CONCEPTUAL ARCHITECTURE TO MEASURE THE EFFECTS OF SUBAURORAL POLARIZATION STREAMS ON RADAR OPERATIONS

THESIS

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Abstract

This thesis provides the initial conceptual development of taking into account subauroral polarization streams when preparing for a radar operation. The DoDAF views created to portray the architecture consisted of operational, capabilities, data and information, and finally system views to ensure consistency and realistic outcomes. OV-2 was the significant view because it set the baseline for required actions necessary for the proposed results the Flow Integration of Ionospheric Activity & Radar Evaluation (FIIARE) system would produce. FIIARE is a computer based system concept that performs consolidations and produce predictions using algorithms from the International Reference Ionosphere (IRI). The data portrayed in the views would come from National Oceanic Atmospheric Administration and Super Dual Auroral Radar Network (SuperDARN). Data from both agencies would then be utilized in the FIIARE system to prepare the radar operators for calibrating the radar to perform in any area of responsibility (AOR). The overall purpose of this thesis is to develop the initial concept of deciding whether SAPS cause clutter during radar operations. There is a negative impact on the mission due to clutter that SAPS could cause in a 24-hour period. To get better data and estimate how much SAPS effects radar operations, the execution of over the horizon radars and documentation of clutter should use the high-level architecture as a baseline.

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Shayla K. Redmond

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CONCEPTUAL ARCHITECTURE TO MEASURE THE EFFECTS OF SUBAURORAL POLARIZATION STREAMS ON RADAR OPERATIONS

I. Introduction

1.1 General Issue

Radar is a big part of what is used to observe the world around us. There are operations, military and non-military, that use radio wave information from the radar system and give the user what they need, often situational awareness of natural or man-made objects' range, direction and cross area. The focus for this thesis will be to provide guidance for radar operations to help account for clutter and degraded data caused by subauroral polarization streams (SAPS).

1.2 Problem Statement

The way the Earth's ionosphere protects us from the sun also causes interference in our daily operations involving radar. We know that weather and vegetation in certain areas can obstruct radar signals (Toomay, 2004). There may be instances where we have clear sky and flat land, but still there is radar clutter. There are auroral occurrences that occur on the sunward side of the Earth near the equator. These occurrences are called subauroral polarizations streams and with these phenomena comes an electric field (Foster & Burke, 2002) that could be the reason for the unexplained radar issues around the world. With advanced technologies, there needs to be a way to correlate interference from our atmosphere to radar operations.

1.3 Research Objective

The goal is to develop an improved radar system architecture that utilizes data from the Super Dual Auroral Radar Network (SuperDARN) and identifies other space weather systems needed to predict how much SAPS affect radar operations. The inclusion of SAPS data could improve the ionosphere prediction models that would contribute to correlating the level of electric field activity to the type of interference.

There are many nuances that occur because of space and terrestrial weather that can degrade operational objectives. The idea is once there is a system in place that can measure the effects SAPS will have on radar operations beyond the horizon, then preventative measures and work-arounds can be established to better equip the user for day-to-day operations that involve radar. While there are many radar systems that utilize a wide variety of radio frequency bands, this research will focus on the High Frequency (HF) band utilized by Over the Horizon (OTH) radar systems.

1.4 Investigative Questions

1. What are the current capabilities that we have to measure SAPS, and how can we use those measurements to correlate with radar effects?
2. What kinds of common equipment/technology are needed to support SAPS for radar measurements?
3. Who will have access to the data from the architecture?
4. How will the data flow among different users, and what data will be available/restricted?

5. How will radar operations benefit from improved definition of ionospheric disturbances?
6. What improvements does SAPS contribute to clutter mitigation methods?

1.5 Methodology

First, an overall operational model of the general flow of information will be established by using concepts from system architecture and the use of the DoD Architecture Framework (DoDAF). After mapping current capabilities, new concepts will be shown in this architecture. The conceptual design of the information flow of SAPS data to radar activity needed for various operations will be portrayed in a systems model to show all parts involved in the measurements. The degree of radar interference due to atmospheric effects, could be used to develop the correlation of the electric field created by SAPS and its effect on other parts of the atmosphere in relation to radar distortion. During the development any limitations that may arise could shed light on what is needed to have a more precise system. This architecture will establish the basis for developing such a system. Finally, mission impact SAPS clutter could have on radar operations will be examined briefly.

1.6 Assumptions/Limitations

With this concept there are some assumptions that need to be established. The limitation of ground clutter will not be considered in developing the architecture so the focus of this thesis can remain on the ionosphere clutter issues. This thesis will assume trained radar operators and imagery analysts who know how to decipher the data given by the radar. The assumption of sunspot correlation to ionospheric activity will be included into the prediction algorithms. Another issue is the SuperDARN has a line of sight (LOS) limitation that prevents worldwide coverage (Nagano 2015).

II. Background

2.1 Chapter Overview

In order to really understand the changes that take place in the atmosphere when SAPS occur and their effects on radar, we have to take a look where the SAPS phenomena originate. Space weather begins with events on the Sun, such as solar flares. This chapter reviews key concepts including the effects solar flares have on the atmosphere, general radar operations, and the equipment that could be utilized to relate SAPS and radar.

2.2 Solar Flares

A solar flare is a sudden and hard-to-predict explosion in the layers of the Sun that can eject charged particles. Flares can release energy across the whole of the electromagnetic spectrum, especially x-rays and gamma rays, and they eject energetic charged particles (protons and electrons) into the solar system. An example of this explosion is shown in Figure 1. Solar flares contribute to space weather, which ultimately affects our life on Earth (Pisacane, 2008).

Figure 1. A Solar Eruption (Courtesy: NASA)

Space weather is continuously monitored in order to predict the outcome of day-to-day operations. It is necessary to pay close attention to solar flares due to the damage they could cause to communications on Earth. One of the contribution's interactions of the charged material with Earth's magnetosphere is auroras that occur near the north and south poles (Pisacane, 2008). In Figure 2 an aurora captured from space is provided (NASA).

Figure 2: NASA astronaut Scott Kelly captured this photograph of the green lights of the aurora from the International Space Station on Oct. 7, 2015. (Courtesy: NASA)

2.3 The Magnetosphere and Ionosphere

The magnetosphere is the region surrounding a planet above the surface where its magnetic field affects the motion of charged particles. This region is formed by the interaction of the solar wind augmented by space weather as it comes in contact with the planet's magnetic field (Pisacane, 2008). It acts like a protective force field preventing the energetic particles from directly interacting with Earth's atmosphere. One of the mechanisms for solar wind energy and mass transfer depends on whether the interplanetary magnetic field (IMF) has a northward or southward direction (Pisacane, 2008). There is a dayside magnetopause reconnection (DMR) that drives a two-cell convection caused by southward IMF as shown in Figure 3 (Goldstein 2005).

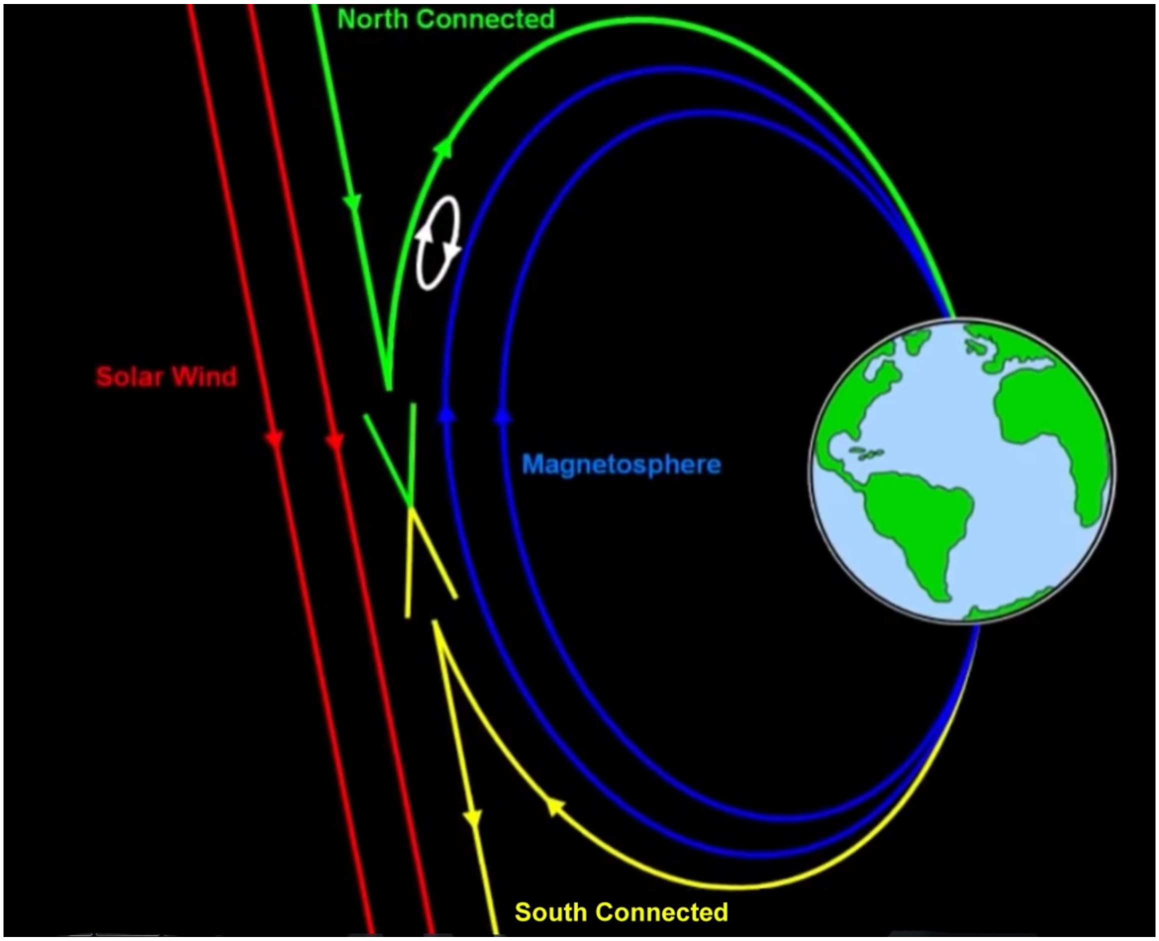

Figure 3: Solar Wind Energy Transfer (Goldstein, 2005)

The ionosphere is an ionized region of the atmosphere at altitudes ranging from about 50 km to about 600 km during the day and starting from 80 km in altitude at night. Solar wind coupling to the magnetosphere triggers particle precipitation into the high-latitude ionosphere (Pisacane, 2008). There are 4 regions in the ionosphere in the day and two distinct regions at night.

For a wave to propagate in a plasma, the frequency of the wave must be greater than the electron plasma frequency. Waves with frequency less than the electron plasma frequency will reflect off of the plasma, which is the explanation of radio waves reflecting off of the ionosphere which allows signals over the horizon (Pisacane, 2008). The electron plasma frequency, defined by equation (1), is the natural frequency of oscillation of electrons in a plasma that are displaced relative to the ion background (Pisacane, 2008).

$$f_{pe} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 8.979\sqrt{n_e} \qquad (1)$$

f_{pe} = electron plasma frequency, Hz

m_e = Mass of electron, kg

n_e = Number density of electrons, m^{-3}

e^2 = Elementary charge (charge on a proton), C

ε_0 = Permittivity of free space, $kg^{-1}m^{-3}s^4A^2$

During the day there is the D region which is the bottommost layer extending from about 50 km to 90 km and often disappears at sunset. The usual maximum electron density for the D region is on the order of $10^9\ m^{-3}$ during the day and several orders of magnitude less at night. Depending on the season the D region may disappear at night altogether. The critical frequencies for the day and night are described in equations (2) and (3) respectively. (Pisacane, 2008).

$$f_{pe,D}|_{day} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 8.979\sqrt{n_e} = 8.979\sqrt{10^9} \approx 0.3\ MHz \qquad (2)$$

$$f_{pe,D}|_{night} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 8.979\sqrt{n_e} = 8.979\sqrt{10^2} \approx 90\ Hz \qquad (3)$$

The second region is known as the E region which has the altitude from about 90 to 150 km above the earth surface. After the sun sets, the electron density decreases because the primary source of the ionization no longer exists. The usual electron density of the peak has a maximum on the order of $10^{11}\ m^{-3}$ during the day and two orders of magnitude less at night. The critical frequencies during the day and night are shown in equations (4) and (5) (Pisacane, 2008).

$$f_{pe,E}|_{day} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 8.979\sqrt{n_e} = 8.979\sqrt{10^{11}} \approx 3\ MHz \quad (4)$$

$$f_{pe,E}|_{night} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 8.979\sqrt{n_e} = 8.979\sqrt{2 \times 10^{9}} \approx 0.4\ MHz \quad (5)$$

The D region of the ionosphere almost disappearing at night and the height increase of the E layer allow for the nighttime increase of range for radio waves to travel by reflection (Pisacane, 2008).

The final region known as the F region has an altitude of about 120 to 1000 km above the earth surface. During the day there are two distinct layers known as F1 and F2 with F2 having a greater electron density than F1. At night the two peaks coalesce into one. The F1 peak is usually at about 180 km with electron density of about 2-5 $\times 10^{11}$ m^{-3} during the day and night it often disappears. The F2 layer peaks around 300 to 350 km with electron density about 1-2 $\times 10^{12}\ m^{-3}$ during the day and about one order of magnitude lower at night. The critical frequencies during the day and night are described in equations (6) and (7) (Pisacane, 2008).

$$f_{pe,F2}|_{day} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 8.979\sqrt{n_e} = 8.979\sqrt{1.5 \times 10^{12}} \approx 11\ MHz \quad (6)$$

$$f_{pe,F2}|_{night} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 8.979\sqrt{n_e} = 8.979\sqrt{2.5 \times 10^{11}} \approx 4.5\ MHz \qquad (7)$$

Geomagnetic field lines convect from sunward to tailward throughout the magnetosphere. The plasma flows across the geomagnetic field lines that collide in the regions of the ionosphere due to field-aligned currents (FAC) that are developed whenever the perpendicular currents and the convection electric field have a nonzero divergence. Figure 4 shows the typical distribution of FAC which is an important coupling mechanism and forms the high-latitude phenomenon known as the aurora (Pisacane, 2008).

