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Defense and Environmental Objectives for the Russian American Observational Satellites (RAMOS) Program

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ABSTRACT: The Russian American Observational Satellites (RAMOS) program represents a new direction for cooperative space-based research and development between the Russian Federation and the United States. The objective of the RAMOS project is to engage in a joint program employing simultaneous stereo-optical techniques from two co-orbiting satellites to address global defense and environmental issues. The satellites are equipped with American- and Russian-made passive electro-optical sensors operating over a spectral range from infrared (IR) to ultraviolet (UV) which can conduct near-simultaneous stereo-optical radiometric, spectrometric, and polarimetric measurements.

The defense objectives will demonstrate the capability for improved target observation and reduced "false alarm" events in early warning systems; the environmental objectives will demonstrate the ability to detect, observe and characterize fast-changing events (e.g., hurricanes, volcanic plumes). A joint Russian-American science team is active in defining these objectives and preparing plans for the experiments. Underlying this program is the goal of demonstrating the ability of the American and Russian defense agencies and their contractors to cooperate in important space-based experiments, compare calibrations, and compare independent analyses.

In this paper we present the RAMOS program definition as it existed at the successful completion of a Joint Preliminary Design Review in June, 2003. The Missile Defense Agency, the sponsoring organization, announced plans in February 2004 to bring the RAMOS program to an orderly closure prior to the Critical Design Review.

INTRODUCTION

Growing in part from a meeting between US and Russian space scientists at the Small Satellite Conference in September, 1992, the Russian-American Observational Satellites (RAMOS) program is the only cooperative space program between the Russian Ministry of Defense and the United States Department of Defense. This important program, sponsored by the Missile Defense Agency (MDA) of the US Department of Defense, has demonstrated the ability of the American and Russian defense agencies and their contractors to cooperate in space-based research important to the national security of both nations. The cooperative effort has included joint requirements definition, interface design, and experiment planning; as it matures it will entail cooperative mission operations, experiment execution, data acquisition and data processing. Although each country will conduct its own rigorous data analysis, the analysis products will be shared to the extent allowed by the security organizations of both countries. This paper presents RAMOS as it was planned and defined at the conclusion of a successful Joint Preliminary Design Review in June, 2003. MDA announced plans in February 2004 to bring the RAMOS program to an orderly closure prior to the Critical Design Review.

While the overriding political objective of the RAMOS program is to engage the Russian Federation (RF) in a cooperative defense-related space program, the primary RAMOS technical objective is to jointly conduct research and development on unique new technological approaches to improving space-based early warning

(EW) tracking systems—specifically to improve detection of dim targets and to reduce false alarms in some of the most difficult remote sensing functions of these systems. The approach to meeting this goal is to jointly design an integrated space/ground system, an experiment set, an operations methodology and a data handling capability that will:

- Demonstrate a unique simultaneous stereo-optical imaging capability and the utility of this capability in identifying scene features,
- Acquire SWIR, MWIR, and LWIR background and target data, including directly comparing the usefulness of traditional observational spectral bands with that of some prospective new bands,
- Measure the polarization components of background sources resulting from scattered sunlight, and
- Acquire 6.3 µm water band data.

In addition to these important defense-related objectives, the RAMOS program will also demonstrate new technological approaches to addressing critical environmental issues of global importance.[1] The RAMOS system will:

- Demonstrate the applicability of simultaneous stereo-optical imaging to accurately estimating the strength of hurricanes, and the volume and extent of volcanic or smoke plumes and similar dynamic systems,
- Acquire time-dependent stereo imagery to determine and model 3-dimensional wind velocity, and
- Acquire 3-dimensional water vapor distribution measurements to aid the understanding of water vapor on IR background scene structure.

SYSTEM DESCRIPTION

RAMOS consists of a constellation of two satellites in co-planar circular orbits at an altitude of approximately 500 km, along with supporting ground-based command, control and data processing facilities. The satellites will have station keeping capability and will maintain a separation ("stereobase") of approximately 500 km, varied to meet different experiment goals. The satellites are designed to provide a minimum of two years of on-orbit operation, with a goal of achieving a five year mission lifetime.

Instrumentation on the two satellites is nearly identical, and includes sensors built both by the US and by the RF. The sensors and their support electronics are mounted on a "Universal Space Platform (USP)," provided by the RF; the USP incorporates power, propulsion, communication and thermal control systems for the satellite. Russian *Rokot* boosters will launch the two satellites from the Plesetsk Cosmodrome approximately 6 months apart.

A Joint Mission Operations Center (JMOC), near Moscow, Russia, provides facilities for joint experiment planning, joint operations planning, communication up- and down-link, data acquisition and preliminary data reduction. Provisions exist or are planned to provide analysts in each country with raw and reduced data which they can use for their independent analyses. Figure 1 depicts the major components of the RAMOS system.

