NORTHROP GRUMMAN

Raytheon

An Approach to Test and Exercise for Space Weather Systems for Storming Conditions

Rhonda S. Davis, Northrop Grumman
David H. Polk, Northrop Grumman

Raymond J. Vigeant, Raytheon
Steven L. McNew, Northrop Grumman

Abstract

Significant geomagnetic storms over the past 150 years warrant attention in preparing operational crews and stress-testing systems to gain insight regarding a "state of readiness" for these events. The type, severity, source, and timing of the observations, alerts, and warnings all play a role in setting up these scenarios for the purposes of test, exercise, and training. Retrieving this data from past events and using them within test scenarios provides a means to test the robustness of the system and verify the system's ability to operate successfully under stress conditions.

This paper provides an approach to collect historical data (including the 1859 storm – aka the "Solar Superstorm") and describes a set of activities to simulate and fabricate input observations that fit into a realistic scenario. It is not as simple as running previous messages from a past solar storm through the software as these messages may no longer be in the correct format. The data must then be coded into the new message formats and ingested in the correct order and cadence to provide a realistic chain of events to assess software behavior. These scenarios may be used to determine the amount of Forecaster-in-the-Loop work that must be done at a time of "Solar Maximum" and assist in training. They may also be used to identify software defects as well as communication and system throughput issues at both times of significant space weather activity and significant inactivity.

Scenarios would be structured to follow a realistic pattern of events. The scenario would send data in to a message processing system, which would process the information and create space weather products on a nominal schedule. Observations from different domains, such as solar (optical and radio), satellite, and ground stations would have to be synchronized to create realistic scenarios that simulate natural environmental conditions. Types of scenarios that may be created include: solar maximum, solar minimum, historical storms, stress conditions, and customized storming conditions. These scenarios differ with respect to volume of data, data extremes, and timing. Past archives will be searched for messages during significant past storming periods. The messages would be analyzed for format and for fields that must be modified (such as dates), and arranged chronologically to use as a starting point for creating historical scenarios. Current data may be used to create stress tests and customized solar storms, focusing on the testing of a specific part of the system. For historic events that occurred prior to the availability of contemporary sensors, simulated data can be generated consistent with the event.

Objectives:

- Offer an approach to collecting historical data
- Describe a set of activities used to simulate and construct input observations that fit into a realistic scenario
- Use scenarios to :
  - Determine amount of work done by Forecasters in off-nominal conditions (solar minimum or maximum)
  - Identify forecaster training needs and assist in training
  - Identify software defects
  - Identify communication and system throughput issues

Approach:

1. Characterize and Correlate Storm Data
2. Focus on Events of Interest
3. Lay out Injection Solution
4. Design/Construct Scenarios
5. Implement Test and Exercise Capability

Focus

Preparing space weather forecasters for impending solar storms with the use of realistic scenarios for training. This helps to make the forecaster aware of the types of effects solar storming conditions may have on various external systems, such as satellites, power grids, GPS navigation, manned space flights, communications, etc.

Solar Cycle

The Solar Cycle is **eleven years** in length, and is caused by the changing magnetic field of the Sun. It varies from **solar maximum** when sunspot, CME and flare phenomena are most frequent – to **solar minimum** when such activity is relatively infrequent. The last solar maximum occurred in 2001 and the next maximum is projected for 2012. Solar minimums occurred in 1996 and 2007.

Years	Number of Storms	Type	Impact	Notes
1859 - 1898	10	Aurora, solar flares	Telegraph communication and compass deflections	Observations noted from general population, telegraph operators, navigators, and science community and magnetograms
1899 - 1937	33	Aurora, solar flares	All of the above. In addition, power line voltage increases, radio communication disruptions	All of the above. In addition, power plant operators and radio operators
1938 - 1969	46	Aurora, solar flares, x-ray flares	All of the above. In addition, satellite impacts, manned space missions.	All of the above. In addition, radar operators, ionosondes, solar telescopes
1970 - 2003	8	Aurora, solar flares, x-ray flares, proton events	All of the above. In addition, interplanetary space missions	Contemporary ground based and space based space sensors. Neutron monitors, SOON solar observatories, RSTN observatories, TELSI, TENET, SCINDA, DISS, DMSP, GOES, DSP, WIND and ACE, SOHO

