Environmental Space Situation Awareness and Joint Space Effects

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"Know yourself, know your enemy, your victory will never be endangered. Know the ground, know the weather, your victory will then be total…" **[1]**

Sun Tzu, 500 B.C.

Successful military operations rely on our ability to effectively integrate weather information into the planning and execution of land, air and sea operations, but does weather and its effects matter to space operations? On the terrestrial side, practical examples of weather's importance to the effectiveness of military operations are numerous. Successful air operations need to know the weather over the target but also to plan for the affect of weather conditions on ingress and egress routes to and from the target. Land force operations would certainly be at risk without understanding the actual and forecast soil conditions and its affect on land force traffic-ability. Naval and marine operations must have accurate observations and forecasts of sea and littoral conditions in order to safely and effectively conduct their part in joint military operations. But, does weather matter to the effectiveness of space operations? Does it impact the ability of our space capabilities to bring desired effects to the joint warfighter? Because our national space capabilities are our military's center of gravity, Air Force Space Command (AFSPC) takes this question very seriously and, addresses it systematically, starting with doctrine.

Space Situation Awareness (SSA) Doctrine

USSTRATCOM defines Space Situation Awareness (SSA) as "the requisite current and predictive knowledge of space events, threats, activities, conditions and space system (space, ground, link) status, capabilities, constraints and employment – to current and future, friendly and hostile – to enable commanders, decision makers, planners and operators to gain and maintain space superiority across the spectrum of conflict." [2]

Figure 1 illustrates the various components of this doctrine[3]. Ultimately, SSA information needs to be integrated into and made available through a Single Integrated Space Picture (SISP). From top to bottom in the figure, the SISP consists of relevant information from intelligence systems concerning threats to our space capabilities such characterizing red and gray space threats and courses of action (COAs)—Space Intelligence Preparation of the Battlespace (SIPB). Additionally space surveillance systems provide space system and object characterization to the SISP via the Space Surveillance Network (SSN). Weather information from space and ground-based weather sensors, models and applications (such as the SSA Environmental Effects Fusion System—"SEEFS") provide actual and forecast environmental conditions and its impact on friendly and enemy space capabilities. Finally space force status information such as asset availability is provided by our blue space forces. Practically speaking, the SISP provides decision-makers and users at the strategic, operational, and tactical level an accurate, up-to-date, and intuitive understanding of the situation--what needs to be done and what can be done. Combined with military judgment, this allows identification of emerging patterns, discerns critical vulnerabilities, and concentrates space combat power where it can have its greatest effect[4].

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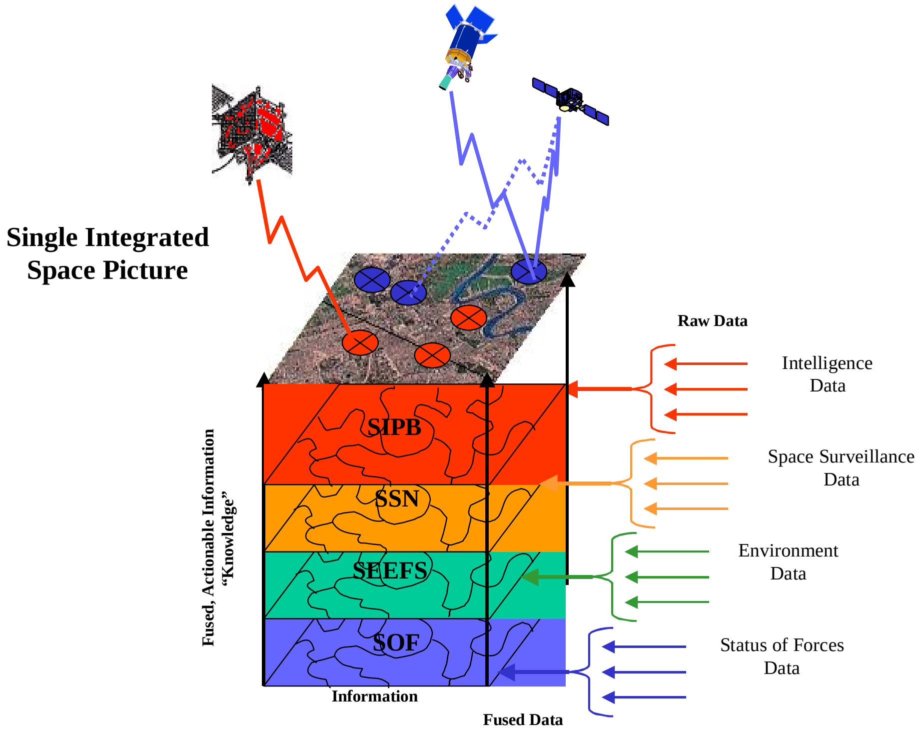


Fig. 1. Single Integrated Space Picture (SISP).