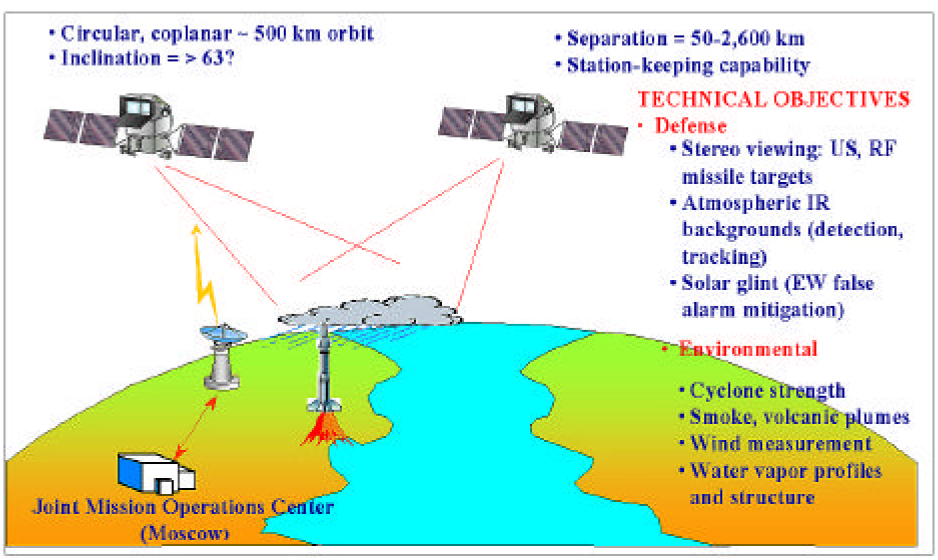

Figure 1: Major RAMOS System Components

INSTRUMENTATION AND SPECIFICATIONS

The two satellites carry complementary (but not identical) suites of electro-optical sensors covering the spectral range from ultraviolet (UV) to infrared (IR), called the Suites of Observational Instruments (SOI). Each SOI consists of an IR module and a visible-domain linear scanner, provided by the US, and a visible/ultraviolet (Vis/UV) module, provided by RF participants. This hardware division simplifies integration of the US sensors to the USP, which will take place in Russia. Both satellites will incorporate pointing mirrors to enable simultaneous stereo-optical measurements of the same scene by both suites of instruments, as Figure 1 illustrates. This discussion focuses on instrument capabilities; a discussion of instrument design appears elsewhere.[2]

The difference between the two SOIs lies in the IR sensor modules, designed and built by Utah State University's Space Dynamics Laboratory (SDL). The IR sensor on satellite #1 is a two-channel staring Radiometer/Polarimeter, with one short- to mid-wave infrared (SMWIR) channel and one mid- to long-wave infrared (MLWIR) channel. The IR sensor on satellite #2 is a two-channel staring Radiometer/Spectrometer covering roughly the same spectral regions.

The Vis/UV modules are identical on the two satellites. Each includes a visible-range high-speed camera/ radiometer (VHSC), a wide-field-of-view visible matrix camera (WFOV) consisting of five cameras with adjacent fields of view, and a UV radiometer (UVR). The RF is responsible for the design, fabrication and integration of the Vis/UV module.

A final instrument, the visible push-broom scanner (VPB), designed and built by Visidyne, Inc., appears in identical form on both satellites. The VPB is not part of either the IR or Vis/UV module, but is mounted directly to the USB sensor bay frame. Consequently it is not independently pointable, as are the other instruments.

Table I summarizes the instrument complement by satellite.

Table I: RAMOS Sensors

Pointing Mechanism	Satellite #1	Satellite #2
Pointing System 1	IR Radiometer/*Polarimeter*	IR Radiometer/*Spectrometer*
Pointing System 2	Wide-field Visible Cameras High-speed Visible Camera UV Radiometer	Wide-field Visible Cameras High-speed Visible Camera UV Radiometer
Body Mounted	Visible Pushbroom Scanner	Visible Pushbroom Scanner

Mirror System and Pointing Modes

The RF has designed a mirror system which is responsible for pointing the visual axes of the sensors in both modules. On each satellite, the primary mirror is dedicated to the IR module; slaved to that mirror is the mirror for the Vis/UV module. Sensors are arranged in such a way that their fields of view (FOV) are coaligned or are offset by known amounts. The pointing mirror arrangement maintains this FOV registry throughout the 30° x 30° overall field of regard (FOR). Figure 2 illustrates the FOV alignments of the various sensors and the limits of their excursion within the overall FOR.

The mirror system provides three different observational modes for the coaligned instruments: scanning, tracking, and step-stare. In the ***scanning*** mode, the optical instruments of both satellites will record images within one and the same scene (e.g., geographic area) when the earth is under observation. The sensors' pointing direction remains fixed relative to the satellite. Thus, as the satellites move in orbit, their fields-of-view move along the ground track: they are scanning the same "frame" that continuously moves along the ground surface as the satellites orbit.

In the ***tracking*** mode, the instruments of both satellites will look at the same area for a specified length of time by simultaneously changing the direction of the optical axes according to a prescribed program, which predicts the anticipated positions of the object under observation. In other words, the "frame" at which the sensors are looking remains fixed, keeping the object of observation in view for the observation period.

The ***step-stare*** mode is in effect a series of tracking mode observations carried out sequentially. Sensors view a stationary ground "frame" for a specified time interval, then move forward to the next programmed "frame" for the next interval.