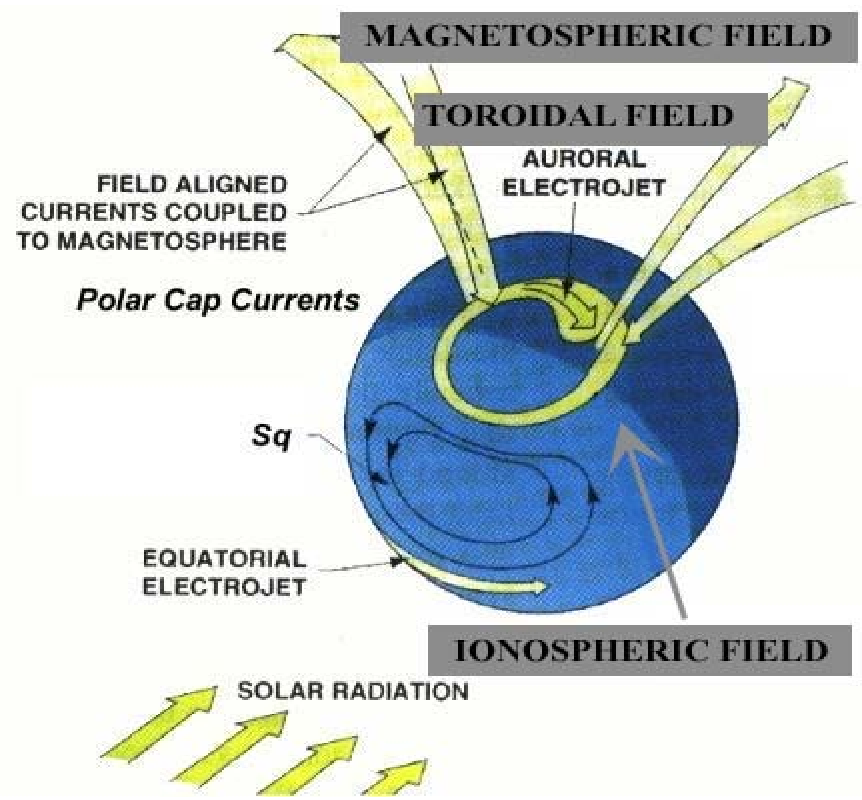

Figure 4: Field-Aligned Currents (FAC) (Courtesy: NASA)

2.4 Subauroral Polarization Streams (SAPS)

SAPS represent rapid westward (sunward) plasma flows located equatorward of the auroral oval predominantly at 1600-0000 magnetic local time (MLT) (Wang, 2008). They can change ionospheric composition (Anderson, 1991), lead to storm-enhanced density and plasmaspheric plumes (Foster, 2002), produce very large field-aligned vertical flows (Anderson 1991), and form F region density troughs (Spiro, 1978). The SAPS location is the result of the interaction of the regional shielding electric field and the large scale convection electric field (Ebihara, 2004).

Electric field and particle population during geomagnetic disturbances give rise to the auroral region expanding equatorward (Foster 2002). The energy of the electrically charged particles depends on the intensity of the solar wind. Sometimes during intense solar storms the wind can be seen at lower latitudes further from the magnetic poles. From polar orbiting satellite observations subauroral ion drifts (SAID) (Smiddy, 1977), is seen westward convection with magnitude in excess of 500 m/s (Foster, 2002). Foster and Burke (2002) introduced the term sub-auroral polarizations stream (SAPS) to encompass both types of observations of the subauroral electric fields, the SAID/ polarization jet structures and the broader regions described by Yeh (1991).

The $\boldsymbol{E} \times \boldsymbol{B}$ drift velocity is caused by the electric field $\vec{\boldsymbol{E}}$ (electric field vector) being perpendicular to the magnetic field lines $\vec{\boldsymbol{B}}$ (magnetic field vector) (Pisacane, 2008). The independent observations of line of sight plasma $\boldsymbol{E} \times \boldsymbol{B}$ velocity from all Millstone Hill azimuth scans over a 20-year interval were screened for bad data and were corrected with a magnetic direction cosine factor to yield the westward component of the flow (Foster 2002). The L-shell is the radial distance shown in Figure 5 of the field line from the axis at the geomagnetic equator in units of Earth-radii (Pisacane, 2008). The Figure depicts earth as a black circle and the L=2, 4 and 6 shells plotted in blue intersecting the Earth's surface at different geomagnetic latitudes. They (Foster, 2002) assumed that the sub-auroral flow is basically L-shell aligned in the region of interest. The magnitude of the westward ion velocity was proportional to the poleward-directed component of the electric field in the F region (Foster, 2002).

The Kp index is the global geomagnetic storm index and is based on three-hour measurements of the K indices with a characteristic integer in the range of 0-9 with 1 being calm and 5 or more indicating a geomagnetic storm. The Kp index is the mean standardization of K index, which is a three-hour-long quasi-logarithmic local index of 13 geomagnetic observations at midlatitudes between 44^o and 60^o northern or southern geomagnetic latitudes, relative to a calm day curve for a given location (Pisacane, 2008). Foster processed nearly two complete solar cycles of data (1978 to 2000) to yield a database of approximately 1.4 million ion velocity measurements for Kp > 2 conditions, each identified by date, magnetic latitude, local time, and activity level (Foster, 2002).

All scans for Kp > 2 were investigated and SAPS were identified in more than 1300 cases (Foster, 2002). Magnetic local time (MLT) indicates the orientation of the Earth relative to the Sun. MLT=12 (noon) is the side facing the sun and MLT=0 (=24) facing the "night side" away from the Sun. The shape of the magnetic environment of the Earth is what we know to be the magnetosphere. Few occurrences of SAPS can be found for Kp < 2 and there are very few occurrences of SAPS in the sunlit sector between 0800 (MLT) and 1600 MLT (Foster, 2002). SAPS was defined as a clearly identifiable region of westward ion convection velocity at or equatorward of the low-latitude edge of the auroral two-cell region (Foster, 2002). The geophysical or space weather significance of SAPS depends on the strength and extent of its effects, and on its probability of occurrence (Foster, 2002). Millstone Hill data was used as a set to investigate occurrence probability (Foster, 2002). For a limited range of Kp they determined the probability of SAPS occurrence as a function of latitude and MLT. SAPS occurrence probability exceeds 30% in the pre-midnight sector (1900 MLT - 2300 MLT) near 57˚magnetic latitude, and in the post-midnight sector near 52˚magnetic latitude (Foster, 2002).

Both SAPS and SAID are associated with magnetosphere-ionosphere coupling and ionospheric feedback in the region where FAC attempt to close across the subauroral ionosphere (Foster, 2002). Subauroral electric fields play critical roles in energizing and transporting ring current ions as well as convecting thermal plasma in the inner magnetosphere and in the mid to low latitude ionosphere (Foster, 2002). The subauroral polarization stream, in varying levels of intensity and spatial extent, is seen as a persistent and effectively permanent feature of the disturbed nightside convection pattern (Foster 2002). Just as the narrow SAID are associated with deep nighttime ionospheric troughs (e.g. Anderson, 1991), Foster (1994) depicts how SAPS spans the lower ionosphere conductivity region between the equatorward edge of plasma sheet particle precipitation and the plasmapause. The position, extent, and intensity of the subauroral electric field and ion convection within the SAPS vary with changing solar activity. In the pre-midnight sector, the SAPS westward convection lies equatorward of L=4 intersection of the Earth's surface, spans 3˚- 5˚of latitude, and has an average peak amplitude of 1000 m/s. In the pre-dawn sector, SAPS is seen as a region of antisunward convection equatorward of L=3 intersection of the Earth's surface, spanning ~3˚of latitude, with an average peak amplitude of 400 m/s. Figure 6 is a depiction of Millstone Hill ISR and simultaneous Defense Meteorological Satellite Program (DMSP), which is the DoD's monitoring program of meteors, oceans, and solar terrestrial physics, passing across the subauroral polarization stream at 20 MLT. SAPS appears as a region of strong westward ion velocity, equatorward of the auroral 2-cell convection and coincident with a deep ionospheric trough. Region 1 (R1) and Region 2 (R2) field aligned currents have been determined using the DMSP magnetometer (not shown). (Foster and Burke, 2002).

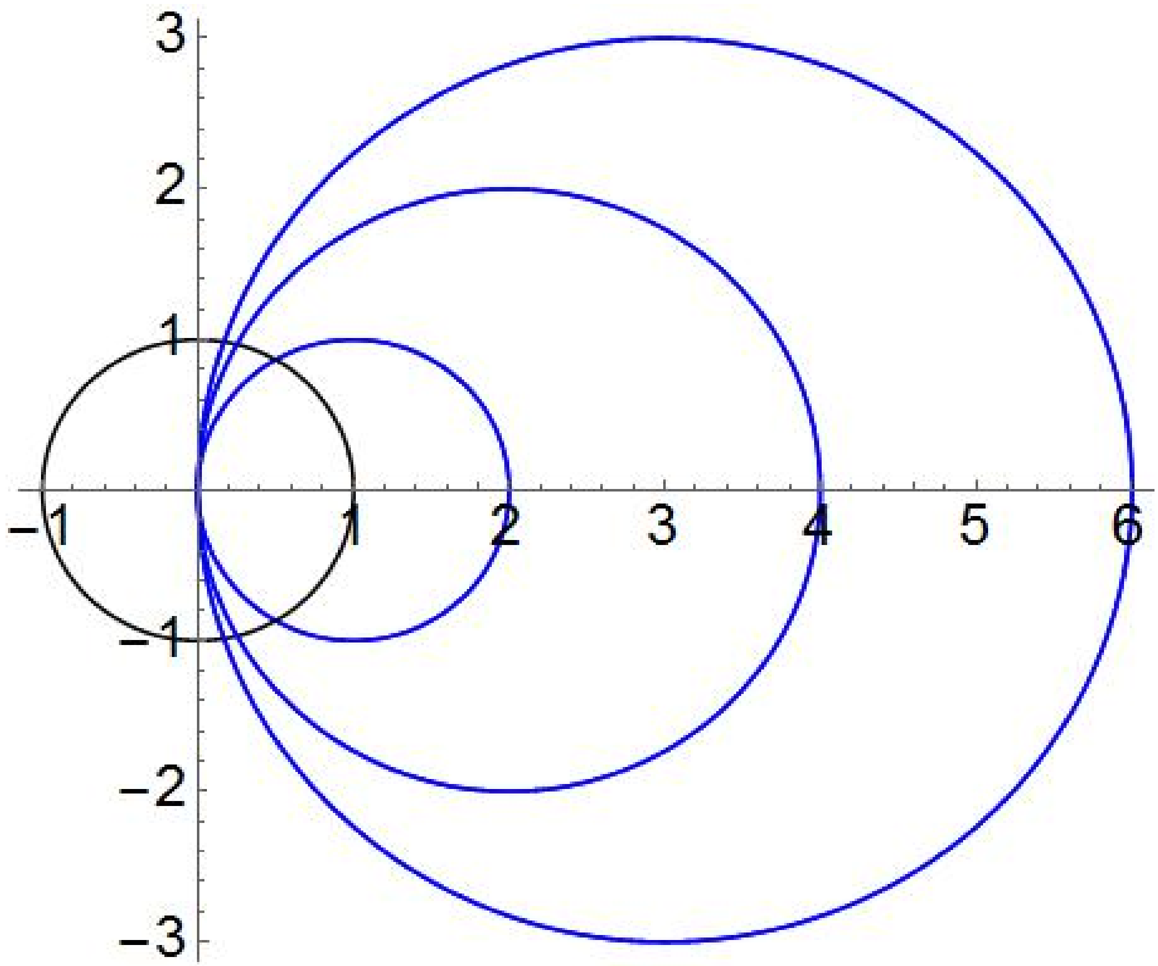

Figure 5: Mcllwain Parameter

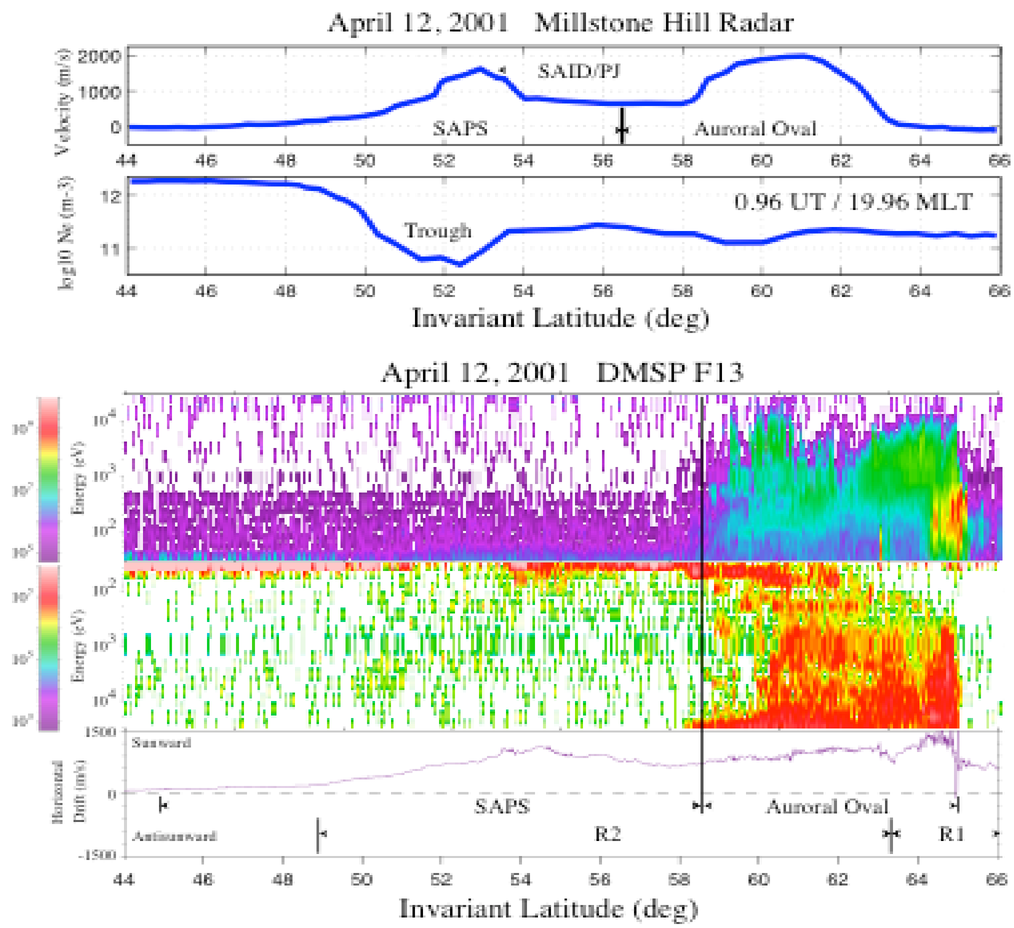

Figure 6: Millstone Hill ISR and simultaneous DMSP SAPS Data (Foster and Burke, 2002).

2.5 Radar

Radar is short for Radio Detecting And Ranging. Radar uses electronic principles similar to sound waves to detect objects of interest. In this case radio frequency radiation is transmitted using electromagnetic energy pulses and reflected from the object of interest. A portion of the energy is returned to the radar system set. The return is called an echo. The radar system uses the echo to determine direction and distance of the reflecting object by use of a highly sensitive receiver. Modern radars are used to measure range and angle. The level of frequency is from High Frequency (HF) to well beyond Ultra High Frequency (UHF).