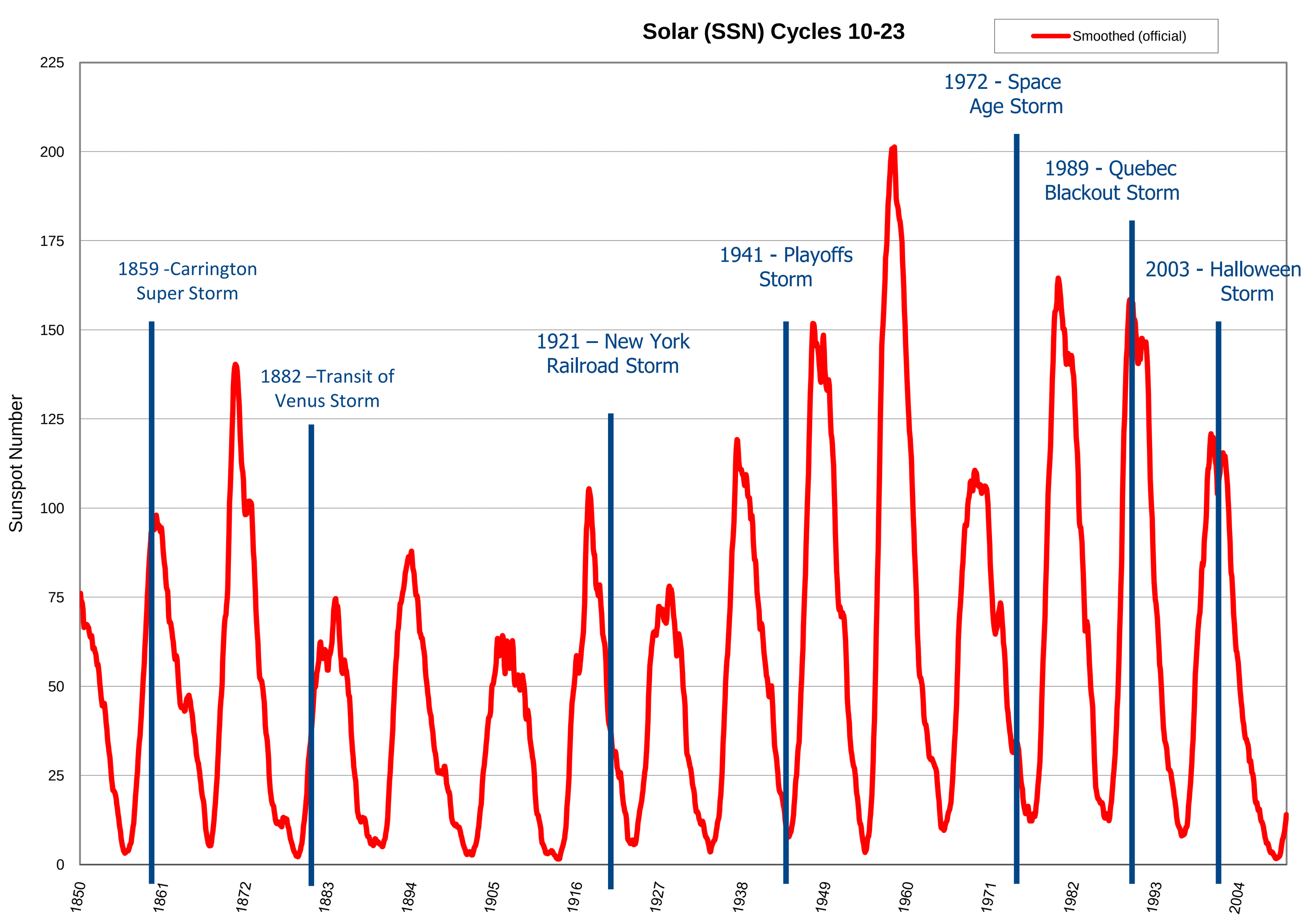
Solar Storms - History

Reviewed 97 Candidate Storms from 1859 - 2003

Storm Characteristics Considered:

