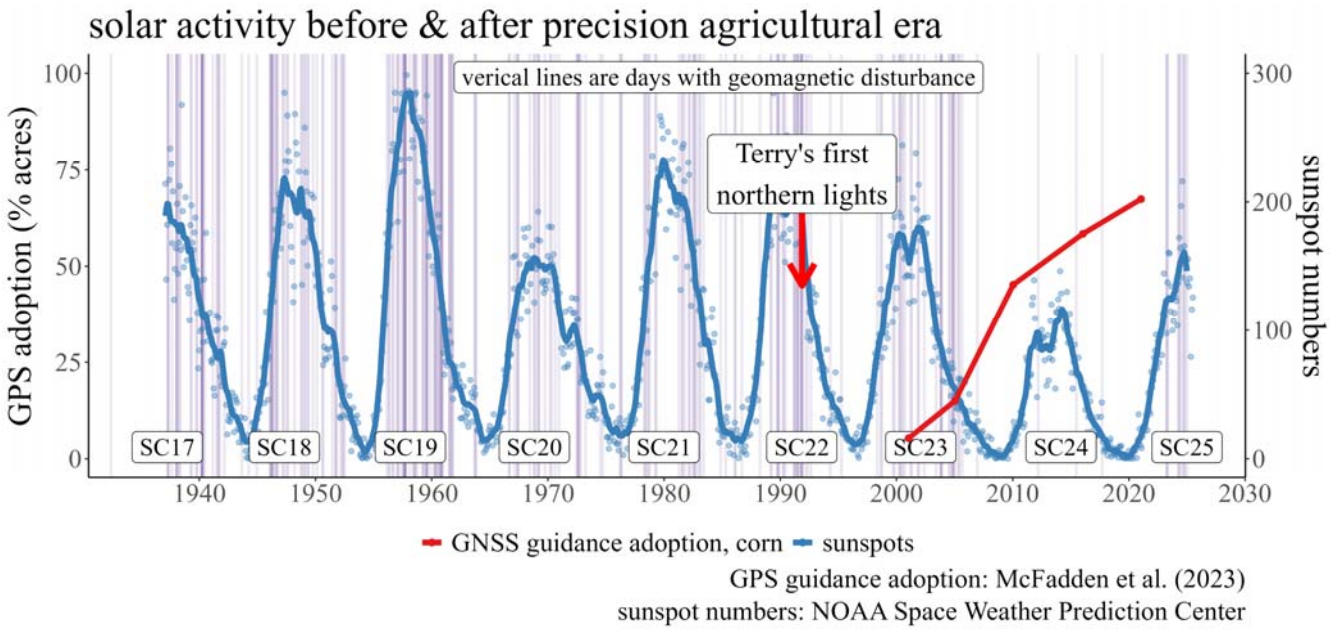
Delores J. Knipp, Brian J. Fraser, M. A. Shea, D. F. Smart