In this discussion we will focus on the HF level because that is where OTH radar operates for ionosphere propagation and exploitation. The radar transmitter produces short-duration high-power radio frequency pulses. The antenna transmits signals with the required distribution and efficiency as electromagnetic waves traveling at the speed of light. The wave travels in a straight line with a constant velocity and is reflected by the object of interest. The antenna receives the back-scattered echo signals and during reception the duplexer leads the weaker echo signals to the receiver. The hypersensitive receiver amplifies and demodulates the receiver radio frequency signals turning the signals into whatever data that is programmed for the output. The output should be a continuous, easily understandable, graphic picture for the relative position of where the radar hit. All objects produce a diffuse reflection, which means it is reflected in a wide number of directions. Backscatter is the term given to reflections in the opposite direction to the incident rays. Radar signals can be displayed on the traditional plan position indicator (PPI) or other more advanced radar display systems. A PPI has a rotating vector with the radar at the origin, which indicates the pointing direction of the antenna and hence the bearing of targets. It shows a map-like picture of the area covered by the radar beam (Toomay, 2004).

Radar can operate beyond the horizon because of the environment of the ionosphere. Under proper conditions radio waves entering the ionosphere will be refracted back toward earth, possibly thousands of miles away from the transmitting antenna (Toomay, 2004). The component of this phenomenon is the way radio waves are bent. The electron density of ionization and the frequency of the wave influence the "bend". With all other conditions being constant, bending will increase with higher ionization density or decreases as the frequency goes up. The situation becomes ideal for a wave to be refracted back to earth when both conditions work simultaneously together. Another important factor that depends on the ionosphere is wave angle. At the wave critical angle it will return back to earth depending on various conditions (Toomay, 2004).

2.6 Clutter

Clutter is considered to be an undesired impact for a specific application (Brooker, 2006). There are many forms of clutter that contribute to the interference of radar systems that operate today focusing on over the horizon radars: Ground clutter, surface clutter, and atmospheric clutter, just to name a few. The focus of this paper will be clutter coming from the Earth's atmosphere. The direct reflections from ionospheric irregularities causes the clutter background of over-the-horizon radars (OTH) (Lauer, 1998). Ionospheric motion causes spreading of surface clutter in Doppler space which fundamentally limits the detection performance for skywave HF OTH radars.

Doppler clutter is defined as the surface scattering within the same range resolution cell as the target (Harmanci, 1997). There are different forms of Doppler clutter that are defined by mechanisms that cause it. "Separated clutter" is often seen during normal midlatitude OTH radar operations where the first-hop ionosphere is processed correctly but the range–folded second hop isn't clear because of the path through the disturbed equatorial region. Separated clutter is Doppler spread that causes range ambiguity. This clutter can be mitigated by Wave Form Repetition Frequency (WRF) signals and non-recurrent waveforms. The second type of clutter is “proximate” clutter which causes the signal on the first-hop to return within the same dwell illumination region as the target, but arrives at a different elevation angle. The mitigation technique for this type of clutter is to select a frequency where only single-mode propagation to the desired ground range is supported. The last type of Doppler spread clutter is “coincident” clutter resulting from the spread of ground returns in the same physical resolution cell as the target. It basically obscures the target signal return. A mitigation approach for this type of clutter involves Bragg-line sharpening which deals with coherent and incoherent scattering (Harmanci, 1997). All of the corrective methods rely on the knowledge of the ionosphere and the development of realistic mathematical models for electromagnetic propagation. Because of the electron concentration variations, the refractive index fluctuates causing unexpected backscatters (Jangal, 2006). In the clutter effects model (CLEM) developed by the Mission Research Corporation there is a field-aligned scatter (FAS) piece in their model to account for the semicoherent backscatter from field-aligned ionospheric irregularities (Lauer, 1998). There are many factors that would describe what would contribute to ionospheric characteristics, such as location, season, and time of day. The radar configuration also plays a part in the clutter issue. Radar location, bearing, and frequency agility are needed to compensate for the continual changes that occur in the ionosphere. Propagation of waves through the ionosphere may result in focusing of energy received at a given location. Spread Doppler Clutter (SDC) comes from the scattering of the propagating HF wave by small-scale ionization structure (Lauer, 1998). A wave undergoes total or partial reflection in the ionospheric plasma when its frequency is equal to the critical or plasma frequency (Röttger, 2004). When the wave frequency is much larger than the plasma frequency, incoherent scatter from thermal motions of free electrons in the ionosphere takes place (Röttger, 2004). For the Mission Research Corporation to model this, the underlying ionization structure has to be known. In order to predict the Doppler spread plasma drift velocities, understanding of plasma structures is needed (Lauer, 1998). The benefits from the development of credible clutter models fall in the category of mitigation, and forecasting. The physical mechanisms for clutter generation needs to become better understood so that signal processing mitigation can be developed to fight against it. One part of the physical makeup of the ionosphere is SAPS, which brings the development of advanced algorithms that could be used to calibrate the radar to perform optimally. SuperDARN radars are optimum instruments to monitor different plasma convection patterns (Röttger, 2004).

2.7 Super Dual Auroral Radar Network (SuperDARN)

SuperDARN is collaboration of institutions in twelve countries. SuperDARN consists of 22 radars in the northern hemisphere and 11 radars in the southern hemisphere, covering the northern and southern high- and mid-latitude regions. Figure 7 shows the antenna layout of the SuperDARN and in Figure 8 the flow of information is described.

Figure 7: SuperDARN Antenna (Nagano Website)

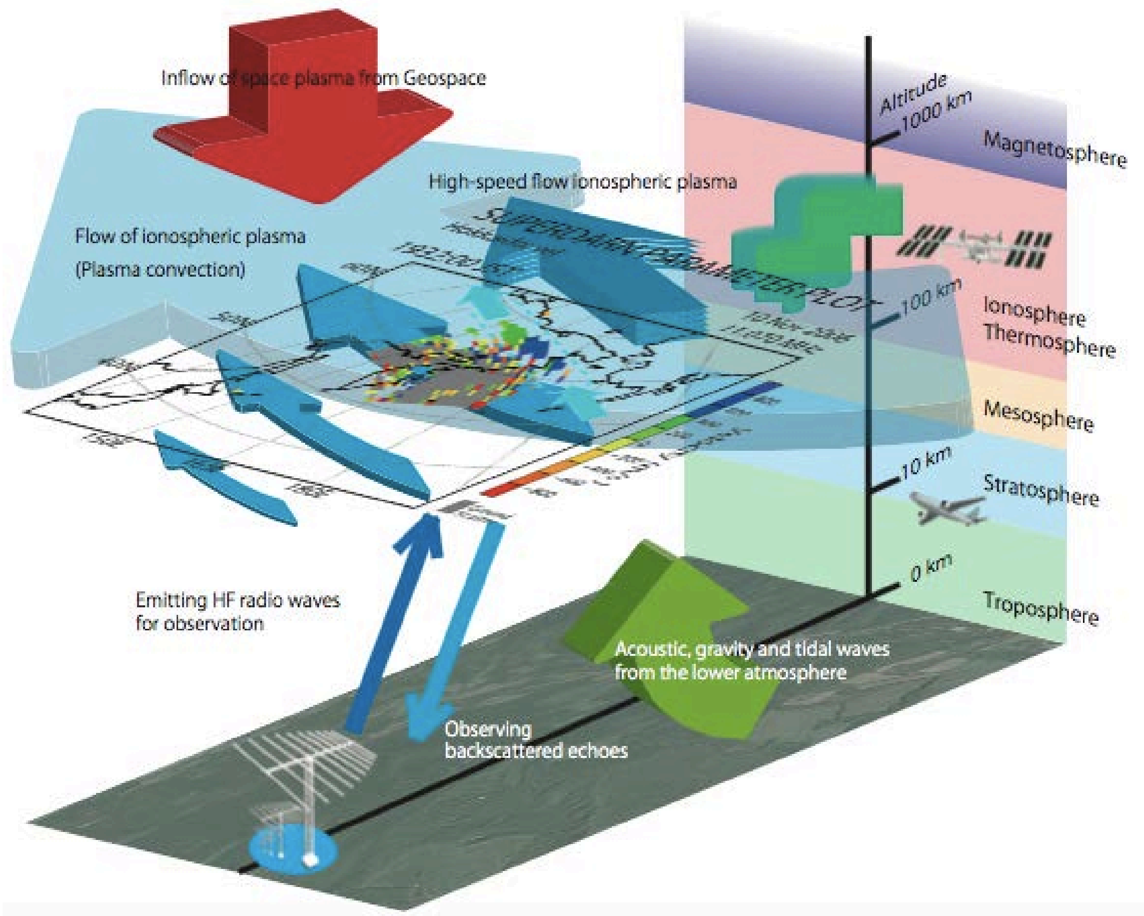

Figure 8: Flow of Data Collection SuperDARN (Nagano Website)

SuperDARN radars operate in the HF band between 8.0 MHz (37m) and 22.0 MHz (14m). In the standard operating mode each radar scans through 16 beams of azimuthal separation of ~3.24°, with a scan taking 1 min to complete (~3 seconds integration per beam). Each beam is divided into 75 (or 100) range gates each 45 km in distance, and so in each full scan the radars each cover 52° in azimuth and over 3000 km in range; an area encompassing the order of 1 million square km.

The main goals of SuperDARN are:

- Structure of global convection—to provide a global-scale view of the configuration of plasma convection in the high-latitude ionosphere
- Dynamics of global convection—to provide a global-scale view of the dynamics of plasma convection in the high-latitude ionosphere.
- Substorms—to test various theories of polar cap expansion and contraction under changing IMF conditions and observe the large-scale response of the night side, e.g., convection pattern to substorms.
- Gravity waves—measurement of gravitationally-induced waves in the atmosphere
- High-latitude plasma structures and ionospheric irregularities; e.g, SAPS characteristics

SuperDARN investigates characteristics of the subauroral polarization stream (SAPS), with focus on the relationship between geomagnetic parameters and occurrence characteristics of SAPS, and is performed using the Super Dual Auroral Radar Network (SuperDARN) Hokkaido East radar, which can observe the Far East region of Russia and has been in operation since 2006 (Nagano, 2015). It should be noted that previous studies have focused on very fast SAPS events and have not discussed the slowest limit of SAPS. The feedback process is considered as an “indispensable” mechanism for generating SAPS (Foster and Burke (2002)). However, past studies focused on the peak velocity of SAPS for data selection and did not confirm the validity of this mechanism. Knowledge of the slowest limit of SAPS could contribute to the clarification of the minimum electric field that generates SAPS, together with its relationship with the feedback process (Nagano, 2015).

A limitation of the radar observation, as well as that of other radars, is that the radar obtains only line-of-sight (LOS) Doppler velocity (Nagano, 2015). Nagano assumed that the LOS velocity toward the radar is due to the westward flows and converted LOS velocity to westward velocity with L-shell fitting that converts LOS direction to L-shell direction. This assumption is based on Makarevich (2011), who used the two-dimensional SuperDARN observation and showed that the direction of SAPS is always westward.

The criteria for choosing westward flows are as follows: (1) The westward speed is over 10.0 m/s. (2) The magnetic latitude of the flow region is 40° to 70°. (3) Echoes identified as ground backscatter using the standard SuperDARN data analysis algorithm (Sundeen, 2004) are excluded from the statistical analysis (Nagano, 2015). Kataoka (2009) used the SuperDARN Hokkaido East radar to perform statistical analysis of the SAPS flows, focusing on 2 years of data for the range of 45° to 65° magnetic latitude and peak velocity of over 1 km/s.

The criteria of Foster and Vo (2002) used a latitudinal range of 45° to 70° and peak velocity of 500–1000 m/s. Wider criteria were used for data selection than in previous studies in order to examine whether there is a lowest threshold of SAPS speed. Next, subauroral region flows were distinguished from auroral oval ones by examining the precipitating energy flux obtained from the total electron detector (TED) onboard the National Oceanic and Atmospheric Administration/Polar Orbiting Environmental Satellites (NOAA/POES) (Nagano, 2015). The lowest results of SAPS speed found from the statistical analysis was at a range of 150–200 m/s. The strength of the electric field that generates the slowest SAPS is calculated from the equation $= \frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2}$. Assuming that magnetic flux density B is 50,000 nT, corresponding to the value at about 55° geomagnetic latitude, the corresponding minimum range of electric field strength is 7.5-10 mV/m. Schunk (1975) performed one-dimensional numerical simulation to estimate the ionospheric parameter changes due to frictional heating and concluded that the electric field should be at least 50 mV/m. The SuperDARN result for the minimum SAPS electric field of 7.5–10 mV/m is not enough to lead to frictional heating that can affect ionospheric plasma density changes (Nagano, 2015).

At first frictional heating was considered as an indispensable mechanism to cause SAPS (Wang and Lühr, 2013). It was later discovered that frictional heating raises the recombination rate and reduces electron density and conductivity, and then SAPS is generated by the electric field that increases in intensity because of current continuity (Nagano, 2015). In other words, "frictional heating is not always necessary to generate SAPS in the framework of the coupled large-scale magnetosphere-ionosphere system", (Nagano, 2015). The low speed limit of SAPS was compared to the low speed limit of the SuperDARN observations by checking the echo power around the limit of SAPS. The result is that the echo power is mostly 3 to 25 dB, well above the noise level (0 dB) around the lowest speed limit of SAPS (250 to 300 m/s); therefore, the lowest speed limit of SAPS is not the lowest speed limit of SuperDARN observation (Nagano, 2015).

2.8 Summary

Solar flares cause space weather that affect the magnetosphere-ionosphere coupling. Space weather phenomena contain material from the sun that interacts with the ionosphere, creating an electric field and producing the auroral oval we often see. Plasma created from the excited particles in the ionosphere near the equator region is known as subauroral polarization streams. How these electric fields affect various radio frequencies is already known. Some correlations between space weather and radar operations are known, but not all. Radar uses the electromagnetic spectrum to identify objects of interest and various information about types of movement or lack thereof. There are many causes of interference, whether internal or external, and the understanding of all possibilities should be exhausted. For OTH radar system Doppler spread caused by ionospheric irregularities is the source of clutter. One possibility of interference when considering over-the-horizon radars is SAPS. The next chapter will cover the method to develop a contribution percentage for the prediction models, conceptual architecture that could measure the effects of SAPS on radar operations beyond the horizon and description of mission impact will be explored. This information could be used to understand how much of an influence SAPS has on radar clutter.

III. Methodology

3.1 Chapter Overview

This chapter will discuss the tools needed for obtaining accurate data on polarization streams and correlating them to radar anomalies. The methodology will include an explanation of the system architecture that could be used to show a conceptual inclusion of SuperDARN to help improve radar operations by measuring space weather effects. Currently, SuperDARN is not a consideration when mission planning for radar operations. A discussion of how this research will go about deciding on the significance of SAPS contribution to ionospheric prediction models will be developed. Finally, a description of how clutter could impact the mission will be presented.