Because the focus here is primarily on the environmental aspects of SSA, the following definition of "environmental SSA" is provided in the context of the USSTRATCOM SSA definition: "The requisite knowledge of current and predicted environmental conditions and the effects of those conditions on space events, threats, activities and space systems to enable commanders, decision makers, planners and operators to gain and maintain space superiority across the spectrum of conflict."[5]

Needed Capabilities

The warfighter's environmental SSA needs are defined within the AFSPC Space Superiority Functional Concept.[6] The first capability below describes the need to gather information concerning environmental conditions relevant to effecting space systems and missions. The subsequent capabilities refer to the application of that information to military decision making or situational awareness:

- Monitor and characterize environmental conditions relevant to space system and mission effects. Access to actual and forecast terrestrial, near-space and space environmental information to allow friendly forces to predict, respond to, mitigate, and exploit environmental effects on friendly and adversary operations.
- Assess and forecast natural environmental effects on blue/red/gray space systems and missions, including user impacts.
- Assess and predict effects of man-made changes (e.g., High Altitude Nuclear Detonation) to the environment on blue/red/gray space systems and missions, including user impacts.

- Support Munitions Effectiveness Assessments (MEA) related to environmental factors (e.g., scintillation effects on GPS-aided munitions accuracy).

- Support anomaly resolution/attack charaterization for blue space systems related to environmental factors (e.g., help DCS distinguish natural from hostile effects).

- Support development and execution of the environmental portion of the Space Tasking Order (S-T-O).
- Assess environmental vulnerabilities of blue, red and gray space forces and assets

For effective SSA it is important to realize environmental conditions can significantly affect a space system's performance and survivability and therefore may impact its ability to bring intended space effects to the joint warfighter. For example, satellite systems, spacecraft components and their payloads, communication links for satellite command and control and mission data, and the satellite's respective ground sites can all be affected by the environmental conditions in which they operate. Likewise, ground-based space systems like surveillance or missile tracking radars that contribute to the space control and missile warning missions can also be affected by the environment. Thus, the degree to which the environment impacts these systems and how environmental information can be applied to improve performance or protect the systems defines the type on information needed for effective SSA. That said, relevant space system environmental information must include both terrestrial and outer space conditions—mud to sun. While most people are aware of the terrestrial environment such as rain, high winds, clouds, temperature and pressure, fewer are aware of the outer space environment. So before discussing the linkage between environmental effects and warfighter impacts, and ultimately the desired effects of environmental SSA, it would be helpful to describe the outer space environment.