Hydro-Québec electricity transmission system

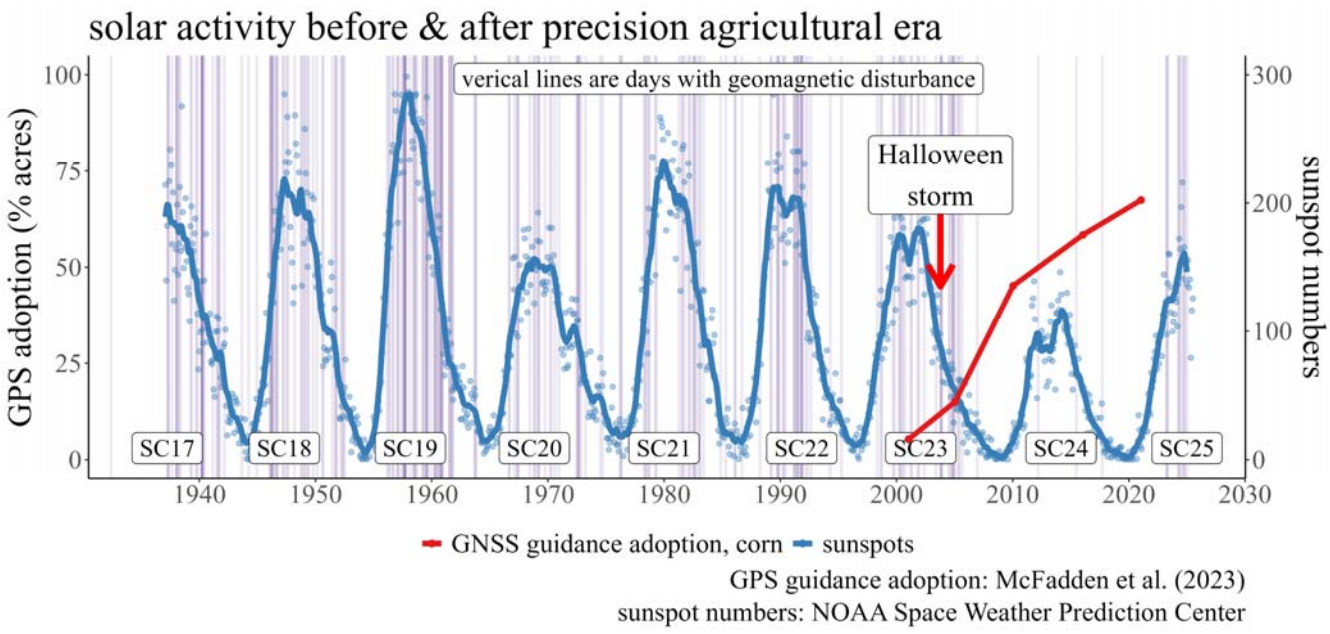
Geomagnetically induced currents (GIC) disrupted voltage regulation, tripped breakers within 90 seconds, 9-hour blackout

solar activity before & after precision agricultural era



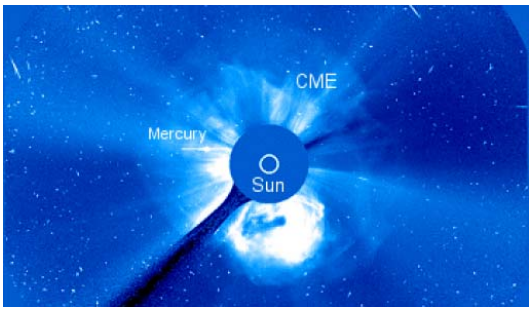
GPS guidance adoption: McFadden et al. (2023)
sunspot numbers: NOAA Space Weather Prediction Center

AgManager.info
KANSAS STATE UNIVERSITY | Agricultural Economics



GPS guidance adoption: McFadden et al. (2023)
sunspot numbers: NOAA Space Weather Prediction Center

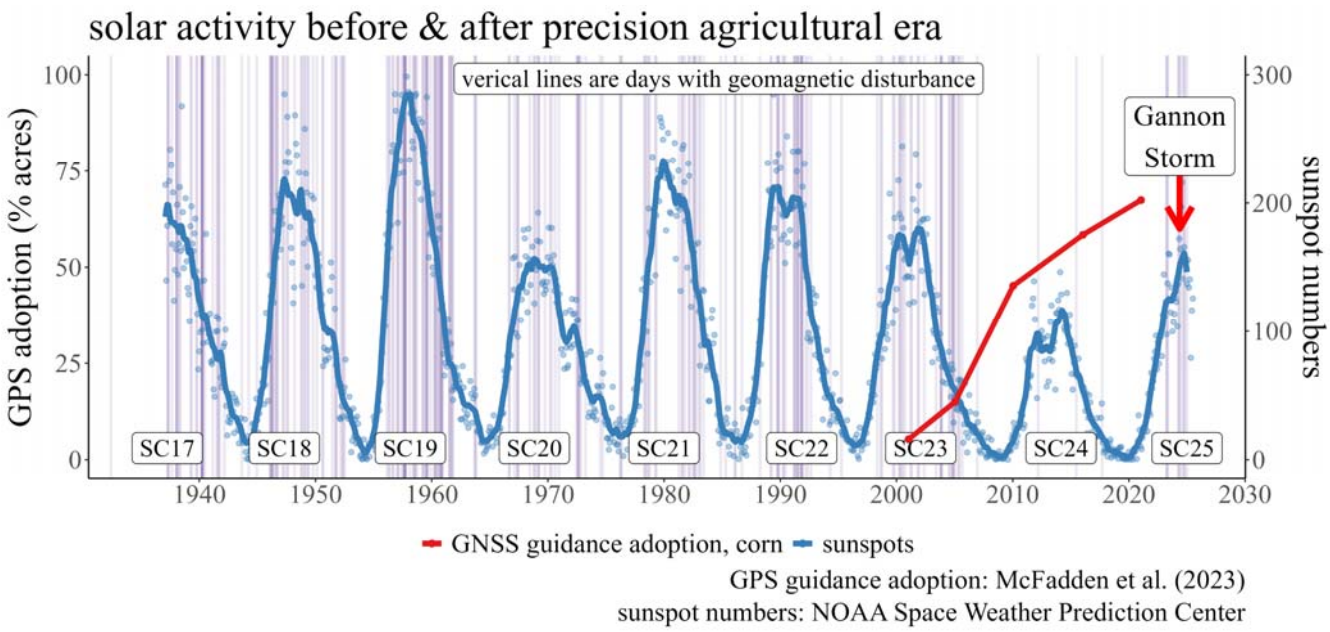
The Day Earth Lost Half Its Satellites (Halloween Storms 2003)