3.2 Sequenced Actions

Before a radar operation event is carried out, companies and government agencies must be capable of integrating with SuperDARN radars that play a key role in measuring SAPS. This includes but is not limited to, data exchange requirements, safety requirements, and information certifications. Once these prerequisites are met:

Operators of over the horizon radar system will conduct pre-mission planning

a. Access National Oceanic and Atmospheric Administration (NOAA)
b. Access SuperDARN radars for information of the area of interest
c. Flow Integration of Ionospheric Activity & Radar Evaluation (FIIARE) will consolidate all pertinent data for area of interest to users as appropriate.

d. Necessary calibrations and adjustments will be made on the radar system to adjust to the ionospheric activity for operation duration
e. During the process the correct frequency management system will be taking appropriate measurements of the ionization level in the ionosphere
f. Ensure all authenticated users are connected to the correct information.
g. Allow real time measurements from radar systems execution to correlate to information with permission planning overlays.
h. Store data in FIIARE for future historical database collection.

3.3 System Architecture

To start the development of logical working systems to provide vital information, a baseline of what is needed must be established. To do this the DODAF views will show requirements mapped to capabilities and operations to various interfaces and flows. With this in place the necessary systems that need to exist will be brought forward. With this information the technology readiness level (TRL) will be evaluated to detect priorities that need focus for future development.

To build a network for mapping requirements to operation execution the DODAF v2.02 will be utilized. Starting with the basic overview of the system through operation and capabilities and ending at systems viewpoints will define the building blocks to produce the system. Table 3 in the appendix shows a chart in association with the All View that provides an overview of the architecture project that will be the baseline for the views and describes all views that will be utilized in the architecture. A big part in the architecture development will be the decision on what the best algorithm to use for the measurement of the ionosphere using data from SAPS and data from NOAA systems.

3.4 Operational View (OV-1)

The view in Figure 9 depicts the interaction of organizations and FIIARE system, showing key information exchanges and primary responsibilities for critical functions that enable planning, launch mission coordination and data storage.

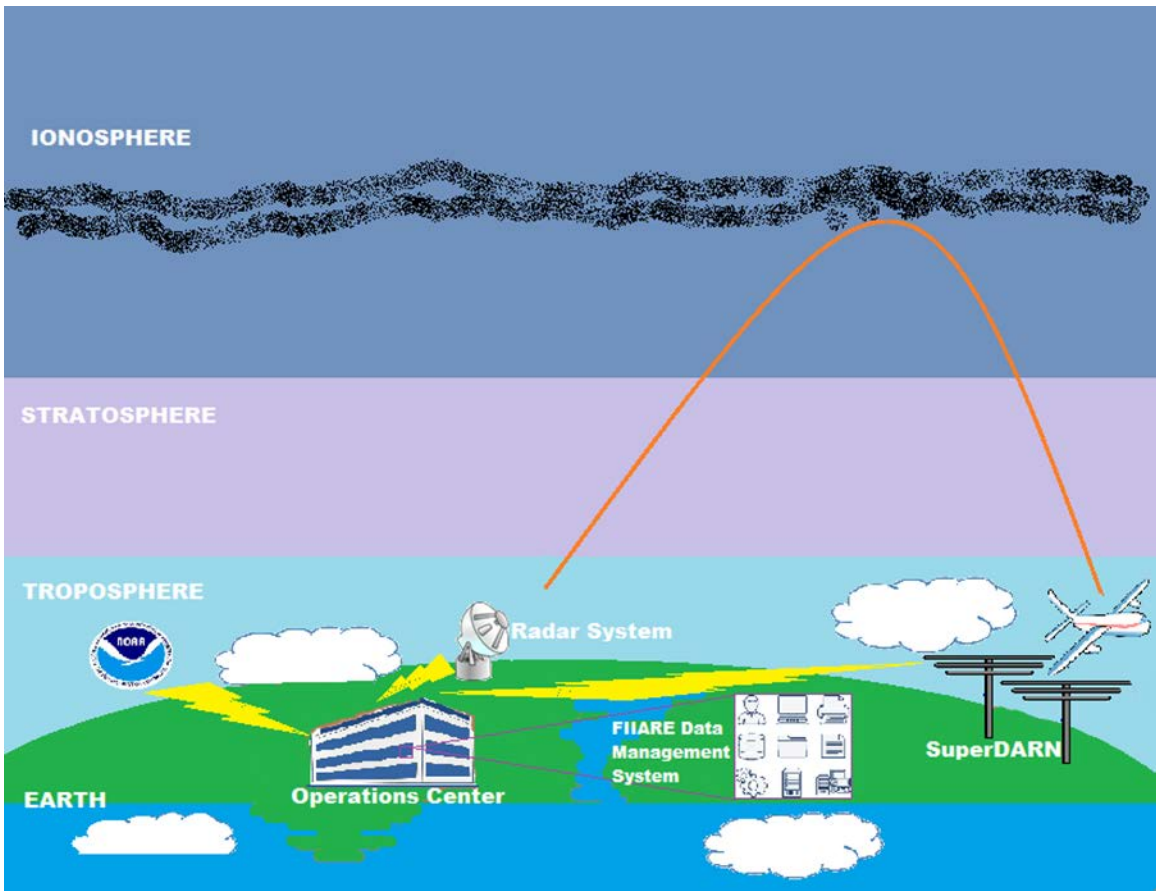

Figure 9: OV-1

After NOAA and SuperDARN information is downloaded into the FIIARE system, the mission planning crew will use that to map out the best calibration to set the radar system as it operates over the horizon. As the proper space weather in correlation to SAPS is predicted the radar operators will also take real-time data information to load into FIIARE system after the mission is complete for data storage.

Prediction procedures will be incorporated into the FIIARE system. Understanding electron density algorithms and the type of predictions needed helps with choosing the best software to use. The International Reference Ionosphere (IRI) is an international software that produces empirical standard model of the ionosphere, from all available data sources. IRI provides monthly averages for the electron density, electron temperature, ion temperature, and ion composition in the altitude range from 50 km to 2000 km. It also provides adjustable Total Election Content (TEC) depending on the height input by the user (“International Reference Ionosphere,” 2016). Some other models do not incorporate the D region, which is necessary to optimize HF propagation. Some models do cover the D region, but do not have multiple sources to confirm correct information. The IRI is the best option because of its capability to cover all regions of the ionosphere and has multiple sources for method development in developing prediction models. Therefore, IRI will be assumed to be a part of the architecture when discussing prediction models.

3.5 Use Cases

The use case diagram in Figure 10 shows the different actors and use cases involved with the system. The desired data being generated will be analyzed by the radar operators. It is important to note that mission planning and debrief are essential to the continual analysis of the ionosphere environment.

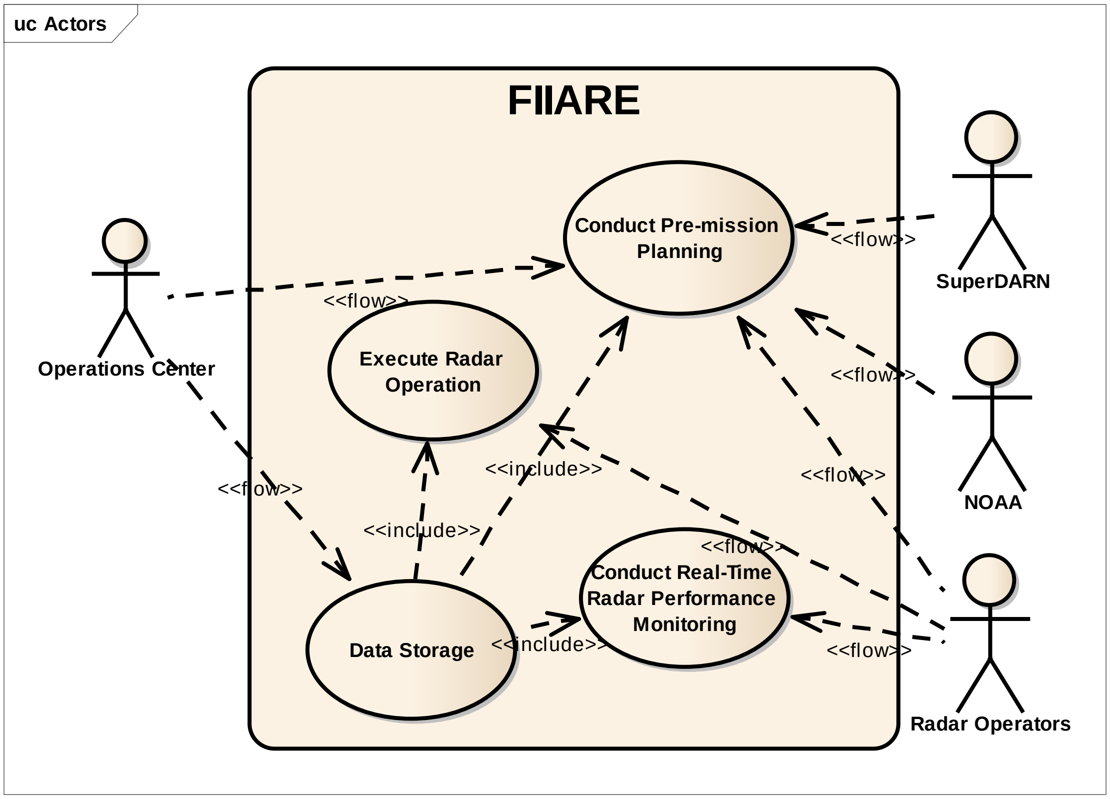

Figure 10: Use Case Diagram

A Use Case 1: Conduct Pre-Mission Planning

A.1 This use case addresses scenarios to adequately plan a mission prior to execution.

B. Actors Involved

B.1 Primary

B.1.1 Radar Operators

B.1.2 FIIARE

B.2 Supporting

B.2.1 Operations Center

B.3 External

B.3.1 National Oceanic and Atmospheric Administration (NOAA)

B.3.2 Super Dual Auroral Radar Network (SuperDARN)

C. Flow of Events

C.1 Basic Flow

C.1.1 Radar operators submits mission window (date/time) to FIIARE system.

C.1.2 Radar operators retrieves NOAA and SuperDARN data from external domain.

C.1.3 Radar operators input data from NOAA, SuperDARN and historical data into the FIIARE System.

C.1.4 FIIARE algorithms output predicted ionospheric activity.

C.1.5 Radar Operators uses FIIARE data to check predicted ionospheric activity in area of interest.

C.1.6 Radar operators uses predicted ionospheric activity to set the calibrations for optimal elevation angle and frequency.

D. Use Case 2: Data Storage

D.1 This use case addresses storing data for a successful ionospheric activity history log in a given location to be used at a later time.

D.1 Basic Flow

D.1.1 The FIIARE System receives Electron Density data from area of interest for the duration of the mission.

D.1.2 The FIIARE system gathers radar performance data from software systems for the duration of the mission.

D.1.3 Radar operators retrieve historical data for area of interest during mission planning.

E. Use Case 3: Execute Radar Operation

E.1. This use case addresses scenarios to complete a successful radar mission.

E.1.1 Basic Flow

E.1.1.1 Radar operators Review FIIARE consolidated data and coordinate calibrations for radar system with operations center.

E.1.1.2 Operations center approves mission plan from data provided.

E.1.1.3 Once mission plan is approved radar operators calibrate radar to optimal elevation angle and frequency based on predicted ionospheric activity of consolidated data of FIIARE.

E.1.1.4 Radar operators initiates mission in area of interest.

E.1.1.5 When mission is complete, Radar operators retrieves FIIARE performance data for area of interest for debrief.

F. Use Case 4: Conduct Real-Time Radar Performance Monitoring

F.1. This use case addresses the performance agility scenarios to compete a successful performance during a radar operation.

F.1.1 Basic Flow

F.1.1.1 During radar operations FIIARE utilizes an agility algorithm to continue to update optimal frequency and elevation angle of the radar.

F.1.1.2 Radar operators adjust radar as needed.

3.6 Operational Resource Flow Description (OV-2) & Operational Resource Flow Matrix (OV-3)

The diagram in Figure 11 describes the specific operation that takes place and the direction that the information flows in. The biggest support in OV-2 is the operation center. In Figure 12 it gives a view of the flow of information.

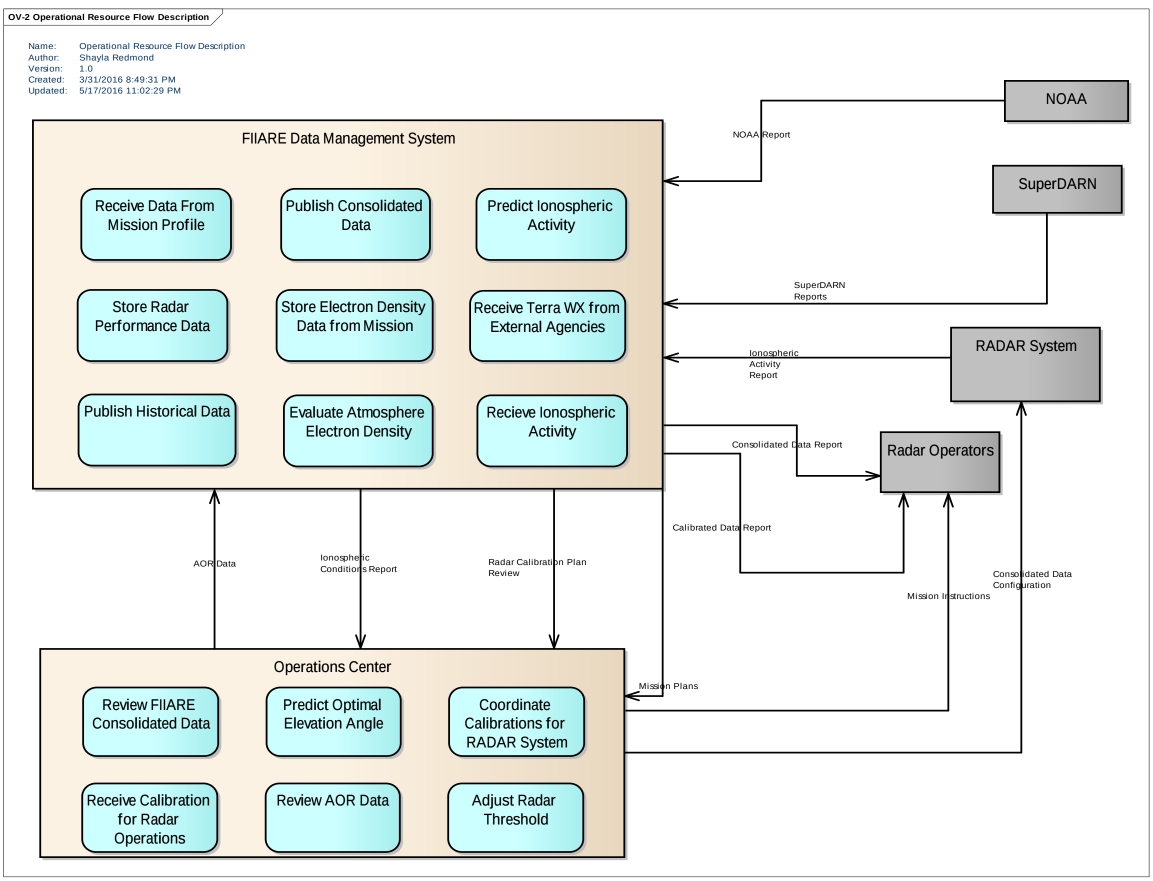

Figure 11: OV-2

Connector_Name	Connector_Type	Conveyed_Type	Conveyed Name	Producer_Name	Consumer_Name
AOR Data	Needline	EntityItem	Airspace_Parameters	Operations Center	FIIARE Data System
Calibrated Data Report	Needline	EntityItem	Radar_Calibrations	FIIARE Data Management System	Radar Operators
Consolidated Data Report	Needline	EntityItem	Atmospheric_Conditions_Report	FIIARE Data Management System	Radar Operators
Mission Plans	Needline	EntityItem	Mission_Plans	FIIARE Data Management System	Operations Center
Ionospheric Conditions Report	Needline	EntityItem	Ionospheric Conditions Report	Radar System	FIIARE Data System
NOAA Report	Needline	EntityItem	NOAA Report	NOAA	FIIARE Data System
SuperDARN Report	Needline	EntityItem	SuperDARN Report	SuperDARN	FIIARE Data System

Figure 12: OV-3

3.7 Capability Taxonomy (CV-2) & Capability to Operational Activity Mapping (CV-6)

In Figure 13 the capabilities that the architecture will achieve is shown. Focusing on the Joint Capability Areas (JCAs) the areas are divided into command and control and building partnerships. The command and control aspect of the capability of this architecture would involve organizing, planning, and developing relationships with foreign partners. Building Partnerships involves developing the capabilities of others while evolving influential programs that would affect the DoD mission. Figure 14 maps the capabilities to the operational activities.