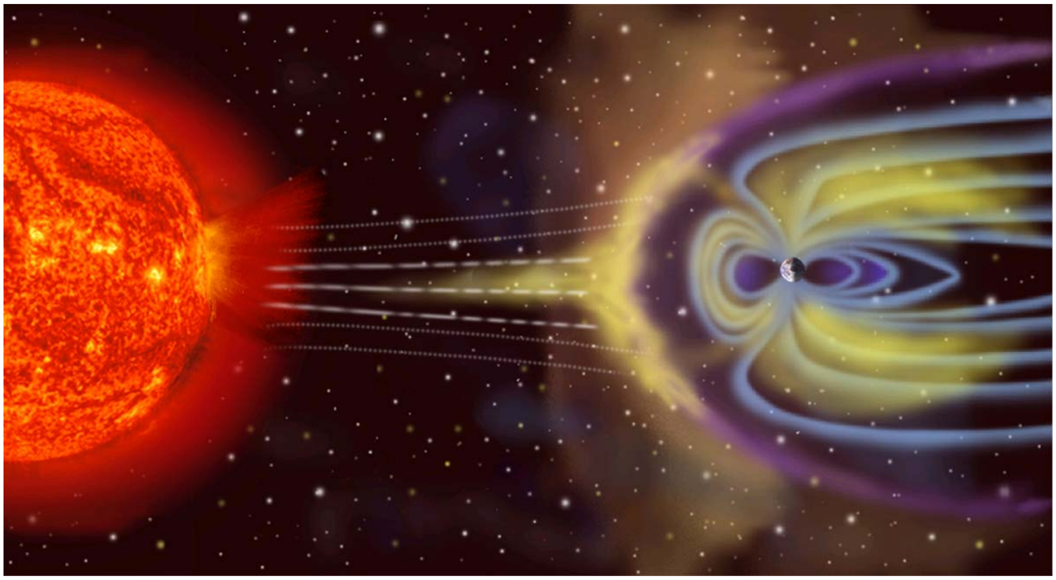


Fig. 2. The Outer Space Environment (Courtesy of NASA)

The Outer Space Environment

The natural outer space environment illustrated in Figure 2 consists of the Sun, the space between the Sun and near-Earth called interplanetary space, and the near-Earth space environment.

The Sun is basically a medium sized star with extreme mass made of mostly hydrogen and a little helium. Nuclear fusion takes place in the Sun's center resulting in the release of huge amounts of energy. The energy is emitted in two forms, electromagnetic and particle energy. Electromagnetic energy travels at the speed of light, taking about 8 minutes to travel the 93 million mile distance from the Sun to the Earth. The form of electromagnetic energy includes the visible light you see, the infrared energy you feel and the ultraviolet energy that reacts with your skin's melanin (the sun also emits X-ray, gamma ray, and radio energy).

The second form of solar energy emitted is particle radiation. The same nuclear processes that produce the extreme amounts of electromagnetic energy described above push out massive amount of hydrogen and helium nuclei called protons and alpha-particles and an equal number of electrons. This makes up the solar wind. This solar wind travels straight out from the sun at about 800,000 miles per hour, plus or minus a few hundred thousand depending upon solar conditions. In addition to the solar wind, solar events known as solar flares and coronal mass ejections emit high energy solar particles that can impact spacecraft components. These particles can travel near the speed of light.

At the near-Earth environment, the solar wind first encounters the magnetic field of the Earth (the geomagnetic field) at about a million miles between the Earth and the sun. This creates a teardrop shaped magnetic shell surrounding the globe called the magnetosphere. This shell is formed due to the balance between the Earth's magnetic field pressure and the pressure exerted by the solar wind. The tail of this shell extends many millions of miles away from the sun. Contained within the magnetosphere are the radiation belts (Van Allen Belts) and other radiation phenomena that can affect spacecraft components. Down closer to Earth's the upper atmosphere and "ionized" upper atmosphere called the "ionosphere" exists from about 1000 miles altitude down to about 50 miles.

Figure 3 illustrates the complexity of this environment in the context of low-earth orbit (LEO), medium earth orbit (MEO), geosynchronous orbit (GEO) and highly elliptical orbit (HEO) satellites. High above the Earth, the figure shows a color cross section of the inner (1500-8000 miles altitude—just outside most LEO satellite orbits) and outer radiation belts (8000-25,000 miles altitude—affects MEO) above the earth. The variation in colors on the globe is meant to illustrate variations in conditions within the ionosphere and upper atmosphere.

