CTU Presents

Solar Cycle Impacts on Radio Propagation: Forecasting Cycle 25

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What is Space Weather?

Essentially Space Weather is:

- A planet's interaction with its host star and the surrounding space environment
- More generally, it occurs at planets, moons, comets, asteroids, and other celestial bodies in the universe
- We see aurora at planets
 - Jupiter, Saturn, Uranus and Mars
- We see effects at Moons
 - Io, Europa, Ganymede, & Titan
- Main effects are **Sun-driven**
- Other sources of space weather
 - Cosmic rays
 - Micrometeroids & interstellar dust
 - Space junk





Basic Types of Solar Phenomena Affecting Earth

Solar Flares



Solar Storms (a.k.a. CMEs)



Solar Radiation Storms



Moderate X-ray flux Product Valid At : 2015-06-22 18:23 UTC Moderate Proton Flux NOAA/SWPC Boulder, CO USA



Coronal Holes (Fast Solar Wind)





Our Complex Star is Always Changing

Giant fusion reactor that drives Space Weather

Lava lamp dynamics with energy output as:

- Electromagnetic radiation (from X-rays through radio waves)
- Solar Wind (plasma & magnetic field)
- Solar Flares (radio blackouts)
- Solar Energetic Particles (SEPs) (a.k.a. solar radiation storms)
- Coronal Mass Ejections (CMEs) (a.k.a. solar storms)





What do Space Telescopes See?

► 6.3 Million °C









Its All Part of the Solar Dynamo









Magnetic Loops Make Sunspots Dark







Sunspots are Visibly Dark but Radio Loud





A sunspot group in 2003, observed by the Total Irradiance Monitor (TIM) radiometer on the SORCE satellite caused irradiance to drop by 0.34%.





This 14 GHz image of the Sun by the Very Large Array (VLA) radio telescope shows the highest intensity radio waves come from a similar location as sun spots

TRACE showing a 8 GHz radio source directly above this sunspot on the limb



The Hidden Source of Solar Flux: Plages, Faculae, & Bright Points





Individual faculae are bright spots on the walls of solar granules, the cells of hot plasma that bubble up to the Sun's surface from the convection zone. Goran Scharmer / Royal Swedish Academy of Sciences



A Different Kind of Butterfly Diagram



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- Many but not all faculae are small bright patches seen around sunspots
- They exhibit a similar latitude distribution over time as sunspots (e.g. "The Butterfly Diagram")
- These faculae can also be used to determine solar cycle variability
- Note that another kind of faculae appear in the polar regions of the Butterfly diagram
- These 'polar faculae' are most numerous at the minimum of sunspot activity

https://solarwww.mtk.nao.ac.jp/en/db_faculae.html

What does Solar Variability Mean for Cycle 25?

- Sun's activity cycle has a quasi 11-year periodicity
- Solar magnetic field constantly reversing orientation
- Activity increases for few years around field reversal (solar maximum) and decreases when field becomes ordered again (solar minimum)
- Other competing cycles cause deviations from 11-years and modulate the strength of the cycle over the long-term
- Sunspot numbers are used as a proxy for solar activity









Solar Cycle 24: Where Are We Now?

- Recent solar cycles (since cycle 22) are showing dramatic changes, making predictions more complicated
- Consensus is we are not dipping into another Maunder Minimum
 - Cycle is slower, lower luminosity, lower activity at maximum, consistent with the "downward trend" exhibited since the activity "peak" in Cycle 22.
 - Current weaker magnetic field strength also means higher cosmic ray flux through this minimum phase (which enhances radio propagation slightly)
 - Minimum in 2019-2020 difficult to predict due to hemispheric asymmetry
 - Possibly higher probability of extreme events during these weaker cycles



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graphics (http://sidc.be/silso) Royal Observatory of Belgium 2017 March 1

Daily

Monthly

Monthly smoothed

SC Predictions

250

Hot Off the Presses!