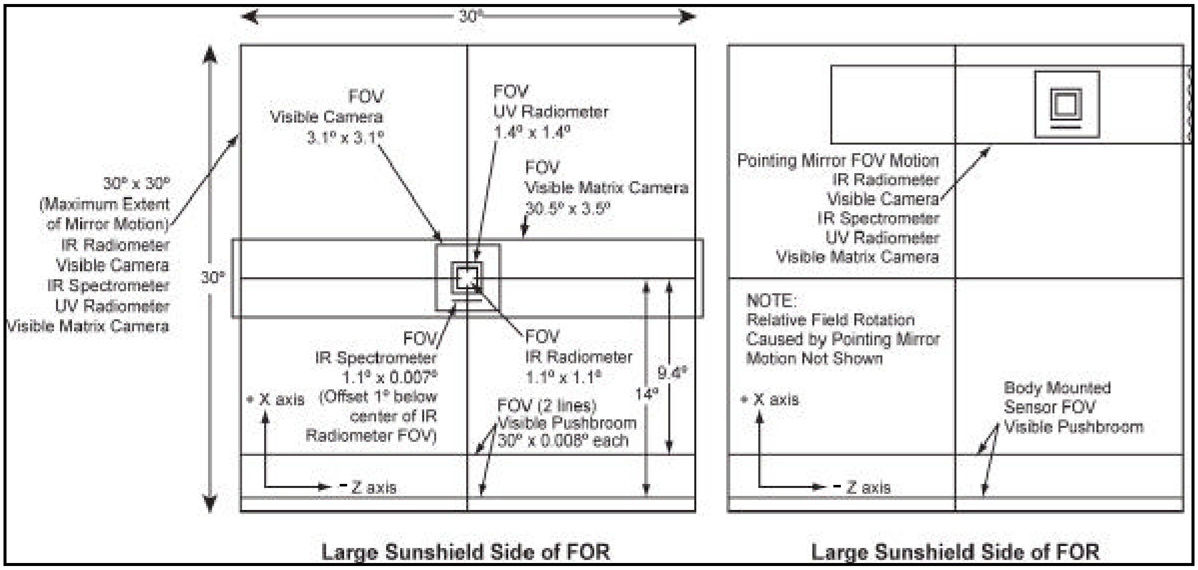

Figure 2: RAMOS Sensor Fields of View and Field of Regard

IR Module

The IR Radiometer/Polarimeter aboard satellite #1 is a two-channel (SMWIR/MLWIR) imaging radiometer with polarimetry capability in the SMWIR channel. A dichroic beamsplitter in the collimated section of the optical train separates the spectral channels, and an internal mechanism can insert a polarizer into the reflected (SMWIR) channel. This polarizing element rotates continuously and is sampled at various rotational points.[3] The instrument can therefore operate either as an imaging radiometer capable of simultaneous SMWIR and MLWIR measurements, or as simultaneous MLWIR imaging radiometer and SMWIR imaging polarimeter.

The IR Radiometer/Spectrometer aboard satellite #2 is a two-channel SMWIR/MLWIR sensor similar to the instrument aboard satellite #1, except that the polarimetry capability is replaced with two-channel imaging spectrometry capability. The spectrometer in this sensor resides on a separate optical bench and shares common afocal fore-optics with the radiometer. Energy entering the fore-optics is divided by field angle, resulting in a 1° offset between the spectrometer slit FOV and the center of the radiometer channel, as Figure 2 depicts. The radiometer and spectrometer are capable of operating simultaneously, providing two streams of radiometric data and two of spectrometric data.

The 2-channel radiometer in this instrument is identical to that in satellite #1, except that the SMWIR channel does not have a polarizer mechanism, and the specific SMWIR bandpass filters are different.

The spectrometer is a two-channel (SMWIR/MLWIR) sensor, with incoming energy divided by a dichroic beamsplitter. The spectrometers are pushbroom-type instruments, wherein the spatial domain data are collected in the cross-track direction and the spectral domain data are collected in the along-track direction. The image is thus built up by the forward motion of the satellite in the along-track direction. Both spectrometer channels are diffraction-grating based instruments, each with a unique grating to produce the required spectral dispersion.

Both sensors have 128 x 128-pixel imaging arrays with 70µm pixels, operating at 77K for improved sensitivity. The combination of these focal planes with the instrument telescope produces an FOV of approximately 1° x 1°, and an instantaneous field of view (IFOV) of approximately 150 µrad. In the radiometer/spectrometer, each row of the focal plane array serves as the exit slit for the spectrometer. The spectrometer optics are designed to produce the same FOV characteristics in the spatial direction as the radiometer

Each spectral channel of the radiometers on both satellites contains a rotating filter wheel that enables selection of specific spectral bandpasses within the broader SMWIR and MLWIR spectral regions. The MLWIR filters are identical on both satellites, but the SMWIR filters differ between the two.

Table II identifies the IR filter bandpasses for satellites 1 and 2, and Figure 3 depicts those bandpasses against earth radiance curves, along with the bandpass of the spectrometer on satellite 2

Table II: Bandpasses of RAMOS IR Radiometer Spectral Filters by Satellite

SMWIR Filters				MLWIR Filters	
Satellite #1		Satellite #2		Satellites #1, #2	
No.	Bandpass (μm)	No.	Bandpass (μm)	No.	Bandpass (μm)
1	2.00 – 2.40 (P)	1	1.45 – 1.60	1	4.66 – 4.90
2	2.70 – 2.95 (P)	2	1.95 – 2.19	2	5.40 – 7.20
3	2.95 – 3.20 (P)	3	2.21 – 2.40	3	5.20 – 6.20
4	3.20 – 3.50 (P)	4	2.70 – 2.95	4	5.20 – 7.50
5	3.75 – 4.20	5	3.75 – 4.20	5	4.66 – 7.50
6	4.23 – 4.45	6	4.23 – 4.45		
7	4.35 – 4.55	7	4.35 – 4.55		