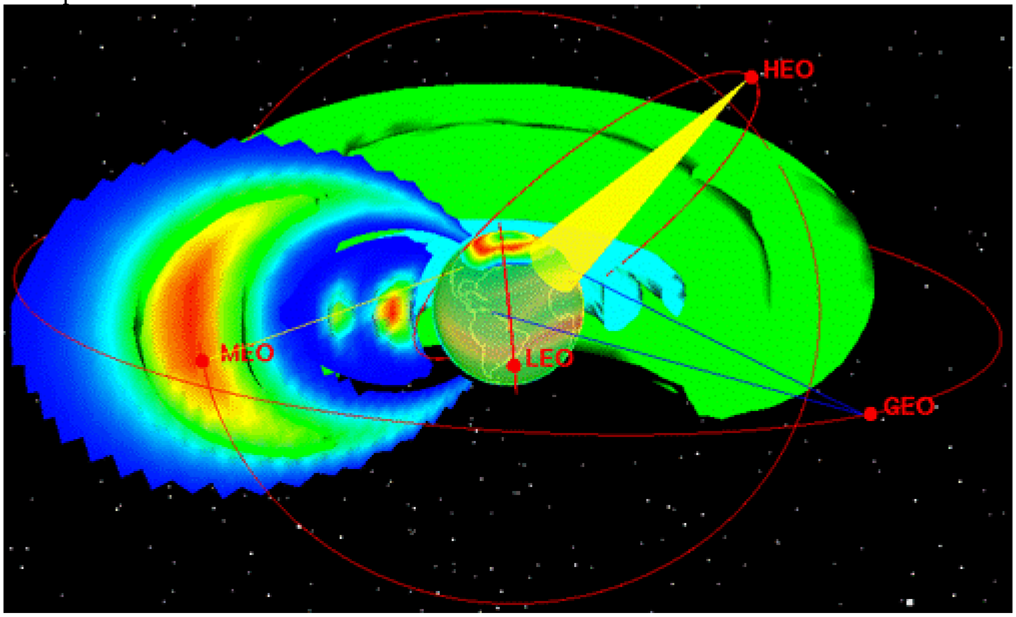


Fig. 3. Cross section of the inner and outer radiation belts, as well as the types of satellite orbits.

Low Earth Orbiting (LEO) satellites such as the Defense Meteorological Satellite Program (DMSP) operate though the upper atmosphere (at about 600 miles) and are affected by atmospheric drag and sometimes trapped and solar particle radiation.. Medium Earth Orbiting (MEO) satellites such as the Global Positioning Satellites (GPS) operate in the Van Allen radiation belts at about 11,000 miles, and are subject to constant bombardment by the highly energetic electrons that populate this region. These particles can cause anomalies in on-board computer systems and degrade inadequately shielded sensors, structures, and materials. Geostationary satellites, like the Defense Satellite Communication System (DSCS) satellites, are at the outside of the radiation belts, but operate in a region where charging and discharging can occur on the surface of the spacecraft. Also, GEO satellites experience effects from highly energetic cosmic and solar radiation not as prevalent at LEO altitudes. Finally, all satellites and some ground-base space systems must propagate their radio frequency (RF) signals through the ionosphere to reach terrestrial users. Depending upon the frequency of the radio signal, the ionosphere can significantly degrade the associated weapon system's performance because of the refractive effects of the ionosphere.

Environmental Impacts

Ultimately, it is the environment's effects on space systems that concern us. To effectively determine what environmental information matters to space operations and capabilities, the source of significant environmental effects need to be linked to system effects and, in turn, to associated warfighter impacts. It is the space system program office's responsibility to design space systems to operate within their specific operational environment as determined by their specific mission. But the environment can only be engineered away to a certain degree before additional costs begin to impinge on other priorities, and trades are made depending upon the desired system life time and performance requirements. For example, radiation hardening prevents parts from wearing out prematurely in the space environment, but add weight and, therefore, cost. Satellite Communication (SATCOM) power requirements account for the effects of some terrestrial conditions such as rain rate, but again add weight and complexity. Severe radiation or meteor events may require other means of system protection, such as shuttering or maneuver that can best be enabled by timely and accurate operational, environmental SSA. The table below provides some example linkages between environmental cause, effect, and warfighter impact.

Table 1: Links between environmental cause, effect, and warfighter impact

Space Capability Joint Effect	**Environmental Cause**	**Environmental Effects**	**Warfighter Impacts**
Comms on the Move	**Ionospheric scintillation, ionospheric refraction**	**Degraded/broken communication link, anomalous radio wave propagation**	**Loss of command and control, lives/missions at risk**
Intelligence, Surveillance and Reconnaissance (ISR)	**Upper atmospheric density change, ionospheric refraction and scintillation**	**Inaccurate space object identification and tracking**	**Space object collision (e.g. shuttle), inaccurate enemy space force position**