300

250

200

150

100

50

So

The New

2010

Solar Cycle 25 will

Sunspot Number

DUR

Timing of minin

2015

Timing of mo

SSN V2 An

Conclusions

 The Sunspot Number has been revised NOAA will be adopting these
 We haven't reached solar minimum
 Cycle 25 similar to Cycle 24

The Downward Trend



Extreme Solar Storms

- Extreme Space Weather events cc... happen near solar minimum.
- March 1989 geomagnetic storm
 - Knocked out the power grid of Quebec
 One of the most extreme storms of the
 - Space Age
- Solar Storm of 2012
 - > Ultrafast CME directed away from Earth with properties that some suggest may have

- Solar Cycle panel at Space Weather Workshop at NOAA in April 2019
- Colleagues snapped shots of the latest solar cycle predictions during presentation

Still to be done...

- Investigate the Hemispheric Asymmetry and Phasing
- Produce the Official SSN Prediction Curve
- Provide a statistical estimate of F10.7 Flux
- Attempt to create a Flare and CME Probability Forecast
- We hope to have this done by the end of the year



NOAA/SWPC Official Cycle 25 Prediction Remains Blurry



Solar Cycle 24: Really, Where Are We Now?





- Returning to bright regions for predictions
- Solar Cycle 25 sunspots could begin as soon as late 2019
- Terminator comes in 2020
- Once terminator hits, solar flux increases abruptly
- Could see near 100% increase in solar flux within a few months of reaching terminator



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How is the lonosphere Affected?

- Ionosphere is a charged plasma layer above the atmosphere comprised of ions and electrons
- It would be neutral but it gets charged from exposure mainly to the Sun's UV radiation (e.g. F10.7 flux)
- This charged nature facilitates radio propagation
- During active space weather, extra energy caught in the Earth's magnetic shield gets dumped into the ionosphere
- This energy (flow of charged particles) lights-up the plasma in the Earth's ionosphere similar to a fluorescent lamp or neon sign
- Result is the aurora borealis (northern lights) and aurora australis (southern lights) along with changes in radio propagation
- Space weather effects enhance an already complex system







What are lonospheric Layers?





Three Temporal Regions of Signal Propagation



Why Do the Layers Change Gradually?



Space Weather Effects on Propagation



The Complex Ionospheric Weather Ballet



- All sorts of dynamic processes in the ionosphere
- Coupling to the neutral atmosphere beneath drives many microprocesses such as gravity waves, scintillation, plasma bubbles, winds and turbulence
 - Many of these are not well understood or characterized
 - terrestrial weather effects often complicate interactions
- Coupling to the magnetosphere above through processes such as particle precipitations along with variations in sunlight can generate waves, conductivity changes, density changes, and currents
 - Space weather effects often enhance these processes

Thank you Jerry K8VGL !



Until models improve, WSPR & Reverse Beacon network activity remain among the most reliable ways to probe real-time ionospheric radio propagation conditions

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Conclusions

- NOAA Official Prediction for Cycle 25
 - Timing of minimum: 2019.5 2020.75
 - Timing of maximum: 2023 2026
 - Strength: similar to Cycle 24
 - Range of Predicted Sunspot Maximum: 95-130
- Cycle 25 will be another low activity cycle, but that doesn't mean activity stays low!
- Hemispheric magnetic asymmetry is main reason why prediction remains blurry
- Including dynamics of the Sun's magnetic dynamo (NCAR/UCAR predictions)
 - Solar activity picks up end of 2019
 - Terminator (e.g. solar minimum) reached by early 2020
 - Once terminator reached, solar flux will rise quickly
- However, Earth's ionosphere has a very complicated weather system
 - Dynamics includes much more than just solar activity
 - Coupling to Earth's magnetic shield above and to the neutral atmosphere below make it extremely difficult to predict radio propagation on a given day
 - Until models improve, WSPR & Reverse Beacon network activity remain among the most reliable ways to probe real-time ionospheric radio propagation conditions