- Significant display of solar activity
- Intensity of all solar flares ever recorded
- Significant Solar Proton Events
- Critical system impacts on both earth and in orbit
- Availability of observing and data collection sites

Key Solar Storming Events

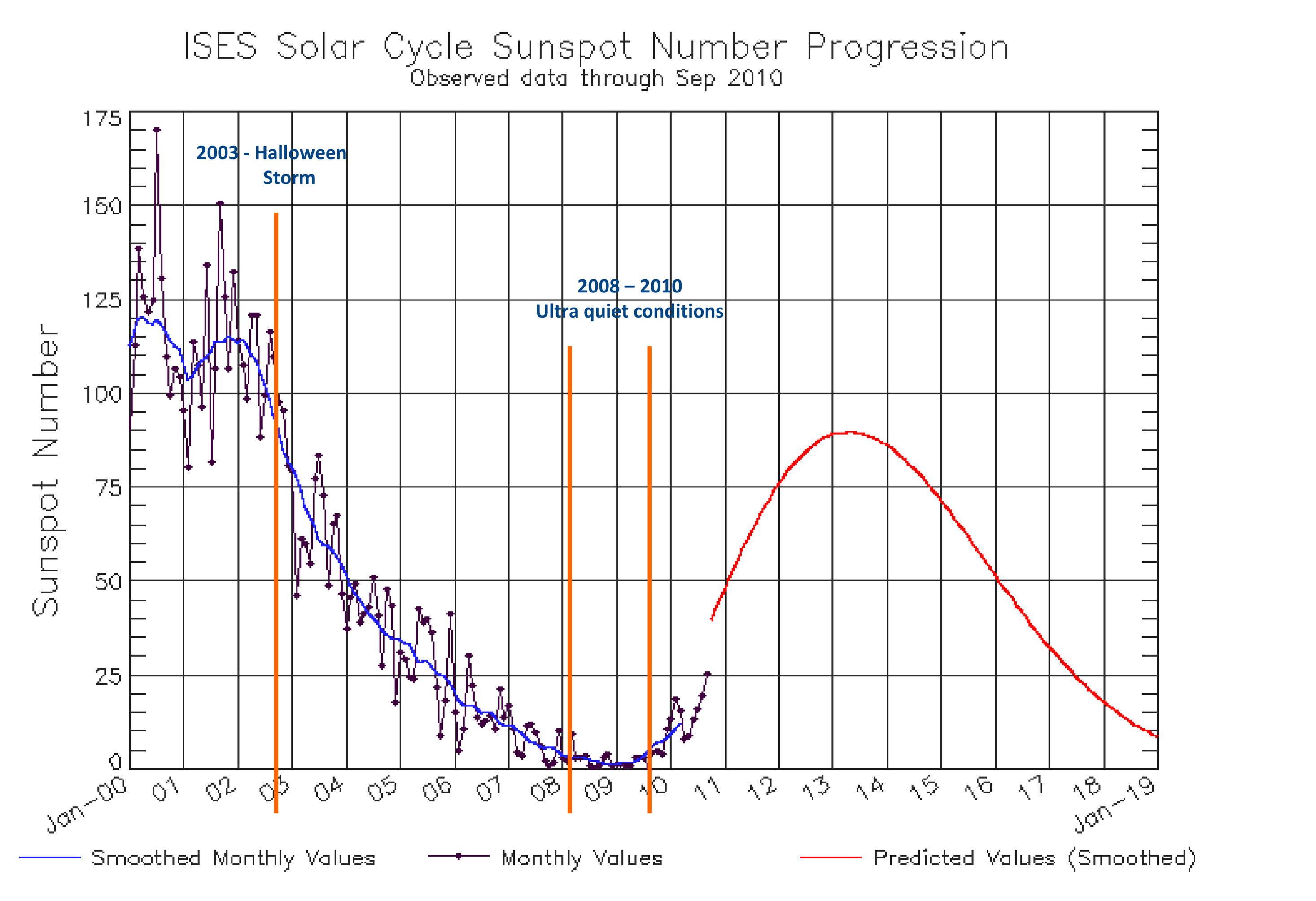


(Source 8)