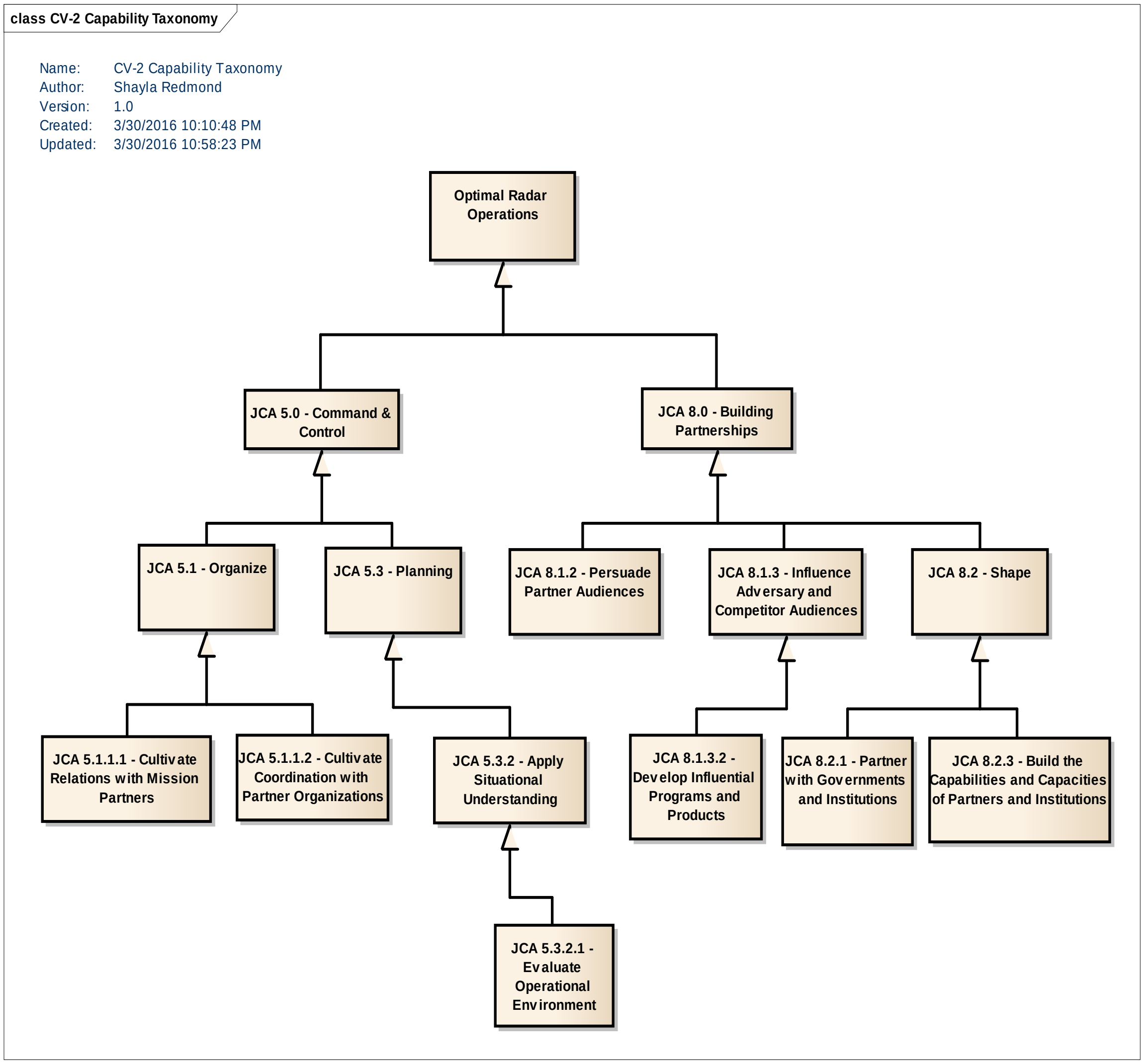

Figure 13: CV-2

	Adjust Radar Threshold	Coordinate Calibrations	Evaluate Atmosphere Electron Density	Predict Ionospheric Acvivity	Predict Optimal Elevation Angle	Publish Consolidated Data	Publish Historical data	Receive Calibrations for Radar Operations	Receive Misson Profile Data	Receive Ionosphereic Activity	Receive Terra WX External Agencies	Review AOR Data	Review FIIARE Consolidated Data	Store Electron Density Data	Store Radar Performance Data
JCA 5.1.1.1 Cultivate Relations with Mission Partners				X						X	X	X			
JCA 5.1.1.2 Cultivate Coordination with Partner Organizations										X	X	X			
JCA 5.3.2 Apply Situational Understanding	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
JCA 5.3.2.1 Evaluate Operational Environment	X		X	X	X	X			X	X	X	X	X		
JCA 8.1.3.2 Develop Influential Programs and Products			X	X	X	X	X	X					X	X	X
JCA 8.2.1 Partner with Governments and Institutions										X	X				
JCA 8.2.3 Build the Capabilities and Capacities of Partners			X		X	X				X	X			X	X

Figure 14: CV-6

3.8 Operational Activity

Another view to consider would be the organizational relationship chart (OV-4). All users will continue to operate under their organizational chains. However the radar operators will be responsible for coordinating their launch, planning, operational phase and real-time data collection and storage via FIIARE. Since the architecture is designed to be used as a tool for optimal radar operations focusing on OTH operations, there isn't any one organization to access/process the information provided by the FIIARE system. The owning operating agency will have their own operations center. The SuperDARN and NOAA information will be loaded to the FIIARE system in the operations center and deciphered by appropriate members with the correct certifications. The overarching organization would be the DoD and then from there, it would depend on the mission set developed from community/organization following the path all the way down to the lowest level of radar operators. Figures 15-18 are operational views each describing a flow of information in a certain activity. FIIARE will provide functionality/capabilities to support mission planning, loading area of interest radar disturbance model, collection and dissemination ionospheric activity. Each activity may be supported by different system or external organizations but are necessary to support mitigation of over the horizon radar clutter due to SAPS. In Figure 17 the rules of the flow of information are established.