OCTOBER 28, 2021 / DR.TONY PHILLIPS

Oct. 29, 2021: Imagine waking up to this headline: "Half of Earth's Satellites Lost!" Impossible? It actually happened on an October day in 2003.

Turn back the clock 18 years. Solar Cycle 23 was winding down, and space weather forecasters were talking about how quiet things would soon become when, suddenly, the sun unleashed two of the strongest solar flares of the Space Age. The first, an X17-category blast on Oct. 28, 2003, hurled this CME directly toward Earth:



Impact of the Gannon Storm on corn production across the Midwestern USA

Terry Wayne Griffin* Delores Jane Knipp† Janelle Shank‡
Tamitha Mulligan Skov§ Scott W. McIntosh¶ Robert J. Leamon‖

2025-03-05

https://agmanager.info/management-finance/precision-agriculture/

AgManager.info
Kansas State University | Agricultural Economics

Impact of the Gannon Storm on **Corn** Production

- **$53.2M** to **$1.7B** across USA
- Conservative estimates ~ **$1B**

Because of GPS…


Planter technology has progressed to the point that John Deere is offering a 120-foot machine that can plant 48 rows, each 32 inches apart.

1995

2005

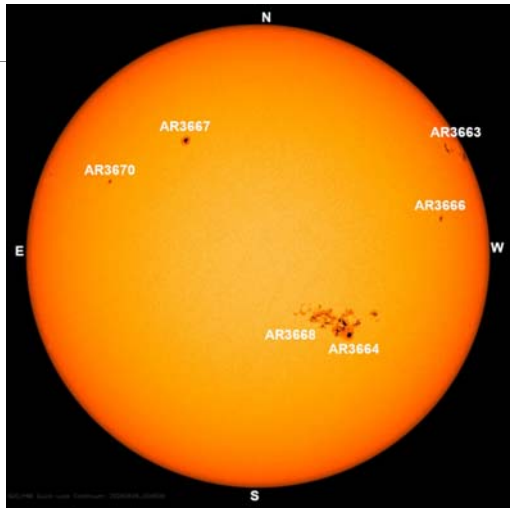
2015

What happened on 10 May 2024? aka Gannon Storm

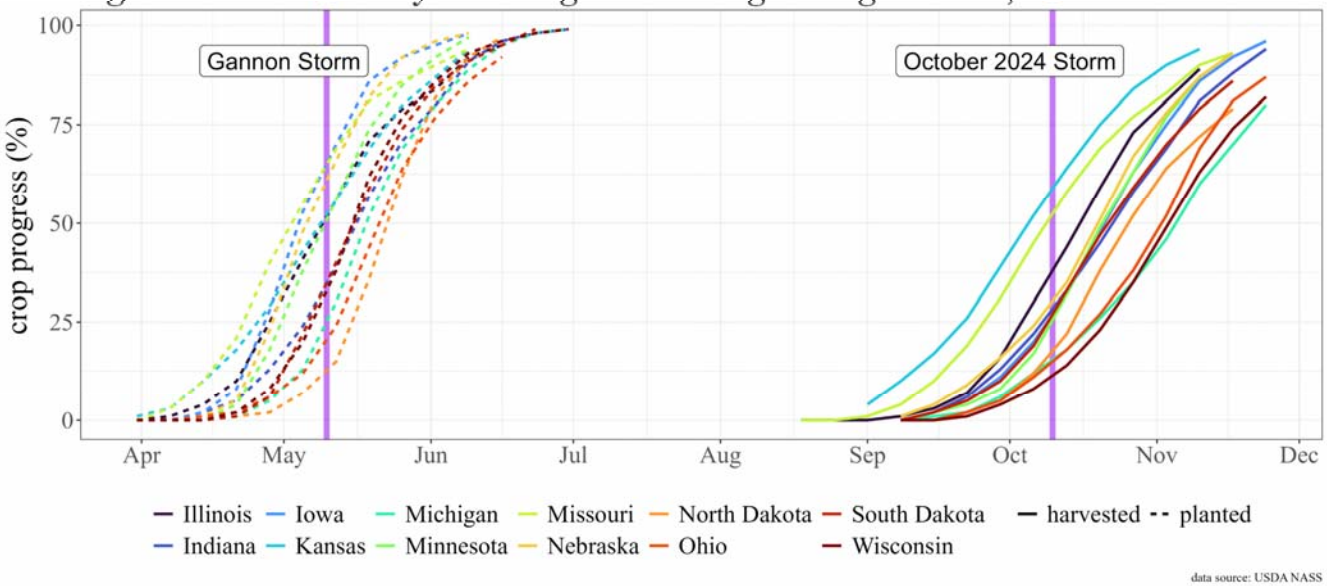
May 7: Active Regions (AR) 3668 and 3664 grew larger

May 8/9: Active regions 3668 and 3664 fused together

May 10/11: G5 storm arrives at Earth with Kp = 9



Agricultural sensitivity to timing of GNSS signal degradation, **corn**



data source: USDA NASS

Sensitivity to GNSS signal degradation, **peanuts**

peanut digging at UGA/ABAC 4D Farm

Value of production in **Georgia**
- ~ **$780M**

Value of RTK ~ **$60M**