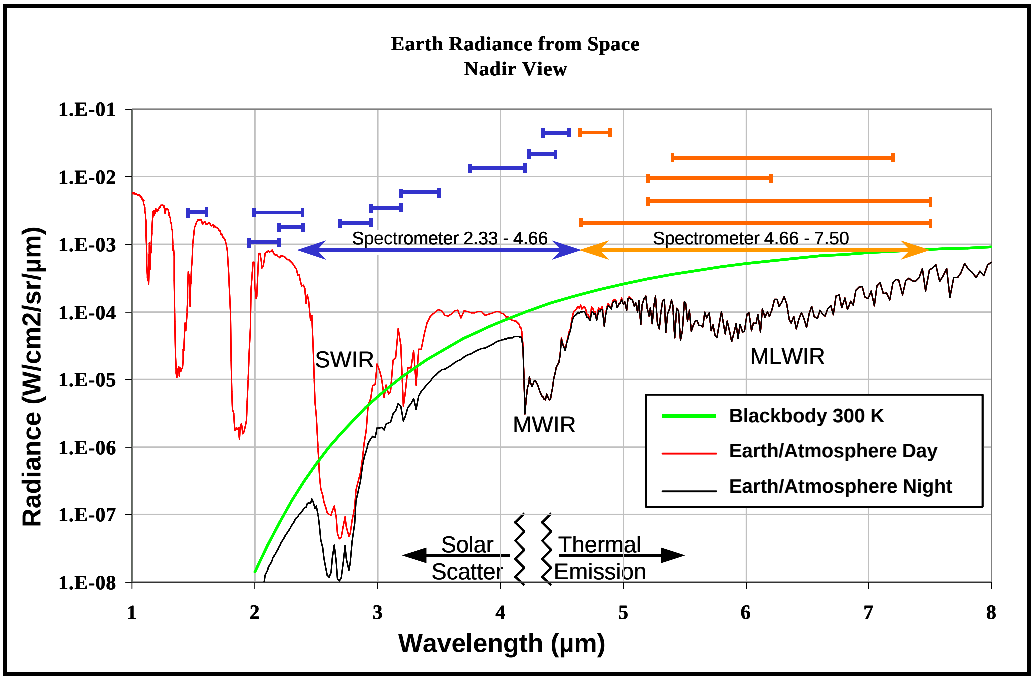

Figure 3: RAMOS IR Spectral Filter Bandpasses Shown Against Earth Radiance Background

Vis/UV Module

The Vis/UV modules, provided by the RF team, are identical on both satellites. Each consists of a visible-range high-speed camera/radiometer (VHSC), a wide-field-of-view visible matrix camera (WVOF) comprising five cameras with adjacent fields of view, and a UV radiometer (UVR). The secondary (slave) mirror points the visual axes of these sensors, and their FOVs are coaligned with those of the IR module sensors as Figure 2 illustrates.

The high-speed visible radiometer comprises a baffle, focusing optics or a lens section, a filter wheel for selectable spectral bandpasses, and a cooled detector unit. The filter wheel contains three discrete spectral filters and an open position. The radiometer's 512 x 512-pixel focal plane array will be read out at a 100 Hz frame rate. The instrument has a nominal FOV of 3.1° x 3.1°; Figure 2 illustrates its location in relation to the FOVs of the other instruments.

The matrix camera consists of an array of five cameras, each with a FOV of 3.5° x 6.25°. These five adjacent FOVs overlap slightly to form a total matrixed FOV of 3.5° x 30°, which fills the entire FOR of the RAMOS SOI in the cross-track direction; Figure 2 identifies this FOV. Each camera consists of a body containing detectors and interfaces, a lens element and forebaffle.

The UV radiometer is an imaging two-channel instrument consisting of a baffle, a lens assembly, a dichroic beamsplitter, and two focal planes along with the appropriate electronics. Each optical channel features a filter wheel to select spectral bandpass. The beamsplitter separates the incoming energy into a reflected short wave channel and transmitted long wave channel. The short wave channel has a FOV of 1.44° x 1.92°; the focal plane for this channel is a 290 x 384 pixel device, which yields and IFOV of approximately 87 μrad. The long wave channel has a FOV 1.47° x 1.47°, and uses a 576 x 576 pixel focal plane, which results in an IFOV of 50 μrad.

The Vis/UV Module sensors together cover a spectral range from 0.2 μm to 0.96 μm in several discrete passbands of specific interest; this spectral filtering is identical on the two satellites. Table III lists the spectral passbands for filters in each of these instruments, and Figure 4 displays those passbands against a plot of daytime nadir-viewing earth radiance at two solar scatter angles.

Table III: Bandpass Filters for Vis/UV Module Sensors

Visible High-Speed Camera			
No.	**Bandpass (μm)**	**No.**	**Bandpass (μm)**
1	0.600 – 0.960	3	0.910 – 0.960
2	0.500 – 0.650	4	0.400 – 0.960
Visible Wide Field of View Cameras			
Channel 1		**Channel 2**	
No.	**Bandpass (μm)**	**No.**	**Bandpass (μm)**
I. 1	0.620 – 0.670	II. 1	0.740 – 0.760
I. 2	0.540 – 0.565	II. 2	0.840 – 0.870
I. 3	0.459 – 0.497	II. 3	0.910 – 0.960
I. 4	Blank	II. 4	0.400 – 0.960
UV Radiometer			
Channel 1 (SW)		**Channel 2 (LW)**	
No.	**Bandpass (μm)**	**No.**	**Bandpass (μm)**
I. 1	0.200 – 0.230	II. 1	0.300 – 0.320
I. 2	0.230 – 0.280	II. 2	0.320 – 0.350
I. 3	0.280 – 0.300	II. 3	0.350 – 0.400
I. 4	0.200 – 0.300	II. 4	0.300 – 0.400