Selected significant storms 1859 - 2003

Year	Storm Name	Type	Impact	Notes
1859	Carrington Super Storm	Auroras, solar flares	Telegraph disturbances	Estimated to have arrived in 17 hours
1882	Transit of Venus Storm	Auroras	Magnetic disturbances, Compass bearing deflections, Telegraph disturbances, Railway signal disruptions, Telegraph communications suspended	
1921	New York Railroad Storm	Auroras, major sunspot sightings,	Magnetic disturbances, Compass bearing deflections, Telephone, Telegraph, and cable disturbances, Railway signal disruptions	
1941	Playoff Storm	Auroras, major sunspot sightings, solar flares	Radio and telegraph communications disruptions	
1972	Space Age Storm	auroras,x-ray flares,	Power surge on phone lines, shutdown phone service in Illinois and Iowa - communications	First storm predicted by SWPC
1989	Quebec Blackout Storm	Solar Proton Storm, auroras	Magnetic storm overloaded power grid - Power systems	
2003	Halloween Storm	Auroras, x-ray flares, radiation effects	Satellite disruptions	Arrived in 19 hours , classified as X34 Flare

(Source 3)



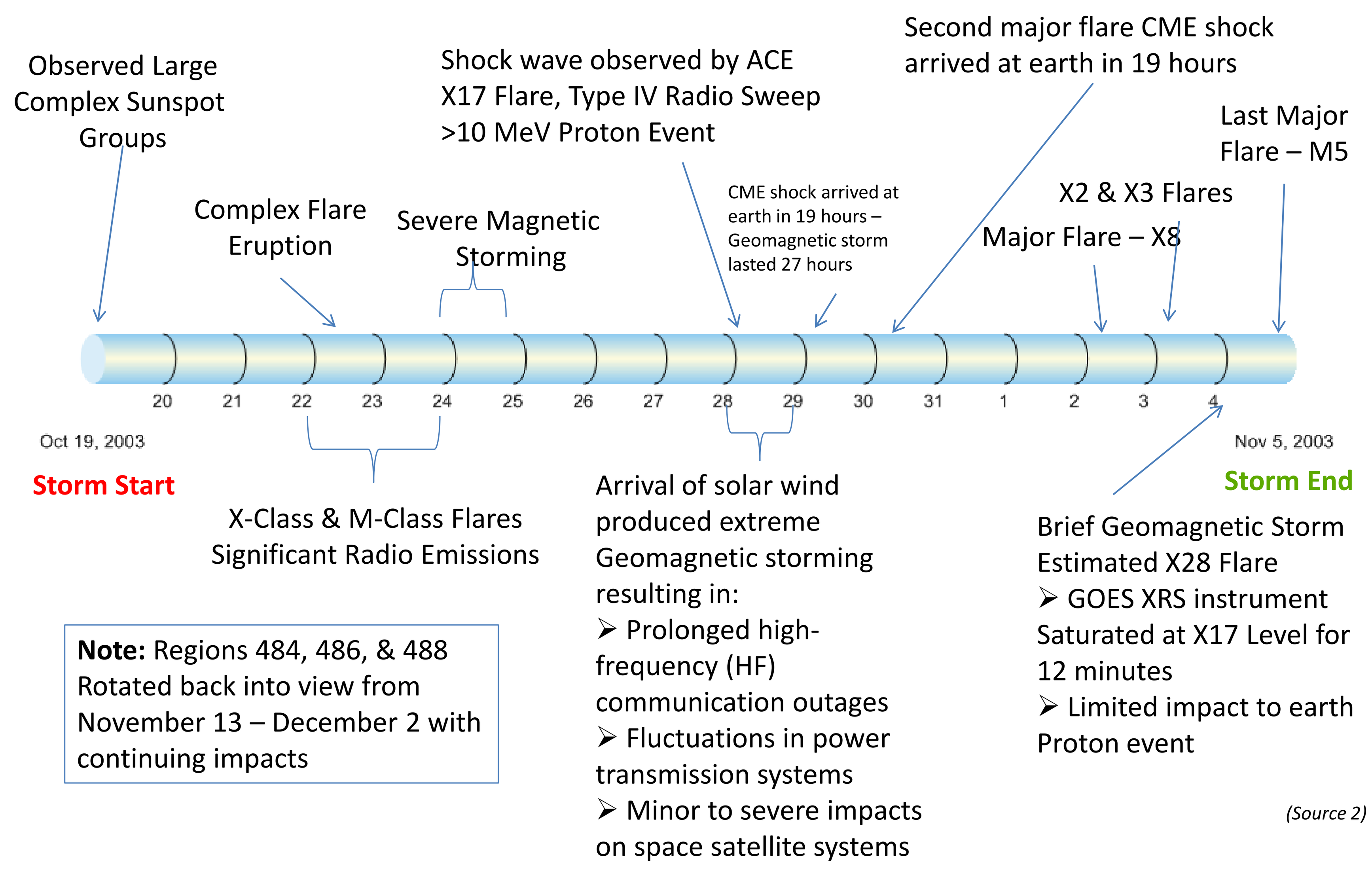
Recent Events of Note

Focusing in on the most recent solar cycle 23 and start of cycle 24 for a diverse set of data.

Events of note are the 2003 "Halloween Storm" and the ultra-quiet conditions throughout 2008 – 2010.

Chronology of the Halloween Solar Storm

The most severe impacts of the storm involved a 3 week period Oct 19 – Nov 5, 2003 (Regions 484, 486, & 488)