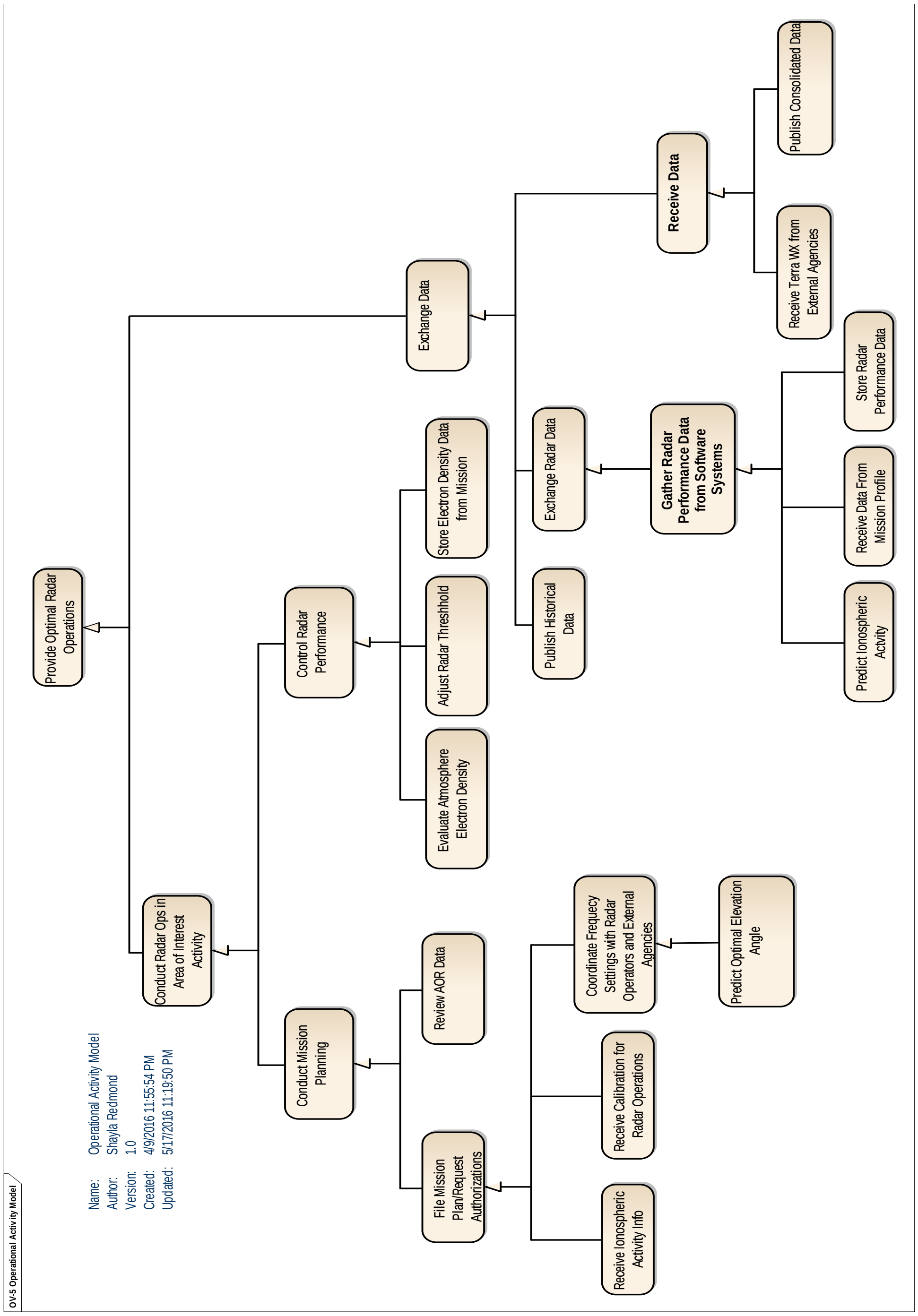

Figure 15: OV-5a

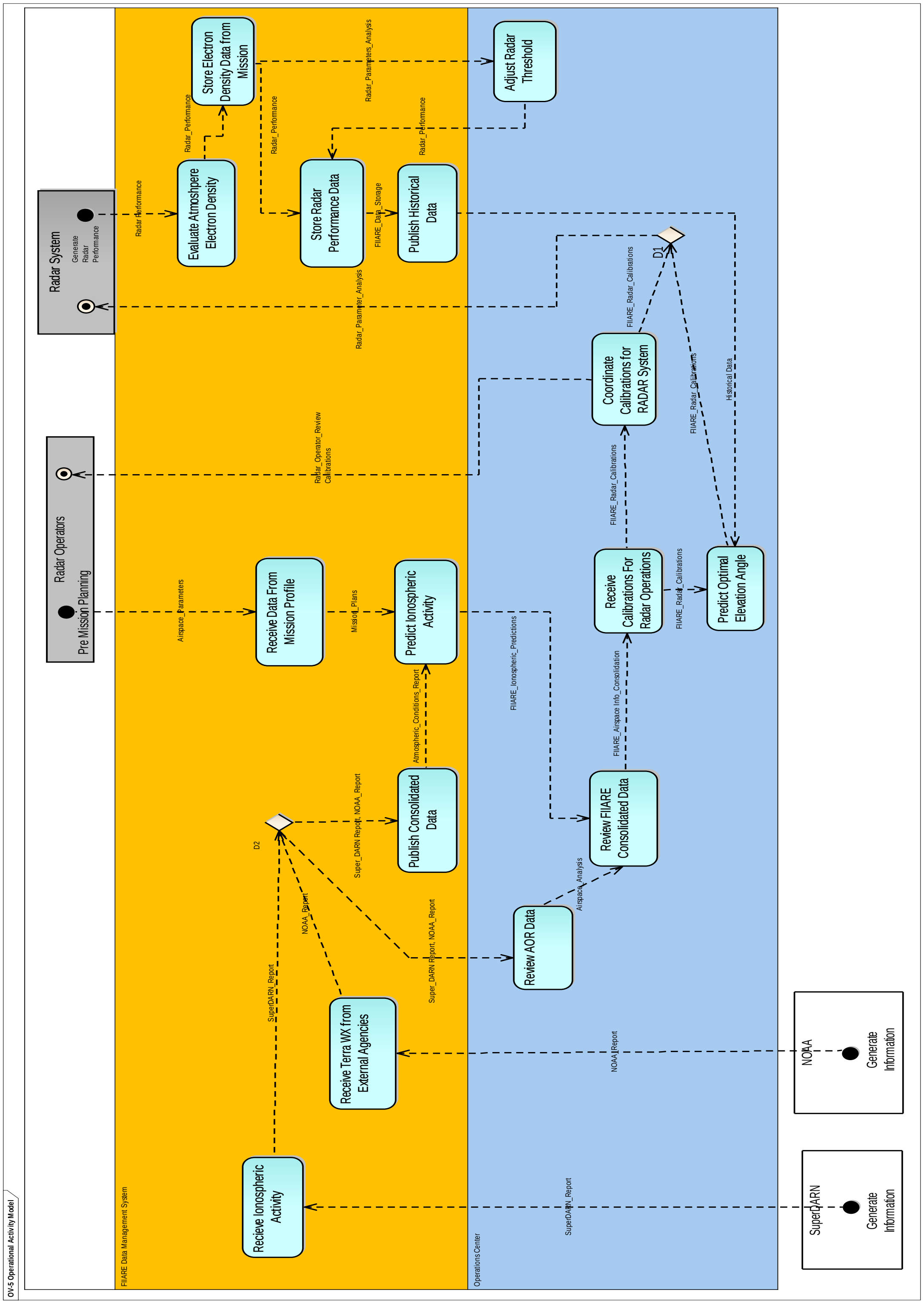

Figure 16: OV-5b

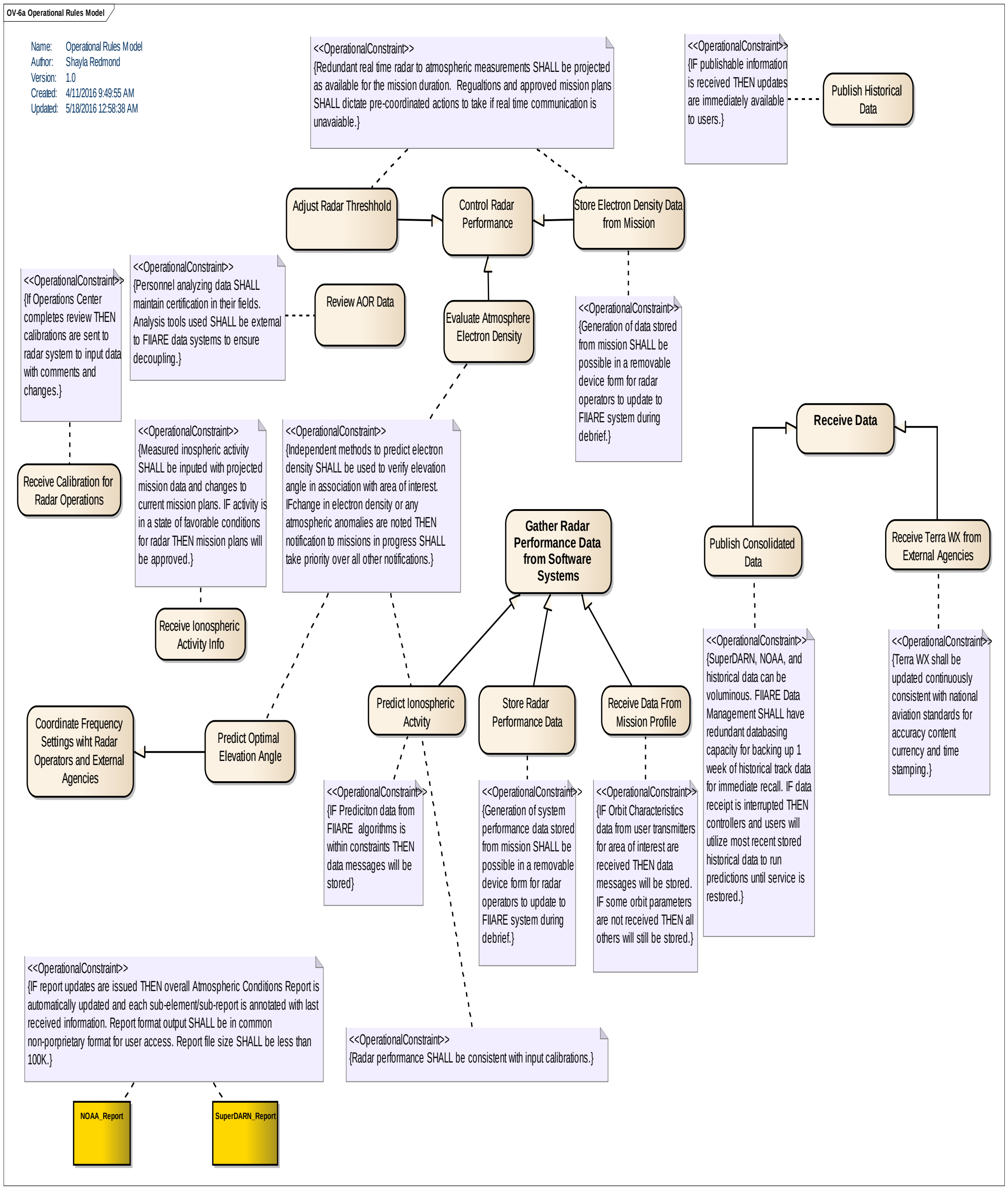

Figure 17: OV-6a

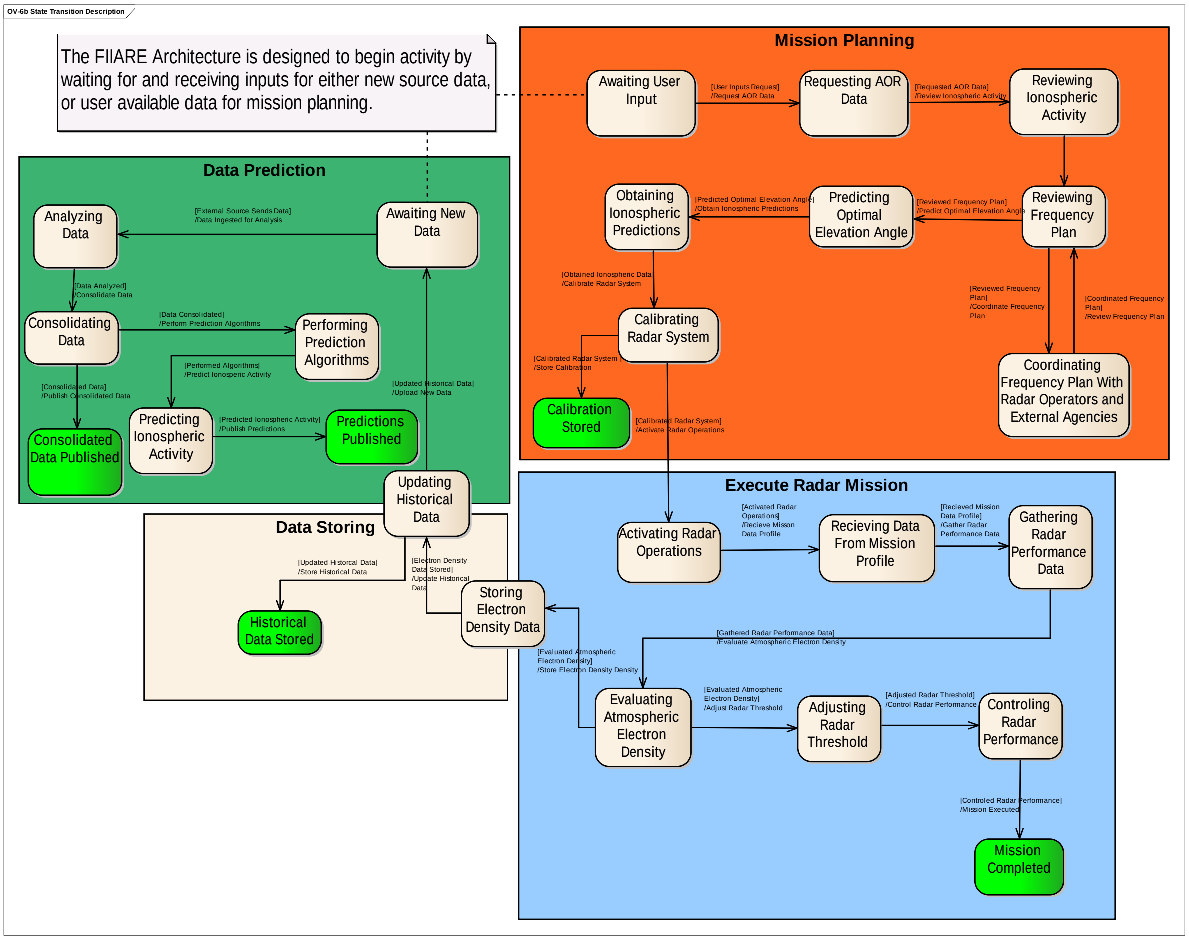

Figure 18: OV-6b

3.9 Logical Data Model & Systems View

In Figure 19 the type of information associated with each entity is presented. Figure 20 shows links between systems and system items are described in this basic systems viewpoint. Figure 21-23 describe the different system components that make up the FIIARE system. Each component is vital to the overall architecture of the system in order for the mission to be successful. Figure 24 show different FIIARE system functions to operational activities. This is an important view to observe in the development of this architecture to make sure all operations are linked to a supporting system function.