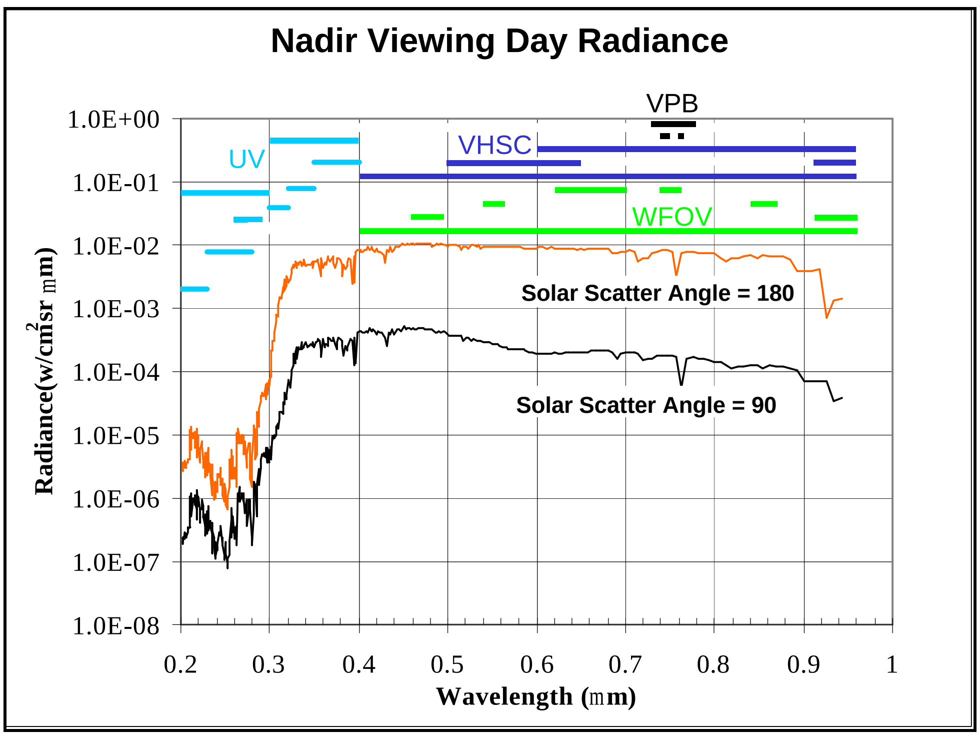

Figure 4: RAMOS Filter Passbands For UVR, VHSC and VPB Shown Against Earth Radiance Background at Solar Scatter Angles of 90° and 180°

Visible Push Broom Scanner

The visible pushbroom sensor, designed by Visidyne, Inc., is a linear-array sensor featuring a sunshade baffle, a focusing lens assembly, polarization and spectral filters, and five linear focal planes. The VPB is unique among the RAMOS SOI in that it is a body-mounted sensor, and its optical axis is not steered with either of the two pointing mirrors. The along-track dimension of the images from the VPB must be built up using the forward motion of the satellite.

The VPB contains five linear array focal planes and associated filters for measuring both polarized and unpolarized light. Three of these arrays are filtered for linear polarization with the electric field vector at 60° increments. The two additional linear arrays make spectral measurements of the unpolarized sunlight reflected from cloud tops.

All five arrays are identical and result in IFOVs of 128 μrad in along-track direction and 64 μrad in the cross-track direction. The total FOV of the VPB is 30° in the cross-track direction, and depends upon the sample frequency in the along-track direction. Figure 2 shows the location of the visible pushbroom sensor's FOV with respect to the other instruments in the RAMOS SOI. Table IV lists the passbands of the VPB filters; the location of these passbands appears in Figure 4 against a plot of daytime nadir-viewing earth radiance at two solar scatter angles.

Table IV: Bandpass Filters for VPB Sensor

Visible Pushbroom Scanner	
Filter No.	**Bandpass (μm)**
1 (Polarization)	0.730 – 0.780
2 (Cloud top I)	0.760 – 0.767
3 (Cloud top II)	0.740 – 0.747

MEASUREMENT EXPERIMENTS

A unique and important feature of the RAMOS program is its ability to obtain image data simultaneously from two vantage points, enabling post-collection reconstruction of three-dimensional images of the observed target.[4] The RAMOS Joint Science Team (JST) has developed a set of unique measurement experiments for the RAMOS satellites that will take advantage of this capability to perform the defense and environmental measurement and technology demonstration identified earlier. RAMOS is designed to also conduct meaningful measurement experiments that are not stereo-optical in nature, but use the sensors' multi-spectral, radiometric, spectrometric and polarimetric capabilities. These experiments constitute a research and development effort using new technologies for the improvement of spaced-based early warning and tracking systems and assessment of environmental phenomena of global importance. The JST has undertaken numerous modeling and simulation tasks to determine trade-offs for the experiments. They have used and will continue to use laboratory and other pertinent experiments, conducted by the national science teams of both countries, to provide truth data for model creation, improvement and validation.

The RAMOS experiments fall into seven generic types, summarized in Table V. A more detailed discussion of each type appears in the sections following the table.

