Reflections Before the Max: The Evolution of Space Weather

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The Survey

Introduction

- A sample of the space weather community was surveyed to understand the history of space weather and how the community views itself
- Researchers in academia and government, operational forecasters, private sector scientists, and policy makers were asked to describe their views on the milestones of space weather, the current state of space weather, and the future direction of the field
- Respondents were also asked to characterize space weather research using Pasteur's Quadrant of research classifications. This classification is a useful system to help demonstrate the priorities and goals of members of the space weather community.

Important Scientific Milestones:

- 1859: Carrington Flare, first recorded event of space environment elements influencing human technology: telegraph systems
- 1958: Solar wind prediction/discovery and magnetosphere reconnection work by Parker
- Interplanetary Magnetic Field (IMF) – Earth Magnetosphere interaction work
- 1970s-1980s: Coronal Mass Ejection theory and observations
- Viewing the Sun-Earth environment as a system science

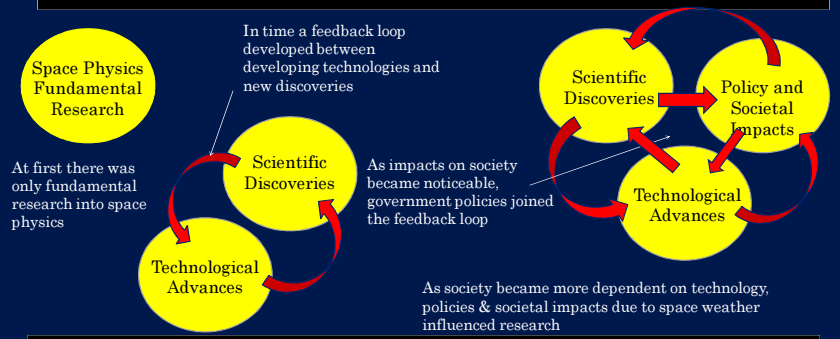
Important Technological Milestones:

- Communications: telegraph, land-line, high frequency (HF) comm, cell phones
- Electric power - gridded systems, interconnected national grid, increasingly higher voltage transmission
- GPS: dependence for precise location, navigation, and timing augmentation systems (e.g. WAAS), civil consumer usage (e.g. car or handheld GPS)
- Satellites: launching failures, communication & data loss, direct damage from space weather events

Important Policy/Societal Milestones:

- March 1989: HydroQuebec Blackout: first significant societal impact due to space weather on modern technology
- 1995-present: National Space Weather Program , the defining plan for interagency cooperation in space weather
- Space Weather Prediction Center: move into the National Weather Service helped solidify the role of operational forecasting of space weather within the government and private sector
- New policies and technologies exposed society to new vulnerabilities due to space weather:
  - Mid 1990s:Clinton administration declared GPS to be a dual-use system for both military and civilian usages
  - 1999: Opening of polar routes for transpolar flights

A Science Evolving

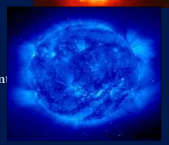


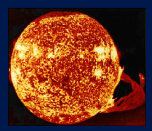
The Evolution of Solar Observations

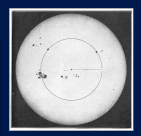
- One of the best of examples of evolution within space weather can be seen in our ability to observe the sun.
- Cave drawings around the world show that in ancient times people wondered and marveled at the sky's fiery orb.
- Thousands of years passed with no real understanding about the sun until the days of the Renaissance and the invention of the telescope. Over the next few centuries the telescope would vastly improve our ability to observe beyond the atmosphere.
- With the launch of satellites, humans had the first clear look at the sun. Each imager and satellite brought new revelations about the sun. Now, with STEREO, the sun can be viewed for the first time in three dimensions.

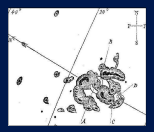

1st CME of Solar Cycle 24, STEREO (2006-present)


Solar coronal activity ACE (1997-present)

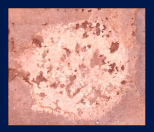

Sun EUV activity SOHO (1995-present)


Solar prominence SKYLAB (1970s)


Photograph of sun disc Mount Wilson Observatory (1940s)


1st solar flare drawing Richard Carrington (1859)


Drawing of sunspots Galileo Galilee (1564-1642)


Cave Painting (30,000+) Palatki Heritage Site, AZ

The Nature of Research

Pasteur's Quadrant Classification System of Research

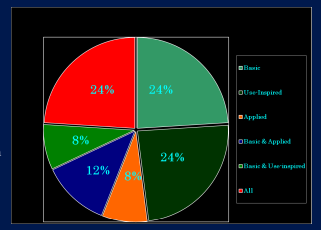
Quest for fundamental understanding	Consideration of use: No	Consideration of use: Yes
Yes	Pure Basic Research (Bohr)	Use-Inspired Basic Research (Pasteur)
No		Pure Applied Research (Edison)

Source: Pasteur's Quadrant, Stokes 1997

- Pure basic research: research guided solely by the quest for knowledge with no thought for application *(Bohr with the model of the atom)*
- Pure applied research: research guided by applied goals with no thought to the gaining of general understanding *(Edison with the light bulb)*
- Use-inspired basic research: fundamental research for knowledge with an applied goal in mind *(Pasteur's work in microbiology leading to pasteurization)*

What is Space Weather Research?

- Within the survey, respondents were asked to classify space weather research according to Pasteur's Quadrant (see figure)
- No single type held the majority, there is no community-wide consensus
- About half the respondents answered some form of basic research , either pure or use-inspired, stemming from space weather's roots in space physics
- Close to half responded some form of combination of research
- Overall, this survey showed that all three classes of research are considered important in space weather



- Further work could show how these three types of research contribute to the community and how they relate to and advance each other

Conclusions

- Space weather is a fast growing science. Its roots lie in fundamental space physics research. Since the onset, the positive feedback loop setup between advances in theory, technology, and policy have pushed the science to evolve faster than any could have expected.
- As the Space Age continues, it is reasonable to assume there will be a growing need for more observational platforms to collect as much data on the sun as possible for research and forecasting. Missions such as SDO and STEREO are leading the way.
- This survey demonstrated how a balance between applied and fundamental research is advancing space weather on all fronts. All types of research lead to one goal though--a thorough understanding of the sun and its impacts on our technology

Acknowledgments

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Timeline of Milestones in Space Weather

30,000+ BC	Early 1600s	September 1859	May 1921	1940s	1958	1960s	August 1972	1973-79	Late 70s-80s	March 1989	1990s	2000s
Cave paintings of sun	Telescope allows for more accurate sun sketches	Carrington Flare first observed correlation between solar flare and technology impacts	Geomagnetic Storm easily the strongest recorded event in past 100 years	WWII: Allies and Axis both notice radar interference via space weather	Parker's solar wind theory	Start of satellite observation of the sun	Major storm causes disruption in land and transoceanic phone lines	Skylab, first US manned space station, equipped with solar observing equipment	CME Research, launch of Solar Maximum Mission	HydroQuebec Blackout, held as the most costly space weather event ever	Ulysses, ACE, SOHO, HINODE, GPS public release , polar routes open National Space Weather Program Space Weather Prediction Center	TIMED, STEREO, SDO SWPC move into NWS CCMC and LWS created Space Weather Symposium