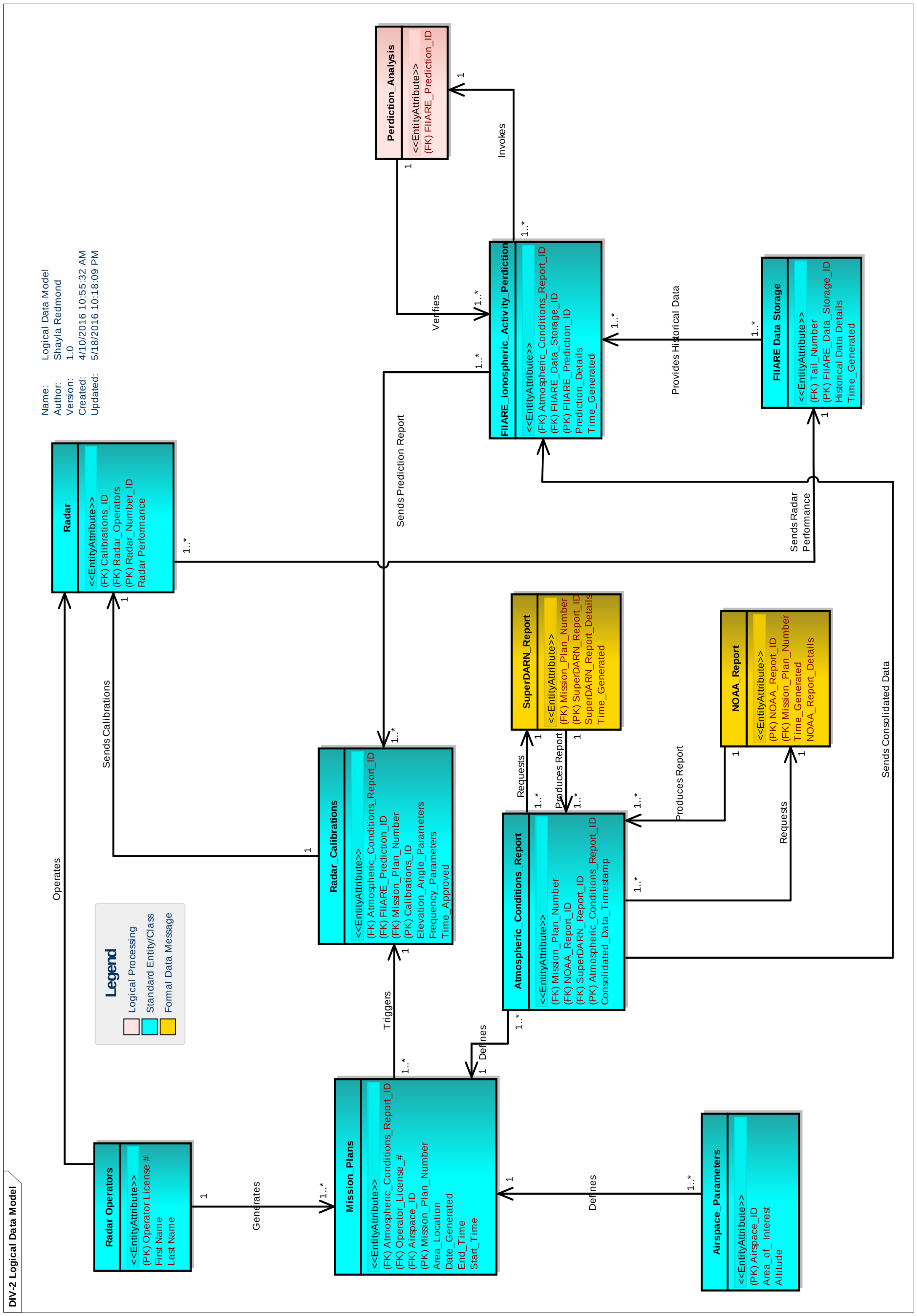

Figure 19: DIV-2

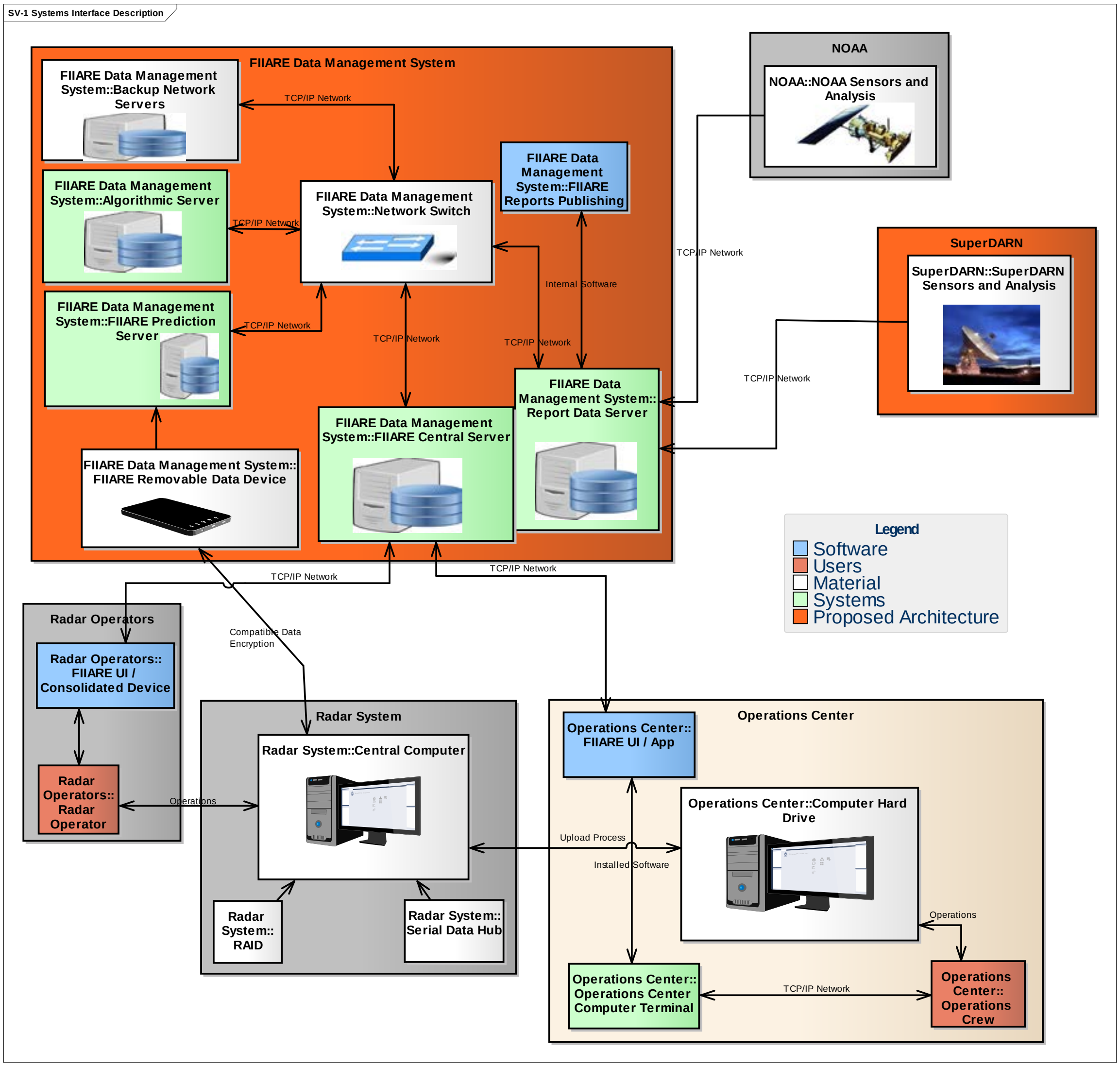

Figure 20: SV-1

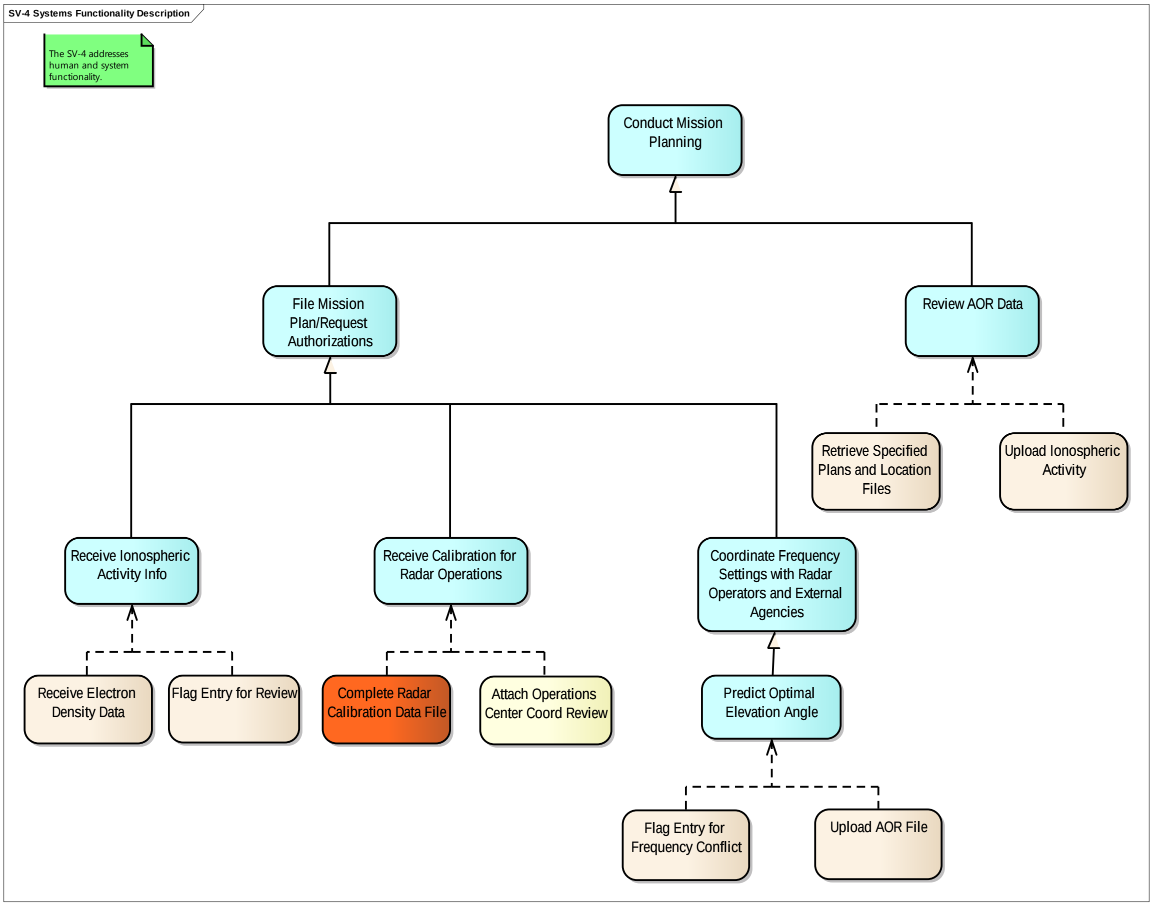

Figure 21: SV-4 part 1

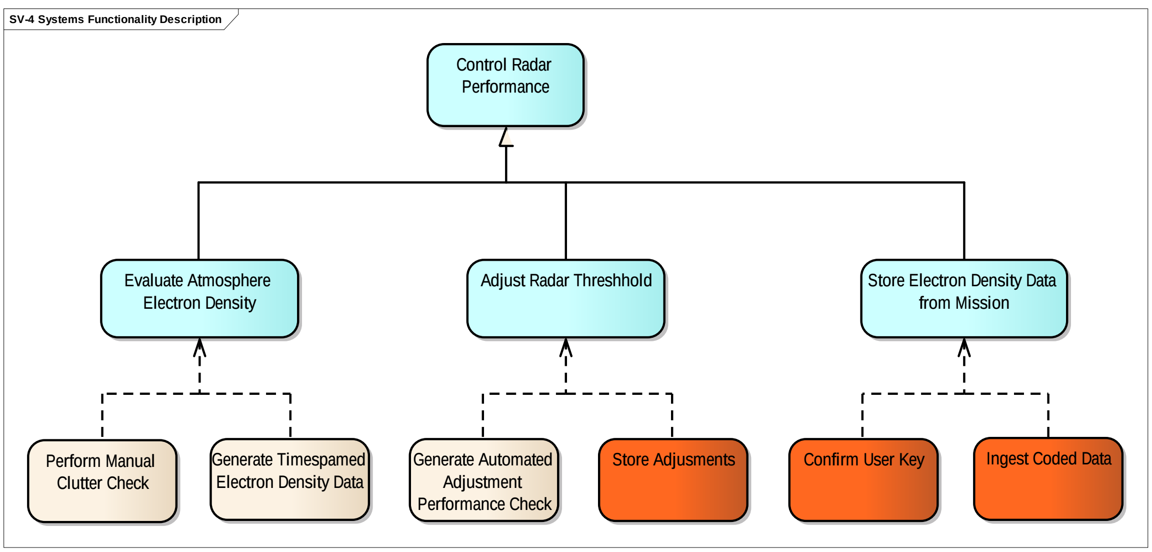

Figure 22: SV-4 part 2

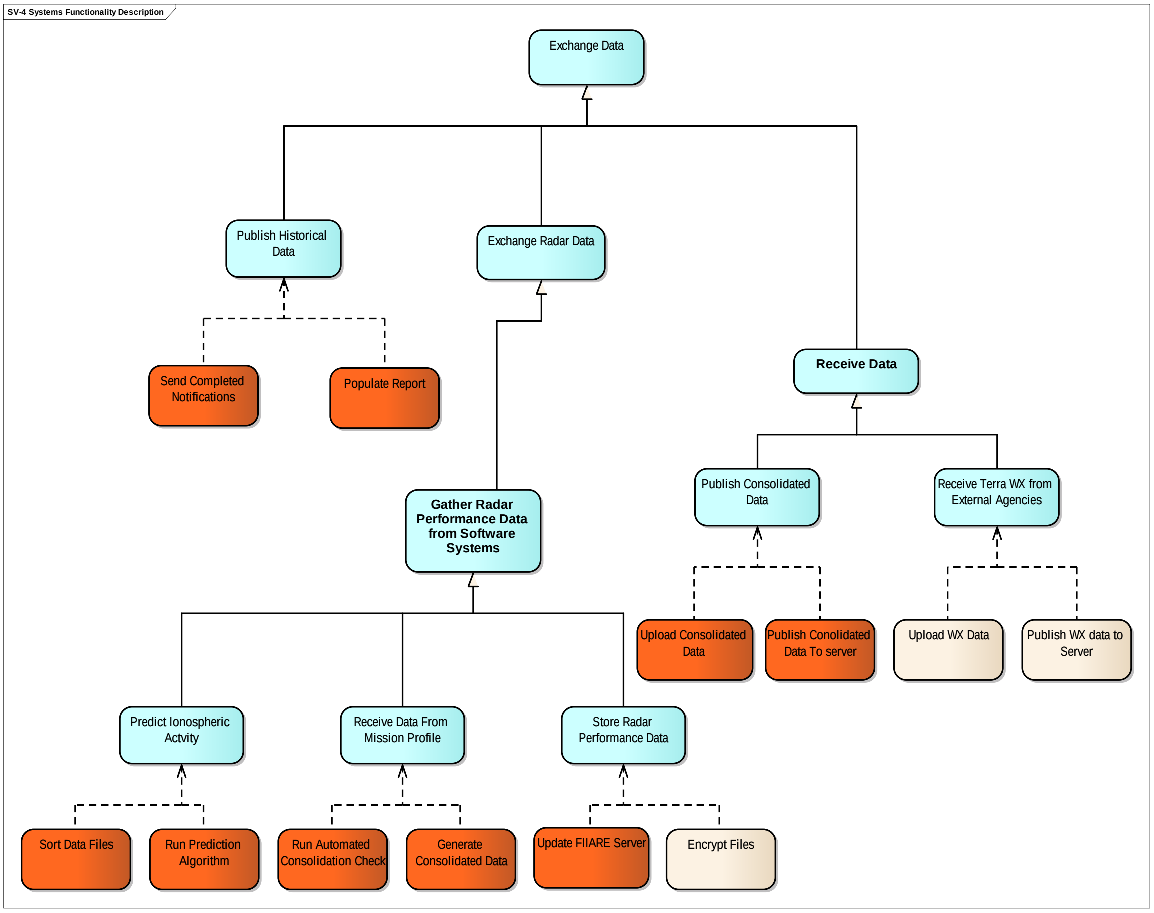

Figure 23: SV-4 part 3

	Attach Operations Center Coord Review	Complete Radar Calibrations Data File	Confirm User Key	Encrypt Files	Flag Entry for Conflict	Flag Entry for Frequency Conflict	Flag Entry for Review	Generate Automated Adjustment Performance Check	Generate Consolidated Data	Generate Timestamped Electron Density Data	Ingest Coded Data	Perform Manual Clutter Check	Populate Report	Publish Consolidated Data	Publish Ionsospheric Data to Server	Publish WX Data to Server	Receive Electron Density Data	Retrieve Specified Plans and Location Files	Run Automated Consolidation Check	Run Predicton Algorithm	Send Completed Notifications	Sort Data Files	Store Adjustments	Update FIIARE Server	Upload AOR File	Upload Consolidated Data to Server	Upload Ionospheric Activity	Upload ionospheric Data	Upload WX Data
Adjust Radar Threshold				X				X															X						
Evaluate Atmosphere Electron Density										X		X																X	
Predict Ionospheric Activity																				X		X							
Predict Optimal Elevation Angle						X																			X				
Publish Consolidated Data														X	X											X			
Publish Historical Data													X		X						X								
Receive Calibrations for Radar Operations	X	X			X																								
Receive Data From Misson Profile					X				X										X										
Receive Ionospheric Activity Info							X										X											X	
Receive Terra WX from External Agencies																X													X
Review AOR Data																		X									X		
Store Electron Density Data From Mission			X								X																	X	
Store Radar Performance Data				X																				X					

Mature technology; full functionality readily achieved, TRL ~7-9
Developing Technology; some risk to full functionality, TRL ~4-6
Undeveloped Technology; high risk to full functionality, TRL ~1-3

Figure 24: SV-5

3.10 End State

The desired end state is repeatable, safe, successful execution of data collection and correlation to mitigate future disturbances caused by SAPS by using FIIARE within sustainable costs.

3.11 Data Contributions Method

The space-time variations of the ionospheric channel, the external noise level as well as the transmission channel bandwidth limitations, are considered the most critical and challenging aspects for the design and operational management of radar (Saverino, 2013). The characteristics of a radio signal received from the ionosphere is necessary to know the electron density variation influences on the radio signal propagation from the transmitter to the receiver (Saverino, 2013). Having accurate data to incorporate into prediction models is of primary importance because of the way it influences frequency selection. Suitable frequency management is needed. There are bits of data missing from what is required to have a more accurate model both empirical and theoretical needed for prediction algorithms as shown in Table 1. Table 1 was modified from (Ivanov, 1986) to show the estimated missing data.

Table 1: Modified Prediction Model Data (Ivanov, 1986)

	Empirical Method				
		Information,Bits			
Region	No. of Parameters	requried	available	Missing Data	Missing Data (Bytes)
D	2	10000000	600	9999400	1249925
E	2	10000000	100000	9900000	1237500
F1	2	10000000	100000	9900000	1237500
F2	2	10000000	280000	9720000	1215000
Above the maximum of F2 region	2	10000000	90000	9910000	1238750
Total	10	50000000	580000	49420000	6177500
			Most Likely SAPS Contribution	39430000	4928750

	Theoretical Model			
Parametrs	Required Information, Bits	Estimated Quantitiy of Available Information, Bits	Missing Data (Bits)	Missing Data (Bytes)
Thermosphere	512	374	138	17.25
Mesosphere	200	100	100	12.5
Flux of short-wave solar radiation	256	192	64	8
Collision and absorption cross-sections	1024	768	256	32
Winds	256	192	64	8
Electric fields	512	384	128	16
Reaction rate constants	400	300	100	12.5
Corpuscular fluxes	400	200	200	25
Magnetic Field	256	256	0	0
Total	3816	2766	1050	131.25
		Most Likely SAPS Contribution	430	53.75

From the chart the total estimated amount missing from the empirical model is 49Mb and from the theoretical model is 1050 bits. Since the theoretical model is better defined, the data of the theoretical model will be used to further explore the possibilities of what SAPS and SuperDARN data can contribute to prediction models.

3.12 Summary

The current procedures in place to access space weather effects on radar are good, but no extensive work has been done on the issue of ionospheric activity due to SAPS and its effect on radar operations. There needs to be new proposed architecture that allows the opportunity to measure and correlate SAPS and over the horizon radar performance. This is all to improve upon operational success.

IV. Analysis

4.1 Chapter Overview

In this section the development of the system will be explained. It will start from the big picture overview to the breakdown of the components involved to make the architecture work. As the system unfolds the views explanation of the whole system will allow us to see a conceptual way of employing a system that has the ability to optimize radar operations.

4.2 Data Contribution Results/Analysis

From the data in Table 1, a chart was developed in Table 2 that provides information on how the data gathered from the SuperDARN is beneficial to prediction models. Since ionospheric basic parameters are made of electron concentration, ion composition, electron and ion temperatures, particle fluxes and drifts, understanding the details will give better definition to the missing bits in question. SuperDARN provides disturbance of ionospheric plasma and the observation that can offer information of SAPS. Once the parameters of SAPS has been identified physically through data collection, better prediction models in association with SAPS causing clutter can be developed. Since SuperDARN does more than collect SAPS information, it would play an intricate part in creating better prediction models and fill in the missing data that SAPS does not in particularly cover.