Table V: Generic RAMOS Experiment Types

Generic Experiment Title	Wavelength Region	Statement of Objective	Data Collected	Analytical Product
Moving Object Experiment (MOE)	MWIR/ MLWIR comparison	Collect data to demonstrate ability to observe post-boost warm body against the hard earth background and reconstruct 3-D trajectory	MWIR-MLWIR scene pairs, from two satellites, collected in step-stare patterns following moving object trajectory	Scene processing to extract target from background, reconstructed 3-D trajectory
Multi-Spectral & Stereo Backgrounds (MSB)	MWIR/ MLWIR comparison	Collect background scene database directly comparing MWIR and MLWIR bands, with characterization of source regions (e.g. clouds) and environment (e.g. atmospheric water content)	Image quadruplets (MWIR vs. MLWIR stereo pairs) for a range of observation conditions, with supporting data to characterize radiance source regions and environments	Comparison of MWIR vs. MLWIR scene structure content, background images suitable for midcourse tracking studies and for model building
Background Effects of Solar Scatter (BES)	SWIR, window bands	Characterize polarized solar scattering from water and ice clouds. Investigate properties of solar glints with multi-angle, multi-spectral and polarization measurements	Polarized SWIR image data for range of observation conditions with emphasis on solar glints. Supporting visible polarization data	Characterization of solar glint phenomenology, and assessment of polarization, multi-angle, and multi-spectral false alarm mitigation techniques
Short Duration Events (SDE)	All window bands: UV, visible, and IR	Observe short duration events in stereo, including detection through clouds, and demonstrate ability to geolocate accurately in 3-D	High frame-rate multi-spectral stereo image data of various short duration events	Characterization of ability to detect, identify and geolocate short duration events under various observation conditions

Generic Experiment Title	Wavelength Region	Statement of Objective	Data Collected	Analytical Product
Fast-Changing Events (FCE)	All window bands	Demonstrate that fast changing events can be detected, observed, and usefully characterized by remote sensing from low earth orbit	Multi-spectral stereo images suitable for source geolocation and characterization	Estimates of hurricane strength, volume extent of volcanic plume, large fire dynamics
Wind Velocity Distribution (WND)	Visible, including VPB cloud-top filters	Demonstrate the ability to determine from remote sensing the three-dimensional distribution of wind velocity on a worldwide basis	Time-dependent stereo image pairs, time-spaced VPB cloud top filter sweeps	3-D distributions of wind velocity
Water Vapor Profiles (WVP)	SMWIR and MLWIR spectrometer	Characterize the three-dimensional distribution of water vapor concentration in the lower 10 km of the atmosphere at the horizontal scale of 100 meters	Three-dimensional data "cubes" (spectral data on a 2-D spatial grid)	3-D water vapor distributions, understanding of water vapor impact on IR background scene structure

Moving Object Experiment

The primary goal of the Moving Object Experiment (MOE) is to acquire and observe theater-class rockets in the mid-course (i.e., post-boost) phase of their trajectories under difficult viewing conditions. This series of experiments will also obtain multi-spectral measurements of the boost phase for later study. Dedicated rocket targets will be launched from instrumented ranges in the US and Russia, and the demonstration objectives will all be met through post-flight processing of the collected data.

The three primary measurement objectives of the MOE are:

- Comparing the performance of the MWIR (4.25 µm – 4.45 µm) with MLWIR (5.4 µm – 7.2 µm) for warm body observation after burnout against a hard earth background,
- Demonstrating that stereo viewing provides significant improvement in rocket trajectory reconstruction, and
- Comparing short-wave infrared (SWIR), MWIR, MLWIR and UV observations during the target rocket boost phase.

Secondary objectives include observing a warm body above the horizon (ATH) at long ranges and, if possible, during rocket reentry.

The MOE will follow a sequence that will be similar for each rocket firing. Both satellites will observe the moving object in a step-stare pointing mode, with each satellite executing its own step-stare sequence in order to keep the object in its field of view. The rocket trajectory will follow a path roughly parallel to that of the satellite orbits in order to maximize the opportunity to meet observation objectives, which include at least 60 seconds of post-boost, below-the-horizon (BTH) viewing with good stereo angle separation. Pre-planned step-stare pointing sequences (points in space, above the earth) will be up-linked to the satellites based on the expected rocket trajectory and calculated satellite trajectories based the latest ephemeris data. Provisions exist for updating this planned sequence to account for inevitable target dispersion.

The visible push broom scanners will collect background data where feasible along the geographic swath of the planned rocket flight trajectory. The visible cameras, co-aligned with the radiometers on each satellite, will also collect data during the entire experiment. The UV radiometer will be activated during the boost phase and later if the rocket re-entry phase is in view.

Both satellites will point their radiometers to the launch site prior to and at ignition. The MWIR (atmospheric carbon dioxide absorption) and MLWIR (atmospheric water-vapor absorption) infrared radiometer bands on both satellites will remain fixed throughout the midcourse phase of the experiment. Simultaneous measurements in MWIR and MLWIR bands will provide direct comparison of the utility of these bands for different observational conditions from BTH to ATH for post-boost objects. In a variant of the MOE, one satellite may collect SWIR data during the boost phase and switch to the MWIR band after burnout

The MOE will obtain multi-spectral observations of the boost phase. These will include ultraviolet measurements as well as the SWIR, MWIR, and MLWIR wavelength regions. Although spectral measurements of plumes is a lower priority, direct comparison of these various spectral intensities as the rocket exits the lower atmospheric absorption (O_3, H_2O, CO_2) regions is of interest.

Multi-spectral measurements of rocket burnout time are also of interest as they affect the post-boost trajectory and impact area predictions. The remote sensing of impulse cessation may be wavelength-dependent, because there are different radiative phenomena involved for each of the spectral regions. Launch detection is a primary question for the ultraviolet region where the signals are known to be relatively weak and the radiative mechanisms are far less well understood than in the infrared.

Finally, the MOE will provide important data with which to investigate the potential for improved discrimination of low-contrast objects through registration of the stereo-optical image pairs.

Multi-Spectral and Stereo Backgrounds Experiment

The objective of the multi-spectral background measurements (MSB) is to acquire spatial/temporal radiance image databases of earth backgrounds taken simultaneously in two or more IR sensor bands which are pertinent to the reconstruction of mid-course trajectories (post-boost, warm-body). Of primary importance is the direct comparison of the nominal MLWIR water vapor absorption band (5.4 µm to 7.2 µm) to the carbon dioxide absorption band (4.23 µm to 4.43 µm). These databases will be useful for model building, as well as for direct use in simulating prospective future space-based sensors whose goal is observing dim targets against the backgrounds. These two uses determine the required quality (precision) and character (spatial resolution) of the database generation.