Missile Intercept	**Aurora, upper atmospheric density change, ionospheric refraction and scintillation**	**Degraded warhead detection and tracking**	**Decreased probability of missile intercept, lives at risk**
Precision Engagement	**Ionospheric scintillation, ionospheric refraction**	**Degraded GPS system performance**	**GPS guided weapons miss target, increased collateral damage/civilian casualties**
Intelligence	**Aurora, upper atmospheric density change, ionospheric refraction and scintillation**	**Decreased intelligence system performance**	**Inaccurate enemy position data**
Spacecraft anomaly assessment	**Solar/Magnetospheric particle radiation, Upper atmospheric density change, ionospheric refraction and scintillation**	**Satellite system anomalies, increased operational downtime of space system**	**Decreased operational space system utility (GPS, Space-Base Infra-Red System (SBIRS), Space Radar (SR), etc.)**
Attack Assessment	**Solar/Magnetosphere particle radiation, auroral, upper atmospheric and ionospheric changes**	**Enemy and friendly weapon system performance degradation**	**Inability to meet attack assessment timelines, inability to distinguish hostile attack from natural effects**

This matrix illustrates the linkages from mission to space environmental condition to system anomaly to warfighter impact from left to right. Ultimately, if we are completely ignorant of environmental stressing effects, the resulting potential warfighter impacts are described in the right hand column. For example, Comms-on-the-Move (OTM) is a capability provided by SATCOM. If space weather interferes with tactical SATCOM at certain times and the user has adequate warning, they can effectively plan for the disruption, switching to terrestrial communication or using more robust SATCOM. Another example is precision engagement. If the accuracy (Circular Error Probable or CEP) for certain GPS aided munitions is affected by space weather, the weapons planners need to know about it in order to more effectively plan for the type of weapon system to be employed—or they might delay the mission in order to avoid potential collateral damage. Still another example is satellite operations and the requirement to unambiguously determine the source of a spacecraft anomaly. For the warfighter, this is especially noticeable if the satellite in question is dedicated to their area of responsibility (AOR) for communications, navigation, weather, or missile warning. Having the ability to rapidly determine the source as environmental not only helps get the system back on line faster, it can also help distinguish from other sources such as hostile attack.

Desired SSA Effects

The desired end state of environmental SSA is the effective application of environmental SSA information—that is, to mitigate negative impacts on and improve performance of our space systems, and exploit potential space environment impacts on enemy systems.

SSA is foundational to the success of the space superiority mission and effectively characterizing environmental effects is a critical part of that foundation. Space superiority operations ensure the continued delivery of space force enhancement to the military campaign, while denying those same advantages to the enemy. When SSA is successfully and sufficiently achieved, the following effects can be achieved:

- Maintenance of Space superiority
- Reduced "Fog of War" for commanders
- Lowered risk of space fratricide
- Rapid assessment of attacks on all blue, gray, or red space systems
- Shortened kill chain and targeting cycle
- Verification of space-related treaty compliance

Figure 4 illustrates desired effects using a satellite anomaly as an example. The circle on the left represents the set of anomalies caused by sources other than the environment. The circle on the right represents anomalies characteristic of the environment. Where there is overlap in characteristic between the two, there is uncertainty (i.e., "fog of war").

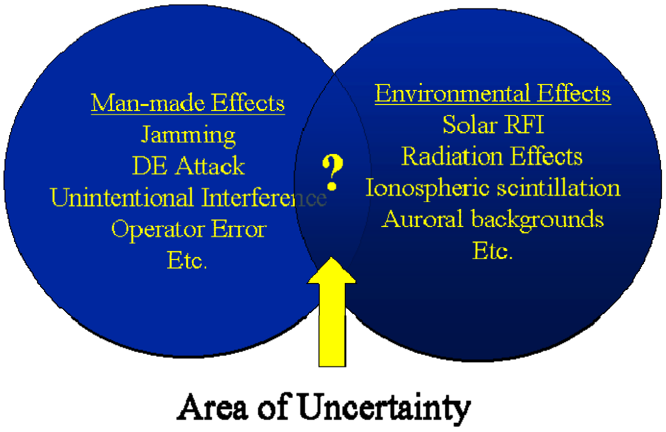


Fig. 4. Desired SSA effects using a satellite anomaly

Ultimately, superior knowledge of both circles will enhance advantages over an adversary from both an offensive and defensive perspective. From a DCS perspective, confirming or eliminating the environment as a factor enables us to respond in a much more effective way to protect our systems. From an offensive perspective, superior knowledge provides potential to exploit environmental effects on enemy space capabilities.

Environmental SSA System of Systems

The list above describes what needs to be done but does not tell how to do it. To understand this, we need to look at what capabilities make up the environmental SSA System of Systems —their current status and how they are envisioned in the future to support space superiority and force enhancement operations. Figure 5 is the Operational View 1 (OV-1) of the SSA architecture. Figure 6 drills down deeper to show the three components of the environmental SSA.