OV-1 provided the overall depiction of integration of information from SuperDARN and NOAA data along with the storage of Ionospheric activity. FIIARE data system will compile all the input information to output the necessary information needed.

In the operational resource flow diagram for the FIIARE data management system we see that the radar operators will be reviewing the FIIARE data and contributing to the switch actions necessary to ensure mission success. Predicting ionospheric activity begins with information from NOAA and the SuperDARN and are complete when mission execution is complete and data is stored in the FIIARE system. The FIIARE is the primary system in the operations center for data. It is the collective information gathered that confirms the ability of the system by the JCA 5.3.2.1 standards solidifying the architectural mapping of the capabilities to the operations in evaluating the operational environment.

Table 2: SuperDARN Data of SAPS and other Capabilities

PARAMETERS	SuperDARN	SAPS
Thermosphere	Emitting HF radio waves for observation	Ionosphere-Thermosphere coupling
Mesosphere	Emitting HF radio waves for observation	
Flux of short-wave radiation	Inflow of space plasma	
Collision & absorption cross-section	Flow of ionospheric Plasma	
Winds	Flow of ionospheric Plasma	Rapid westward Plasma Flow
Electric fields	Flow of ionospheric Plasma	Rapid westward plasma Flow
Reaction rate constants	Dynamics of global Convection	Disturbed nightside convection pattern
Corpuscular Fluxes	Substorms	
Magnetic fields	Gravity Waves	Convecting thermal plasma in the inner magnetosphere

The basis of the research was if SAPS causes clutter during radar operations, how would the problem be solved. The outcome of this research is SAPS could contribute to clutter, specifically OTH radar that uses the ionosphere during missions. The study continues to further advance a system that would not only identify SAPS, but further improve prediction models. The overall goal is to increase radar productivity by identifying hindering factors to the mission to ultimately mitigate them. Ivanov states, “Any method of ionospheric prediction should enable calculation of all the ionospheric parameters and their planetary and altitude distributions” (Ivanov, 1986) meaning the development of global parameters in the upper atmosphere. With this in mind the combination of the NOAA organization and data from the SuperDARN “calculation of all ionospheric parameters” (Ivanov, 1986) shall be known. From this information, we can develop better prediction models that provide the information for accurate correlation of SAPS to clutter effects. OV-5 shows the operational activities between the FIIARE data management system and the operations center. The overall focus for the success of the mission would be the data collected from the mission itself, documenting any clutter occurrence and noting if the SAPS phenomenon was in effect. The background literature encourages more SAPS considerations when developing ionospheric models especially when dealing with radar clutter.

CV-2 of the FIIARE system is divided into the command and control and Building partnerships, which this system would be supporting if it were developed. Results of the two categories would help the evaluation of the operational environment with optimal radar operations.

SV-5 maps the different system functions to the operational activities. The operational activities are shown in OV-5 and the system concepts are collected from the SV-4 information. This is to ensure operations are matched with a supporting system function. If there were any operational activities that could not be mapped to a system this would indicate missing information in the FIIARE data management development.

The method satisfied by the operational-to-system mapping in Ivanov's book is the deterministic method which is based on rigidly quantitative descriptions of physical effects and relationships involved in the process of developing prediction models (Ivanov, 1986). The system views allows this method to be applied to the ionospheric formation and phenomena with respect to solar and geophysical factors.

4.3 Mission Impact

The productivity degradation would be due to clutter theoretically caused by SAPS. Losses in mitigation effectiveness, whether by preventative measures or simple switch actions, results in negative impact on the mission. Considering a 24-hour period of data clutter at any moment could negatively impact performance of any target information necessary to accomplish DoD objectives. Looking at possible data loss during the hours of disruption was the best form of conceivable analysis. SAPS can last anywhere between 30 min to 4 hours (Grocott, 2011), which would result in an average 10% loss of data in a 24-hour period. This compromises the ability of radar operators to perform their missions because 30 min is too long to fight through clutter due to atmospheric disturbances. Taking time deciding on the best settings to help the radar cancel out unwanted signals when preventative measures could've been taken if parameters were already known is detrimental to the mission in a time sensitive environment.

4.4 Questions Answered

1. What are the current capabilities that we have to measure SAPS, and how can we use those measurements to correlate with radar effects? There are many systems

used to measure SAPS, such as the Millstone Hill Radar, Falkland Islands Radar (Grocott, 2011), and the SuperDARN. The current system used with the most up to date measurement of SAPS is the SuperDARN. If the information obtained by radar could be compared to SuperDARN measurements, the correlations of the effects during radar operations could help prepare for future missions.

2. What kinds of common equipment/technology is needed to support SAPS for radar measurements? The FIIARE system would primarily be a data storage system that can use data from operators and output a product that could be used to calibrate the radar system to operate in the necessary frequency mode to execute the mission. SV-1 described systems necessary to start the development in support of SAPS correlation to radar measurements. Better algorithms need to be developed in order to continue to pave the way forward for a more accurate prediction model.
3. Who will have access to the data from the architecture? The DoD will have primary access to the data from the architecture since the foundation of the capabilities are from the JCA and many mission sets utilize the OTH radar system and ionosphere coordination.
4. How will the data flow among different users, and what data will be available/restricted? The use case diagram in Figure 10 describes the data flow being primarily fed into the FIIARE system then into the radar system. Div-2 and OV-6b described the flow of data depending on the mission. Certain information would be restricted such as the area of interest (AOR) and results of the mission dealing with the radar performance.

5. How will radar operations benefit from improved definition of ionospheric disturbances? All radar systems that operate over the horizon will benefit from the data capabilities of this architecture.
6. What improvements does SAPS contribute to clutter mitigation methods? An improvement of prediction models will be an improvement of radar operations. As a result of better prediction models better mitigation techniques against clutter would be developed.

4.5 Summary

The FIIARE system is an important attribute to radar operations. It can help with mission effectiveness by mitigating time spent trying to figure out the cause of interference and to plan on a work-through when the information of the environment is known ahead of time.

V. Conclusions and Recommendations

5.1 Research Review

The primary objective of this study was to develop an architecture concept to take a look into the effects of SAPS on radar operations along the lines of interference. The focus that was chosen, since radar can be a wide range of frequencies, was the HF range and the idea of airborne radar operations utilizing such a system to produce a longer range of detection using the sky wave concept.

5.2 Summary of Research Gap, Research Questions and Answers

Going into this research there wasn't much information on the specific radar - SAPS relationship. The understanding of basic radar theory and the electron density levels played a significant role in the development of this architecture. Breaking down the concept starting from an operational standpoint to a conceptual system dynamic allowed the answering of capabilities-to-requirements question while exposing some research gaps in the study. OV-2 specific operations was seen throughout the majority of the views and was a major part in defining the architecture. Another indispensable view was CV-6 because it set the outline for what JCAs were being satisfied from which operational capabilities proposed by the FIIARE system, which help coincide with the purpose of this architecture to not only develop a better system but to also help with the continual improvement on satisfying the DoD objectives. After fortifying the purpose of the architecture DIV-2 provided types of information that would be exchanged and flow of information and OV-6a broke it down into categories allowing the architecture to portray a start to finish process of each activity. DIV-2 and OV-6a help with the understanding on how to get the operational activities to satisfy the JCA from planning to execution.

5.3 Study Limitations

The biggest challenge was not having resources available due to the lack of knowledge of SAPS in literature. Weather organizations were contacted to get a basic insight to see what process they had as far as space weather detection and type. websites were utilized pull NOAA reports. When the concept of SAPS was presented not much was known. Radars such as the SuperDARN that focus on such anomalies are still in the early stages.

5.4 Recommendations for Action

The development of additional SuperDARN radars should be put in place so that the specifics of SAPS can be measured across the globe. There are workshops occurring in the summer of 2016 to understand SAPS and the employment of the SuperDARN. Companies and schools doing research; for example, the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) is a program sponsored by the National Science Foundation in the United States. In 2014 the CEDAR workshop began at the University of Washington in Seattle, Washington and shared research collaboration on the SuperDARN. In summer 2016 Fairbanks, Alaska, hosted a SuperDARN workshop to bring “scientist, students and engineers from over 10 counties to discuss results in magnetospheric, ionospheric, and upper atmospheric physics, review technical data analysis developments, and coordinate the network operations and sharing of the data.”(SuperDARN Workshop 2016).

5.5 Recommendations for the Future

As this architecture is put into action a view that would benefit the development would be project portfolio relationships (PV-1) and project timelines (PV-2). From the research there is a chance that SAPS could contribute to prediction models but the mere definition of SAPS and undefined bits does not allow a complete conclusive solution to the problem of whether or not there are effects on radar operations. The next step would be to take the architecture developed here and utilize SuperDARN radars to pinpoint SAPS in real time and perform radar operations detecting targets on the ground or air and compare interference levels when SAPS is active and when it is not. That will give a more accurate solution, and from there better measures can be taken into account during prediction model analysis. The views suggested would help with the development of this venture.

5.6 Significance of Research

There are always ways to improve the way radar is employed. "Heavy propagation losses due to very long traveling distances as well as strong absorption losses caused by ionospheric dispersion must be dealt with" (Saverino 2013). In order to start tweaking and refining the radar system as it fights through all forms of clutter and interference, we have to start looking at all the possibilities that could cause an issue with radar. The process of starting the brainstorming a conceptual development is the first step which is what this thesis described. Now the door of opportunity is open for a closer look at how the process of mission planning to execution would be if SAPS were to be taken into consideration as the radar mission continues.

Appendix

Table 3: AV-1

Architecture Project Identification	
Name	Architecture System to Measure the Effects of Subauroral Polarization Streams on Radar Operations
Description	This architecture is a system of collaborating organizations and equipment that coordinates with space weather companies to link information to appropriate agencies about SAPS effect on radar operations.
Architects	Captain Shayla Redmond
Organization	Air Force Institute of Technology
Assumptions and Constraints	• DoD will continue to have a vested interest in space weather, and how it affects the mission. • Lack of funding could limit the equipment needed to maintain accurate data of SAPS to

	space weather agencies. • Technology development (or non-development) among participants could prohibit compatibility of systems and oversight of operations • Political opposition (internationally or domestically from private entities) towards regulation of how the information is disseminated could slow formation of appropriate governing bodies and mechanisms. • Treaty, policy or national security requirements could prohibit sharing information from space weather.
Approval Authority	Dr. Jacques, Dr. Loper, and Dr. Colombi
Scope: Architecture View and Models Identification	
Views Developed	- AV-1 (Overview and Summary Information) - AV-2 (Integrated Dictionary) - CV-2 (Capability Taxonomy) - DIV-2 (Logical Data Model) - CV-6 (Capability to Operational Activity Mapping) - OV-1 (High Level Operational Concept

	Graphic) -OV-2 (Operational Resource Flow Description) -OV-3 (Operational Resource Flow Matrix) - OV-5a (Operational Activity Decomposition) - OV-5b (Operational Activity Model) -OV-6a (Operational Rules Model) -OV-6b (State Transition Description) -SV-1 (Systems Interface Description) -SV-4 (Systems Functionality Description) -SV-5a (Operational Activity to Systems Function Traceability Matrix) StdV-1 (Standards Profile)
Capabilities	● JCA 8.0 Building Partnerships ● JCA 5.0 Command and Control
Time Frames Addressed	5+ Years
Primary Organizations	NASA, FAA, NOAA, AFSPC and associated

Involved	sister service commands.
Secondary Organizations Involved	SuperDARN
Purpose and Viewpoint	
Purpose (Problems, Needs, Gaps)	With the dynamic operations the DoD execute everyday and the large use of radar in accomplishing the mission objectives more ways to optimize radar performance need to be a priority.
Questions to be Answered	1. What are the current capabilities that we have to measure SAPS, and how can we use those measurements to correlate with radar effects? 2. What kinds of common equipment/technology is needed to support SAPS for radar measurements? 3. Who will have access to the data from the architecture? 4. How will the data flow among different users, and what data will be available/restricted? 5. How will radar operations benefit from improved

	definition of ionospheric disturbances? 6. What improvements does SAPS contribute to clutter mitigation methods?
Architecture Viewpoint	This system network will be developed as an enterprise architecture.
Context	
Mission	This architecture aims to reduce the unknown realm of SAPS in correlation to radar.
Doctrine, Goals, Vision	The DoD seeks to mitigate radar clutter ambiguous nature.
Rules, Conventions, and Criteria	This architecture will be developed in accordance with DoD Architecture Framework (DoDAF) Version 2.0

Table 4: Standard (Std-V)

Standard Name	DISR Service Area	Details	CAO	Status	Comments
ICAO Annex 10 Aeronautical Telecommunications: Volume V	N/A	Aeronautical Radio Frequency Spectrum Utilization	4/22/2011	**"As-Is"**	This standard addresses civil Air Traffic Management (ATM) interoperability for DoD aircraft in order to operate in the evolving global civil aviation airspace arena. Use by DoD is mandatory.
IEEE 802.11ac (WiFi)	Network Technologies		12/1/2013	**"As-Is"**	Possible emission security (EMSEC) issues.
IEEE 802.3bp (Ethernet)	Network Technologies		5/1/2014	**"As-Is"**	The newest "bp" standard defines gigabit applications in industrial environments.
ISO 13249 (all applicable)	Database Management Systems	ISO 13249 defines SQL usage in database management systems, encompassing structure / design considerations down to interface specifications.	2005-2006	**"As-Is"**	FIIARE will include massive databases - DoD requires compliance with ISO 13249 (and it just makes sense)
RTCA DO-224B	Satellite Communications	Signal-in-Space Minimum Aviation Systems Performance Standards (MASPS) Advanced VHF Digital Data, Communications Including Capability with Digital Voice Technique, 03 August 2005	8/3/2005	**"As-Is"**	This standard has been in place for many years, and is required for any program intending to interoperate with civil aeronautical/aerospace systems. Use is mandated by the DoD IT Standards Registry (DISR)

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14. ABSTRACT

This thesis provides the initial conceptual development of taking into account subauroral polarization streams when preparing for a radar operation. The DoDAF views created to portray the architecture consisted of operational, capabilities, data and information, and finally system views to ensure consistency and realistic outcomes. OV-2 was the significant view because it set the baseline for required actions necessary for the proposed results the Flow Integration of Ionospheric Activity & Radar Evaluation (FIIARE) system would produce. FIIARE is a computer based system concept that performs consolidations and produce predictions using algorithms from the International Reference Ionosphere (IRI). The data portrayed in the views would come from National Oceanic Atmospheric Administration and Super Dual Auroral Radar Network (SuperDARN). Data from both agencies would then be utilized in the FIIARE system to prepare the radar operators for calibrating the radar to perform in any area of responsibility (AOR). The overall purpose of this thesis is to develop the initial concept of deciding whether SAPS cause clutter during radar operations. There is a negative impact on the mission due to clutter that SAPS could cause in a 24 hour period. To get better data and estimate

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