The MSB experiment will collect data in each band as a function of sensor viewing angle, geographical location, season and time of day. Repetitive measurements under these conditions will permit the study of scenes having pronounced stochastic character such as cloud cover, cloud type and altitude distribution, temperature or water vapor fluctuations, auroras, mesospheric clouds, or gravity waves induced by various occurrences such as thunderstorms. In the wide field, both filtered band data and temporal-sequential stereo reconstruction will determine cloud altitudes.

To obtain an experimental database that supports wavelength band selection it is necessary to use an IR spectrometer for measurements in near-horizon viewing geometry. The uncertainties in water vapor distribution and scene structure are not amenable to modeling with sufficient accuracy, particularly at the large nadir angles of importance for world-wide sensing from low earth orbits. For many background scenes of interest, water vapor dominates the observed radiance and spatial structure. Consequently, spectral measurements are required to determine the water vapor distribution along the line of sight.

The IR radiometers will collect background data operating in a step-stare mode. In most cases the sequence of stare points will be designed to provide partially overlapping (~20 percent) images suitable for "stitching" together into a large mosaic. In some cases, the sensors will operate in the tracking mode, collecting data as a function of viewing angle as the satellites fly by. Another intermediate variant will be to revisit several times a small swath of overlapping image positions.

For stereo reconstruction of the background, both satellites will measure the same pair of bands. The MLWIR measurements will include other (narrower) spectral passbands in addition to the baseline band. Simultaneous observation in the visible band (VPB, VHSC and/or WVOF matrix cameras) will help characterize the type of backgrounds being measured and allow post-processing registration of the IR images.

Background Measurements for Reducing False Alarms

The Background Effects of Solar Radiation (BES) experiment will examine three approaches to minimizing the potential for false alarms in EW systems: stereo-optical measurements, multispectral measurements and polarization measurements.

The BES will record stereo-optical data taken under a variety of viewing conditions (different viewing angles, solar angles and cloud conditions) representing background scenes typical of both low- and high-earth orbits. Post-processing and three-dimensional reconstruction from these stereo data will enable analysts to assess the potential for improved detection of dim targets in cluttered backgrounds. Stereo observations of glint events will identify sources and suggest potential methods for mitigating false alarms arising from solar glints. Stereo reconstruction of selected background data will facilitate model building and enable model predictions to fill gaps in the database that cannot be sufficiently populated by the measurements.

Most background clutter in the SWIR spectral region (2.5 µm to 3.5 µm) arises from solar radiation scattering primarily from clouds, and secondarily from other surface features such as lakes or snow fields, if the passband sees to the ground. The BES experiment will collect data to support evaluation of a potentially powerful two-color approach to significantly reduce early-warning false alarms, where the background signals from the second color result from a totally different phenomenology. While background clutter in the SWIR regime is dominated by solar scattered radiation, the clutter in the MLWIR spectral region (~ 5 µm to 7.5 µm) is dominated by thermal emission – the MLWIR background is the same both day and night. One can also band-limit observations in this band to control the altitude to which a sensor can see. A target (plume) has strong signals in both spectral regions because of hot water vapor emissions, whereas a phenomenon producing a potential false alarm would be expected to radiate primarily in one or the other region. RAMOS will make simultaneous SWIR/MLWIR background measurements to assess this false alarm mitigation approach. The BES may also measure the ultraviolet background. These backgrounds, dominated by atmospheric ozone at altitudes above typical cloud layers, are expected to be very smooth.

The BES experiment to measure solar glint regions will characterize the polarization of the scattered sunlight (total intensity, percent linear polarization and polarization angle) as a function of solar scattering geometry for a variety of background conditions, assessing the value of polarization background measurements for reducing false alarms. The IR polarization measurements will be limited to the SWIR, where solar scattered radiation prevails, and they will be supported by correlated visible band polarization measurements from the VPB. Viewing geometry will include: a) clouds near the horizon; b) clouds near the Solar Specular Area (SSA) at small scattering angles, and c) other natural phenomena that are commonly observed far from the SSA and which currently do not have firm theoretical explanation. RAMOS will make polarization measurements for a wide variety of solar scattering angles (from less than 10 degrees to more than 170 degrees depending on sight path nadir angle) to support model-building and development of clutter mitigation strategies. Measurements in at least two near-infrared bands will provide data for cloud diagnostics, to identify the cloud particles as ice crystals, water droplets, or mixed phase. Analysis of infrared and visible polarization measurements from aircraft and in the laboratory (cloud chamber) will support model validation and optimization of the space-based experiments.

Short Duration Event Observations

The RAMOS sensors' fast frame-rates will enable observation and characterization of optical radiation from very short duration events (SDE), such as ignition spikes at launch sites, rocket engine burns, artillery engagements, and explosions. These signatures have in common very fast rise time and duration ranging from a few to hundreds of milliseconds. The SDE observations call for visible, SWIR, MWIR, and MLWIR data to be taken simultaneously in up to six bands (one visible and two IR bands for each satellite). UV observations will provide data to explore for possible signatures. The IFOV (~ 100 meter footprint) of the RAMOS sensors will demonstrate useful geolocation estimates of the short-term events. Footprints at nadir for the UV photometer are on the order of 50 meters for the far UV and 25 meters for the near UV, so measurements from these instruments can support source geolocation. Controlled experiments of detonations and launches will permit the RAMOS program to build the database and to evaluate the accuracy of the geolocation estimates using stereo methods.