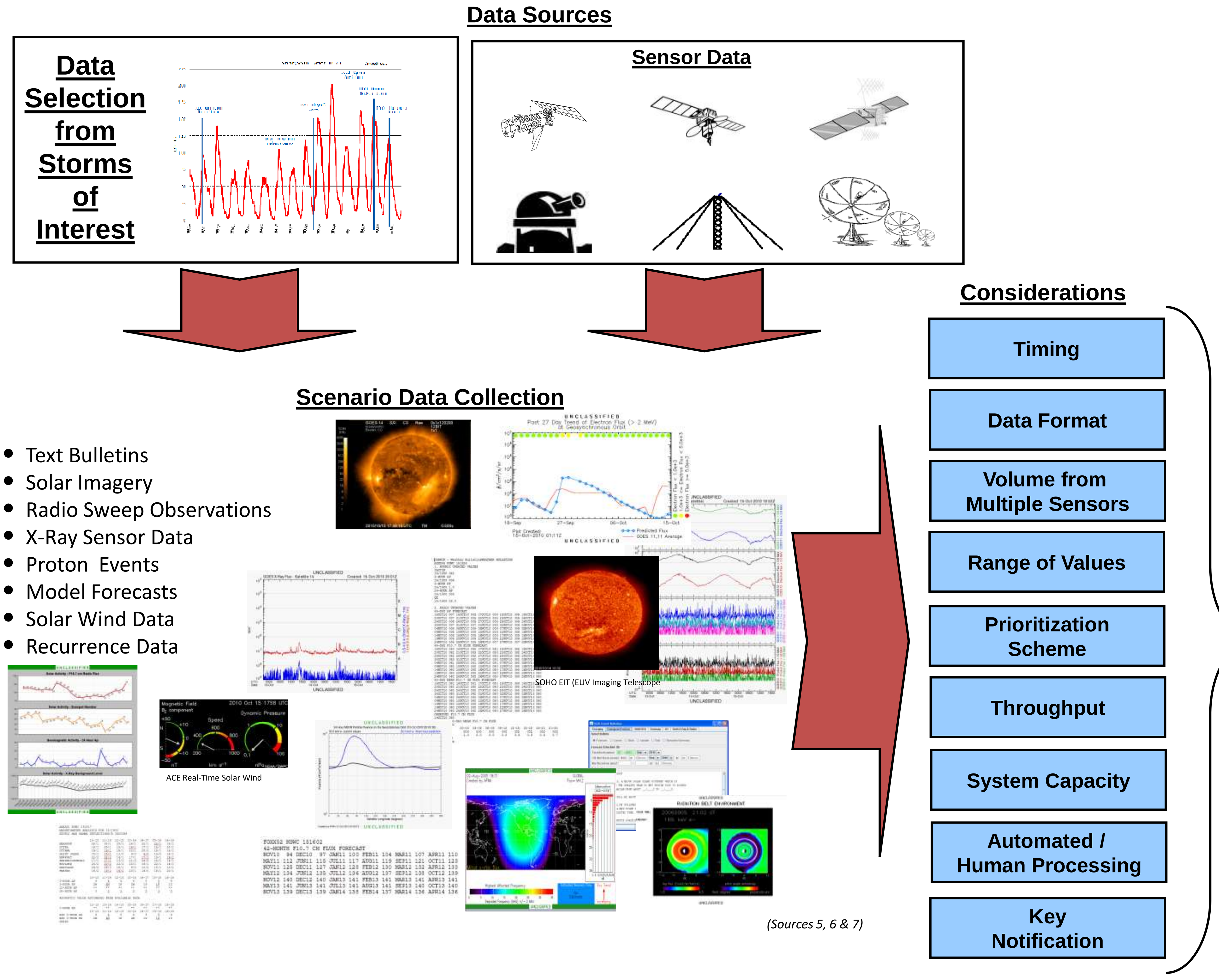


Sequence and Timing

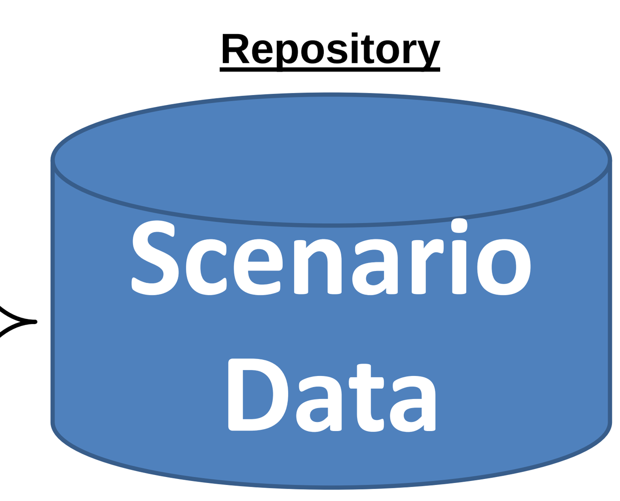
Systems directly impacted by the Halloween Storm

- International Space Station
- NASA Deep Space Missions
  - Mars Odyssey
  - Stardust
  - Smart-1
  - Mars Explorer Rover
- Other Spacecraft
  - ADEOS-2
  - Advanced Composition Explorer (ACE)
  - SOHO
  - DMSP F16
  - Chandra
  - GOES 9, 10, & 12
  - Inmarsat (fleet of 9 geosynchronous satellites)
  - TV and Pay Radio satellite services
- Operations relying on GPS (survey, mining, & drilling operations)
- Airline Operations
- HF/VHF Communications
- FAA's Wide Area Augmentation Systems (WAAS)
- Antarctic Operations
- Electric Utilities