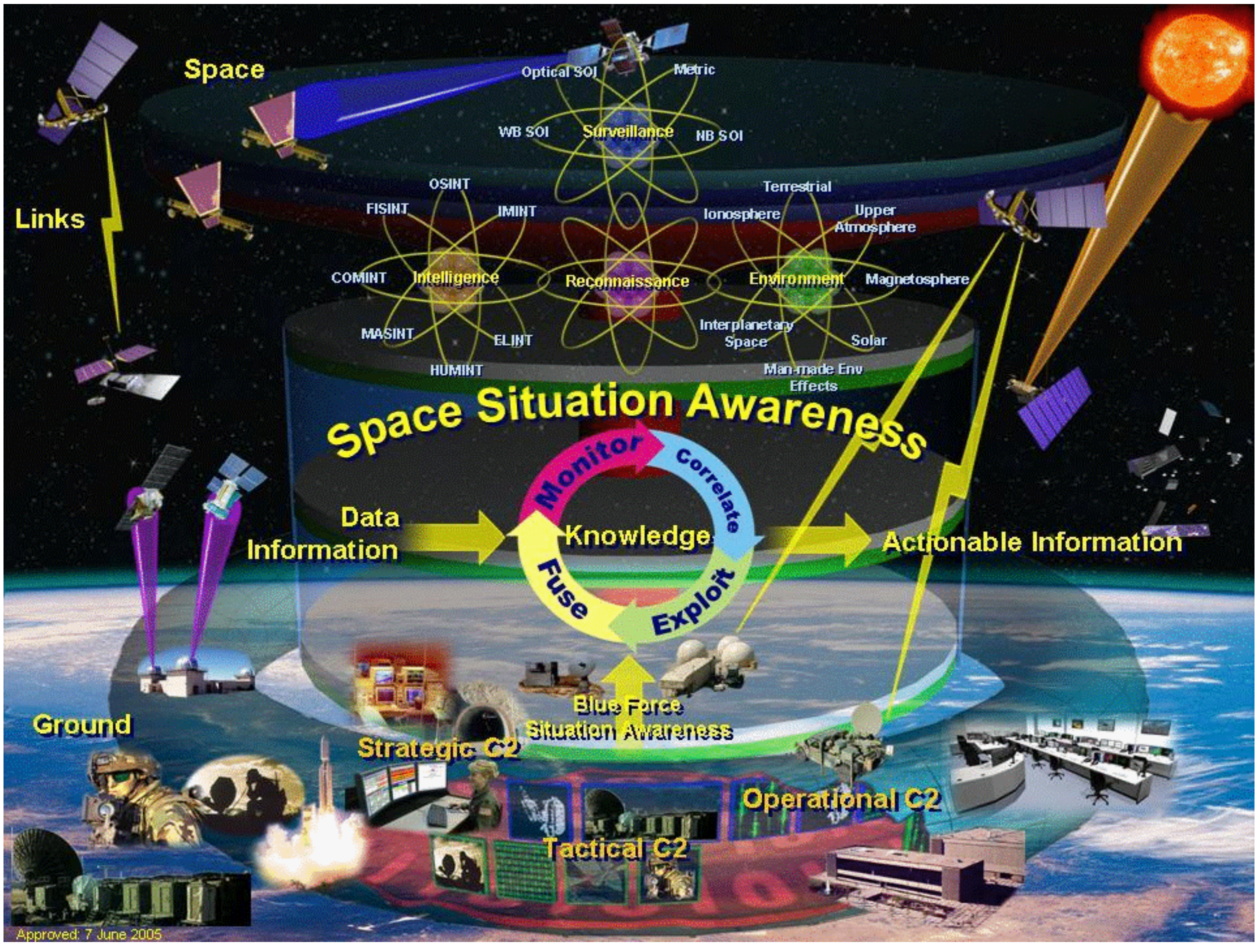


Fig. 5. SSA Operational View (OV-1)