Fast Changing Events Observations

"Fast changing" events (FCE) are those dynamic environmental occurrences with optical signatures that change on time scales ranging from minutes to hours or days. They include such things as cyclones, volcano eruptions, forest fires, industrial fires, and fires from accidents such as aircraft crashes. The RAMOS FCE observations will provide data with which to evaluate the utility of RAMOS-type measurements (i.e., multi-spectral, stereoscopic measurements with good spatial resolution) to identify, measure and predict the course of disaster events. Information from analyses of these measurements could support the National and Global Disaster Information Networks (NDIN and GDIN) in their disaster mitigation efforts. Short tasking times are important for implementing successful observations of this nature, and short receiving times are valuable for reporting the results.

The FCE observations planned for RAMOS will examine two types of events: volcanic plumes and cyclones.

FCE measurements will demonstrate the ability to use the data from one or both satellites to define the plume from an active volcano, when it is far removed from the source and has thinned to become a translucent cloud, but still poses a threat to jet aircraft that might penetrate it. In this case, defining the extent (top, bottom and width) of the plume is crucial. RAMOS will use tomographic methods with data from each satellite, correlating the two views to assist in defining the cloud's spatial extent. To validate this approach, RAMOS will similarly measure aircraft contrails, where ground measurements of the altitude and width of the contrails can provide truth data.

At present, the best estimates of cyclone strength come from flights of "Hurricane Hunter" aircraft into these storms. These estimates are available only for a small region hear the east coast of the United States, however; the strength of cyclones far at sea can be only crudely estimated from measurements inferred from weather satellites. Theory predicts that the RAMOS remote, stereo-optical measurement capabilities can provide significantly improved hurricane strength estimates over current methods. The requirement for this improvement is the ability to measure the altitude of the turrets protruding above the cyclone's eye-wall to an accuracy of about ±100 meters, and their temperature to within a few Kelvins; both requirements are well within RAMOS capabilities. In addition, RAMOS can also provide input to steering wind prediction models by making 3-dimensonal stereoscopic measurement of the motion of cloud fragments in the eye and outflow zones of interest. The FCE observations will attempt to demonstrate this capability by targeting storms in the Atlantic, where the "Hurricane Hunter" aircraft system can provide truth data.

Wind Velocity Distribution

RAMOS will demonstrate the capability to unambiguously measure the wind velocity altitude profile world-wide by stereo tracking cloud fragments over a time period of a few to many minutes. These measurements can impact numerical weather forecasting far removed from land based observation sites. These measurements will be conducted when possible in conjunction with ground truth measurements being made by other agencies.

Water Vapor Profiles- Worldwide

Using the satellites' spectral measurement assets, RAMOS will demonstrate the ability to ascertain the vertical distribution of water vapor in the atmosphere, especially near the tropopause and in the 0 to 3 km altitude range. Remote sounding requires data in the water vapor spectral band supported by additional spectral measurements to determine surface contributions, atmospheric temperature profiles, and contamination of the data by the presence of clouds and/or aerosols. These measurements at 100 meter spatial scale (or less) will assist in the forecasts of climatological change and weather prediction.

CONCLUSION

RAMOS is a unique program in many ways. It has been the only cooperative space-based research program extant between the US Department of Defense and the Russian Ministry of Defense, it has enjoyed support at the highest levels of both governments, and it has brought scientists and engineers of the two countries together for more than a decade of fruitful cooperative research. In addition to its "pathfinder" status, RAMOS has been the only program investigating the usefulness of simultaneous, multi-spectral stereo-optical imaging in the reduction of potential false alarms inherent in early warning systems—a capability of crucial importance to the US, Russia and the entire international community of nations. Finally, no other program is evaluating the utility of this unique simultaneous stereo-optical/multi-spectral imagery in assessing hazardous environmental phenomena worldwide and predicting their evolution and potential impact on human health and safety.

In February, 2004, MDA announced plans to bring the RAMOS program to an orderly closure prior to a Critical Design Review.

REFERENCES

1. Humpherys, T., R. Anderson, A.T. Stair, I. Schiller, V. Sinelshchikov, V. Abramov, V. Misnik, "Environmental Objectives for the Russian American Observational Satellites (RAMOS)," Proceeding of the SPIE Conference on Multispectral and Hyperspectral Remote Sensing Instruments and Applications, Vol, 4897, pp. 99-108, June 2003

2. Crowther, B., V. Zakharenkov, G. Jensen, V. Sinelshchikov, T. Humpherys, V. Misnik, R. Anderson, J. Atkinson, "Sensor Design and Capabilities for the Russian American Observational Satellites (RAMOS)," Proceedings of the SPIE Conference on Sensors, Systems and Next-Generation Satellites VII, Volume 5234, pp. 96-105, February 2004.

3. Peterson, James Q., G.L. Jensen, J.A. Kristl, J.A. Shaw, "Polarimetric Imaging using a Continuously Spinning Polarizer Element", Proceedings of the SPIE Conference on Polarization Analysis, Measurement, and Remote Sensing III, Vol. 4133, pp. 292-300, July/August 2000.

4. Stair, A.T., V. Abramov, A. Sidorin, T. Stephens, J.W. Carpenter, A.J. LePage, V. Sinelshchikov, V. Misnik, T. Humpherys, P. Gretzkowski, "RAMOS (Russian American Observational Satellites) Experiments to Obtain a Three-Dimensional Background Data Base," Multinational Ballistic Missile Defense Conference & Exhibition, June 2003.