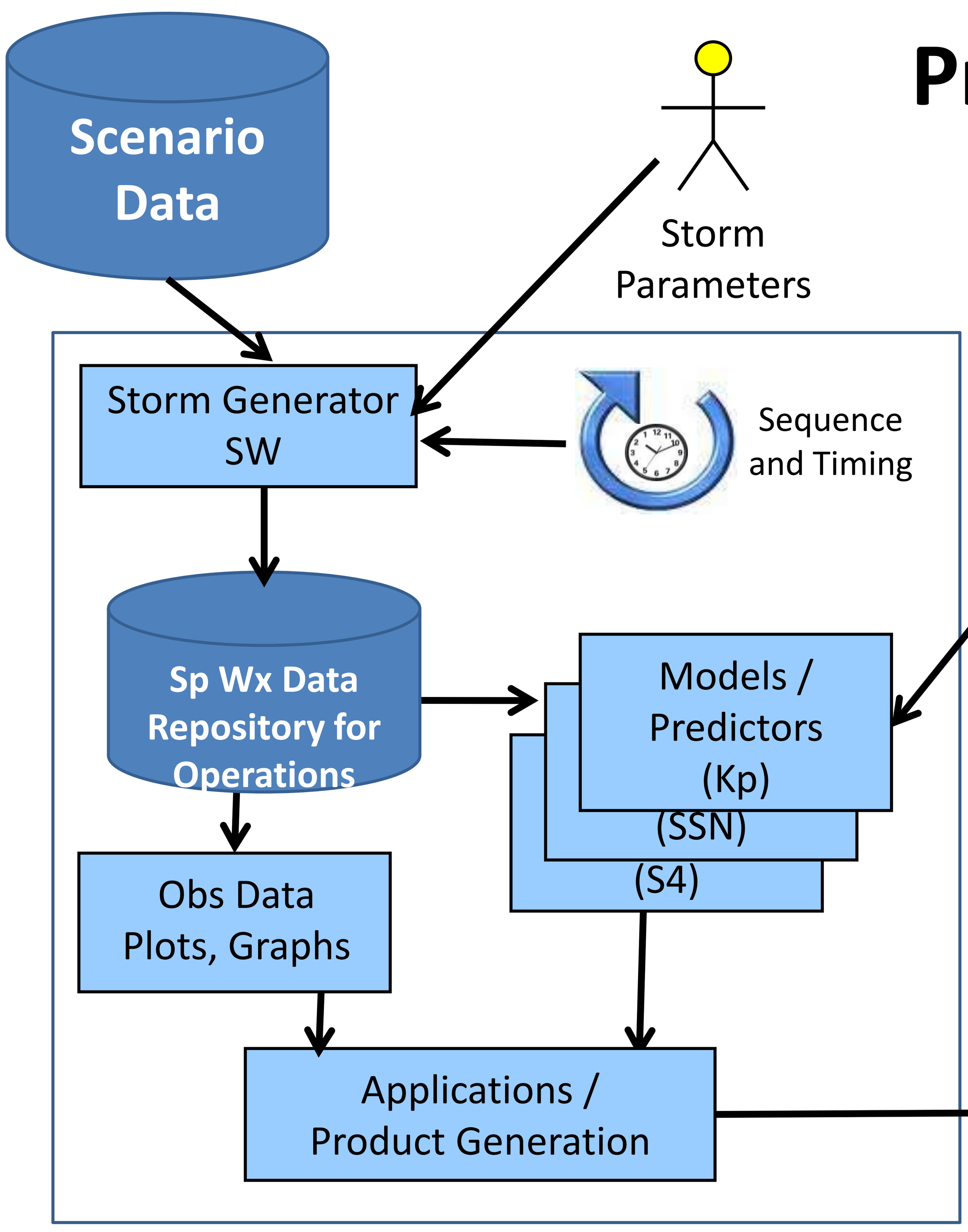
Data Translation to Storm Scenarios

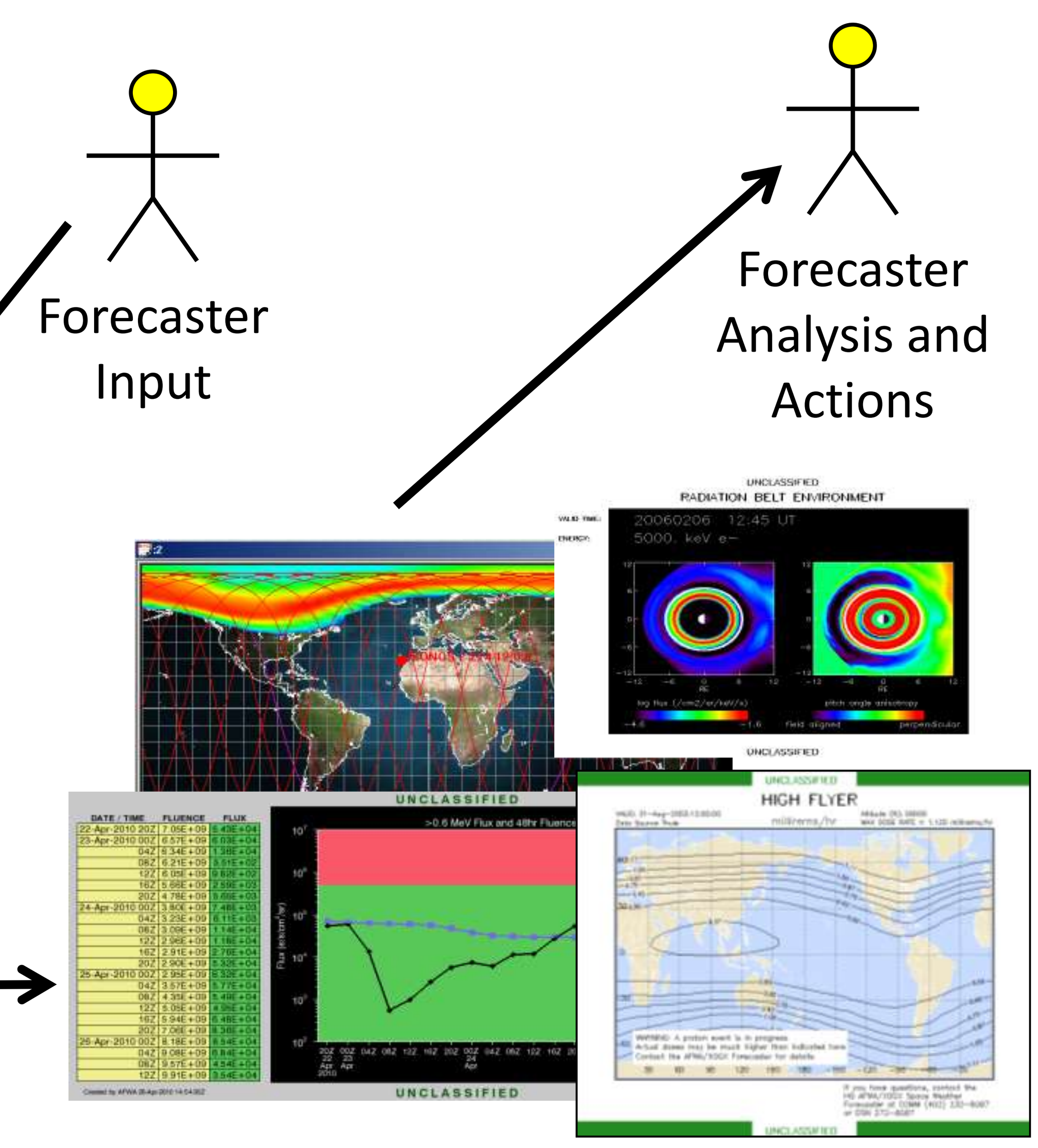


Once sample storms have been identified, the data from the storms must be collected or re-created to replicate the event(s). Factors such as timing, data format, volume, etc. must be considered to re-create a realistic storm. This information is stored in a “Scenario” repository for future use.



Proposed Scenario Implementation





Future Steps:

- Collect, construct, and organize data from selected solar storms
- Construct the scenario repository with observations and input data
- Construct the storm injection software with capabilities to adjust given characteristics (region, timing, severity)

Summary

Over the last 150 years, there have been a number of significant storms that if simulated, would provide a tremendous training opportunity. Unfortunately, the length of time between events, coupled with the availability of stored storm data, varies tremendously. In this paper, we have identified a manageable subset of storms that could provide a very realistic and stressing training condition. In all cases, the more recent the storm, the greater the data availability and data variety.

Several tasks remain. One task is collecting and adapting this data to contemporary training simulators. Another is extrapolating known events and attempting to match these conditions with older storms where incomplete data is available. One closing note is that storming conditions make for exciting training scenarios - however, as we have seen recently, *extended quiet conditions* present a different set of challenges (such as space weather model instability and decreased forecast accuracy) that must also be considered when designing training scenarios.

Acknowledgements:

1. http://www.solarstorms.org/SrefStorms.html
2. Halloween Space Weather Storms of 2003, NOAA Technical Memorandum OAR SEC-88
3. Summary of Major Solar Proton Events, M. A. Shea and D. F. Smart, 29 January, 1990
4. N/A
5. AFWA/ 2WS/WXZ https://weather.afwa.af.mil/jaawin/space/main.jsp
6. NOAA/SWPC http://www.swpc.noaa.gov/
7. ISES Solar Cycle Sunspot Number Progression, NOAA/SWPC, Boulder CO
8. SIDC-team, World Data Center for the Sunspot Index, Royal Observatory of Belgium, *Monthly Report on the International Sunspot Number,* online catalogue of the sunspot index: http://www.sidc.be/sunspot-data/, (1850-2010)