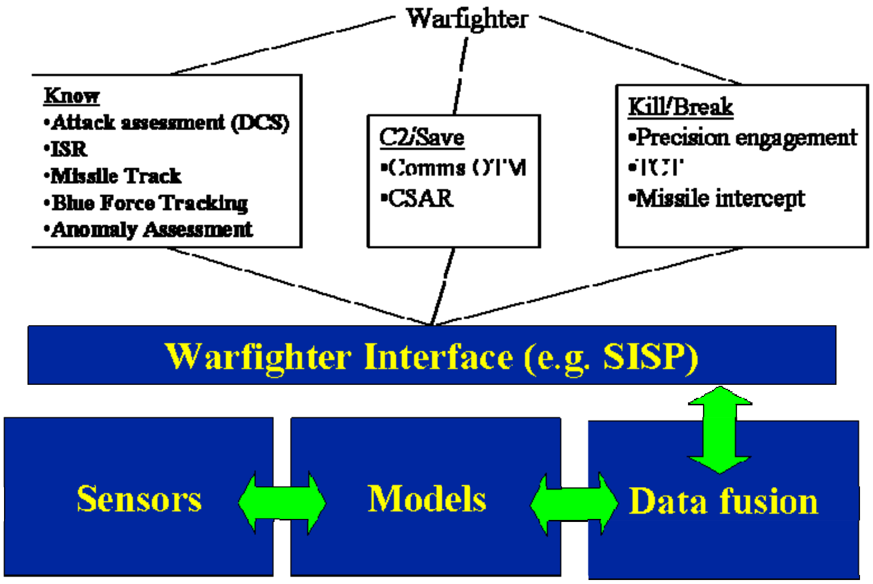
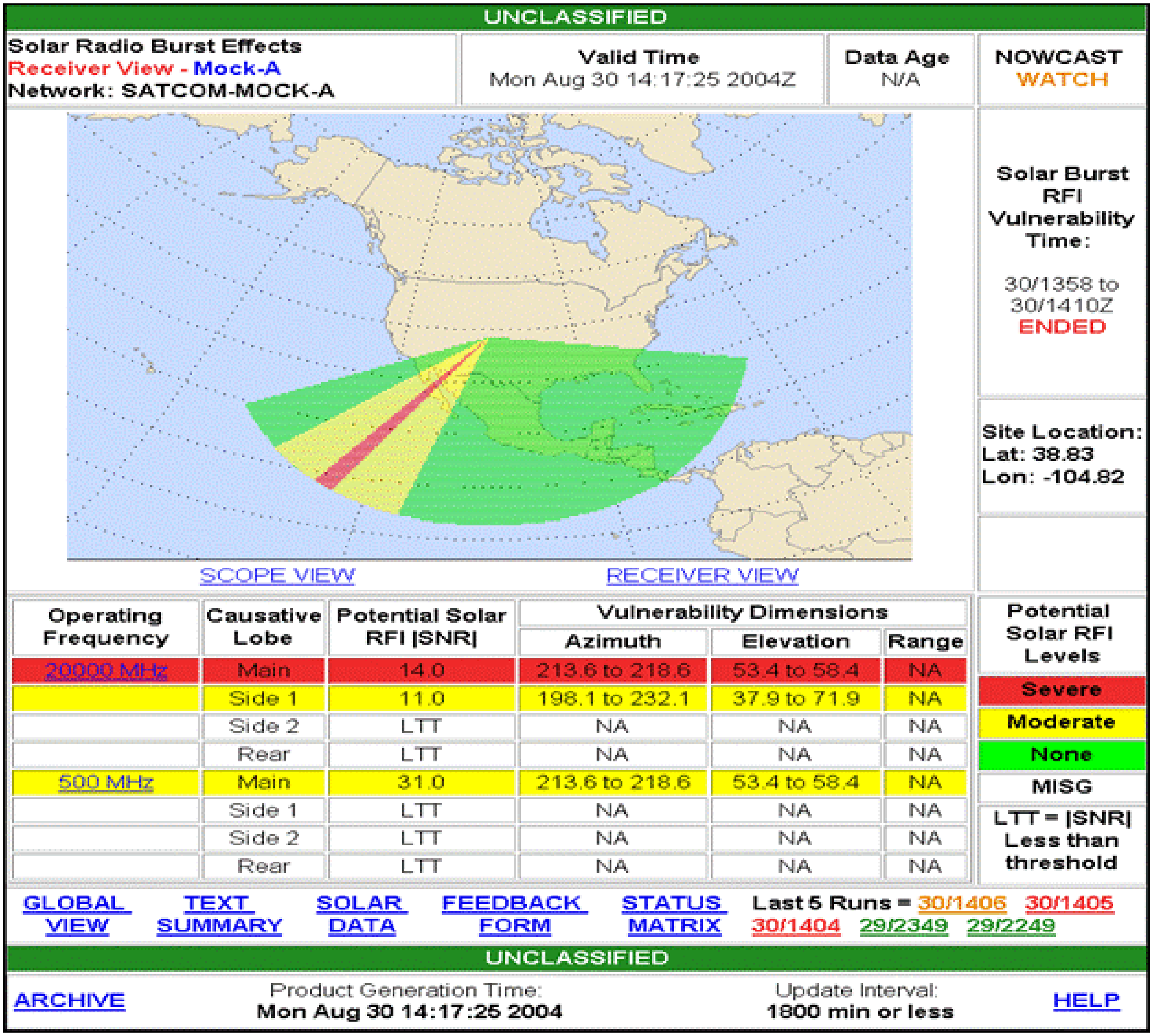