Continue without RTK
- 11% **digging** penalty

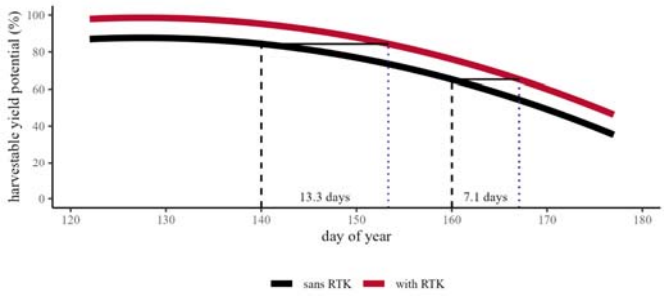
Wait for RTK,
- **delay** penalty may be < or > 11%??

Digital, Data-Driven Demonstration Farm

peanut digging at UGA/ABAC 4D Farm

<u>GNSS outage forecast informs decision:</u>
continue (accept 11% **digging** penalty)
or
wait (accept **delay** penalty)

Value of RTK forecast: **$35M**



derived from David Jordan 2025

Space weather impacts on agriculture

Check Planetary K-index

SPACE WEATHER PREDICTION CENTER
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Latest Observed

R	S	G
none	none	none

- https://www.swpc.noaa.gov/
- https://www.spaceweather.gov

Wait, outage likely only a few hours (if R4)

- R2 or R3 ~ 1 hour

May 2024 GPS outage: NOT a once-in-a-lifetime event

Acknowledgements

This material is based upon work that is supported by:

National Institute of Food and Agriculture, **U.S. Department of Agriculture** under award number 2023-68016-39403

Digital, Data-Driven Demonstration Farm

https://4dfarm.org

AgManager.info
KANSAS STATE UNIVERSITY | Agricultural Economics

Going forward

NOAA SWFO-L1 media briefing 21 August 2025

- first satellite devoted entirely to space weather, launch next month
- better forecasts

Space Weather Advisory Group (SWAG)

- advises Interagency Working Group on policies and strategies to enhance the nation's ability to prepare for, mitigate, respond to, and recover from space weather events.
- User needs survey

Contact information

Terry W. Griffin, Ph.D.
Professor and Extension Economist
twgriffin@ksu.edu
@SpacePlowboy

Amir Bahadori, Ph.D.
Nuclear Engineering Program Director
Hal and Mary Siegele Professorship in Engineering
bahadori@k-state.edu