Fig. 6. Environmental SSA Sensor to Shooter Context

Like a three legged stool, all legs are needed in order to meet SSA requirements. AFSPC has analyzed the current and desired state of these three components in the context of SSA task satisfaction. The current state shows a need to develop data fusion capabilities to effectively merge environmental information and system performance parameters in order to objectively characterize and forecast the effects of the environment on space systems and missions. The current program underway to perform this mission is the SSA Environmental Effects Fusion System (SEEFS). This network centric capability takes environmental information and merges it with system performance data (for mock-up see Figure 7), then provides it to the SISP and other network centric user defined systems. In this example, the effects of solar radio noise are merged with SATCOM terminal performance to show the Sun as a source of radio frequency interference (RFI).



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Solar Radio Burst Effects
Receiver View - Mock-A
Network: SATCOM-MOCK-A

Valid Time
Mon Aug 30 14:17:25 2004Z

Data Age
N/A

NOWCAST
WATCH

Solar Burst RFI Vulnerability Time:
30/1358 to 30/1410Z
ENDED

Site Location:
Lat: 38.83
Lon: -104.82

SCOPE VIEW   RECEIVER VIEW

Operating Frequency	Causative Lobe	Potential Solar RFI |SNR|	Vulnerability Dimensions		
			Azimuth	Elevation	Range
20000 MHz	Main	14.0	213.6 to 218.6	53.4 to 58.4	NA
	Side 1	11.0	198.1 to 232.1	37.9 to 71.9	NA
	Side 2	LTT	NA	NA	NA
	Rear	LTT	NA	NA	NA
500 MHz	Main	31.0	213.6 to 218.6	53.4 to 58.4	NA
	Side 1	LTT	NA	NA	NA
	Side 2	LTT	NA	NA	NA
	Rear	LTT	NA	NA	NA

Potential Solar RFI Levels
Severe
Moderate
None
MISG
LTT = |SNR| Less than threshold

GLOBAL VIEW   TEXT SUMMARY   SOLAR DATA   FEEDBACK FORM   STATUS MATRIX   **Last 5 Runs =** 30/1406 30/1405 30/1404 29/2349 29/2249

UNCLASSIFIED

ARCHIVE   Product Generation Time: **Mon Aug 30 14:17:25 2004**   Update Interval: **1800 min or less**   HELP

Fig. 7. SATCOM RFI Analysis Display

Referring back to Figures 1 and 6, information like this can be used at the tactical and operational level. At the tactical level, one could objectively analyze equipment RFI issues. At the operational level this information could be aggregated from many users or operators to identify trends and potential vulnerabilities. Figure 7 is only one example of the capabilities SEEFS will bring. SEEFS will provide analogous support to example space capabilities and systems illustrated in Table 1.

Conclusion

Because of the criticality of joint space effects to successful military operations, our adversaries will seek ways to degrade or destroy our space capabilities and ways to enhance their space capabilities. This elevates the importance of SSA within space superiority and makes its directly analogous to situational awareness for air superiority. Although not as well appreciated, environmental effects on space superiority must be on our radar screen. AFSPC is addressing this concern through careful analysis and is equipping our forces with the kind of environmental effects information that is relevant to maintaining and improving desired joint space effects.

References:

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