Environmental objectives for the Russian American Observational Satellites (RAMOS)

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ABSTRACT

The RAMOS program embodies a new direction for cooperative space-based research and development between the Russian Federation and the United States. The planned system configuration is a constellation of two satellite orbiting in approximately the same plane at an altitude of about 500 km. These satellites, equipped with passive electro-optical sensors operating from infrared (IR) to ultraviolet (UV), are designed for near-simultaneous stereo-optical measurement capability. The projected launch date is 2007 with an on-orbit lifetime of two years minimum and five years possible. The environmental objectives are: 1. Measuring cyclones to predict their future strengths and paths, 2. Measuring fires and winds to demonstrate location and assessment capability, 3. Measuring volcanic plumes in three dimensions to assess aircraft hazards, 4. Measuring global three-dimensional wind velocities, 5. Measuring water vapor profiles at the 100-meter scale, 6. Obtaining a three-dimensional multi-spectral background data base in the mid-wave infrared, visible and ultraviolet wavelength regions and making infrared and visible polarization measurements of solar scattered backgrounds.

Keywords: remote stereo sensing, hurricane, backgrounds, polarization, scattering, tracking, water vapor.

1. INTRODUCTION

The scientific objective of the RAMOS project is to employ simultaneous stereo-optical techniques from two co-orbiting satellites to address global environmental issues (Fig. 1). This stereo capability will enable multi-spectral stereo-optical measurements of hurricanes, volcanic plumes and fires, polarization measurements of solar glints, 3-D wind velocity measurements, 3-D water vapor soundings and numerous other experiments. The results of these experiments will point the way toward improving existing technologies and developing new technologies for spaced-based global environmental monitoring systems.

Two Russian-made satellites will be launched into a common low circular orbit of about 500 km altitude. The satellites are controlled independently but in concert. They are capable of accurate pointing, of maintaining the desired separation over a range of distances, of accurately determining their respective positions, and of conducting simultaneous observation of scenes of interest. The satellites are equipped with American- and Russian-made sensors which can conduct radiometric, spectrometric, and polarimetric measurements. The satellites can simultaneously conduct observations in one of the three modes: scanning, staring, and step-staring. A joint Russian American science team is active in defining the objectives and preparing experiment plans of the experiments[1].

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, to compare calibrations, and to compare independent analyses. Exchanging scientific data between the users in the two countries is a key component of RAMOS. A Joint Mission Operation Center (JMOC) in Moscow, Russia, will coordinate the functions of communication, spacecraft constellation maintenance, experiment execution, data collection and data distribution. The JMOC will be responsible for directing the satellites to perform an average of two data collection experiments (DCEs) per day over the life of the mission. Each DCE can be as long as 10 to 12 minutes of continued observations. The science data will be downlinked to the JMOC from the satellites, quickly validated, and distributed to both Russian and American science teams for farther processing and analysis.

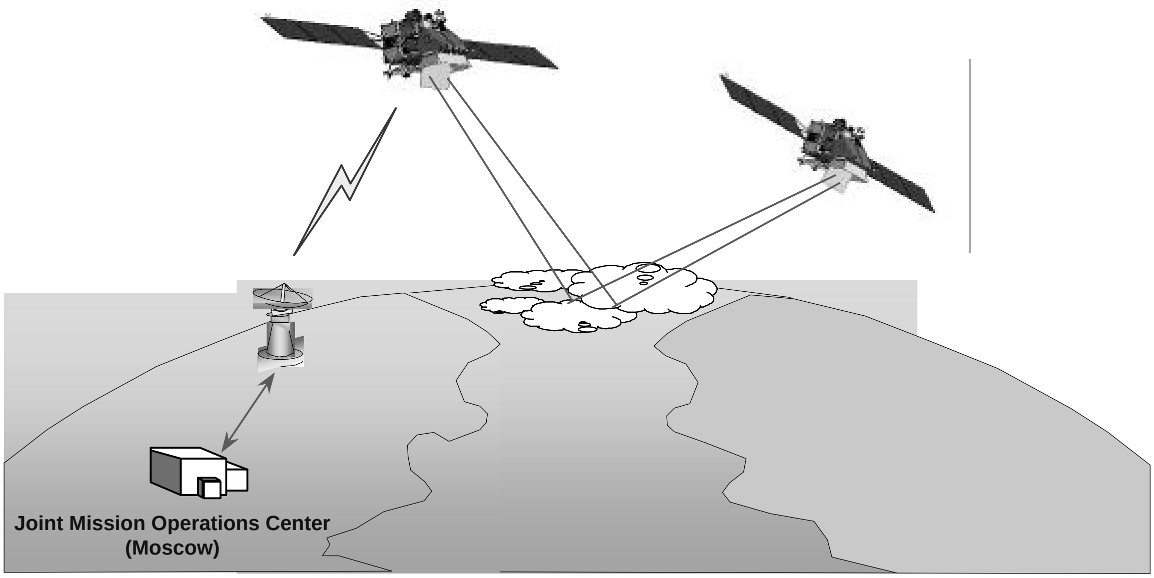

Figure 1: Orbiting approximately in the same plane at the altitude of 500 km, the two RAMOS satellites are designed to use their on-board passive electro-optical IR, visible, and UV sensors for near-simultaneous stereo-optical measurements in a variety of environmental and defense-related experiments. .

2. PAYLOAD CONFIGURATION

Two satellites, based on the Russian Yacht universal space platform, will feature a unique configuration of high resolution payload sensors designed to support a vide variety of experiments. Nearly identical sets of payload sensors on the two satellites are grouped behind two pointing mirrors (Fig. 2). The first mirror will point the IR radiometer, and the second mirror, slaved to the IR mirror for co-registration, will support the wide field of view (FOV) matrix camera, the visible camera and the UV radiometer. In addition, a body- mounted visible push-broom scanner camera will make polarization and cloud top measurements.

The payload sensors can be pointed anywhere within 30.5º by 30.5º (4p steradian) field of regard to provide flexible simultaneous measurements (Fig. 3). The field of regard can be located over 4 p steradians by rotating the satellites. The payload suite on each satellite is listed in Table 1 and consists of:

1) An IR radiometer, the primary instrument, with a 128 x 128 detector array with about 140 µrad pixel IFOV (~ 1º total field);
    a) Satellite 1: radiometer has multiple filters and polarization capability
    b) Satellite 2: radiometer will be able to provide both image and spectral observations in MLWIR to SWIR bands (7.5 to 1.5 µm).
2) A co-aligned 3º x 3º, high speed (=100 Hz) visible camera with similar pixel IFOV;
3) A co-aligned wide field 3º x 30º visible camera system consisting of 5 cameras featuring red, green, blue filters or other selected passbands on demand that provide adjacent and slightly overlapped images for continuous wide field reconstruction;
4) A multi-filtered, two-channel ultraviolet photometer: one channel covers 200-300 nm with a 2º x 2.6º field of view, and the other covers 300-400 nm with a 1.4º x 1.4º field of view;
5) A 30º wide FOV visible push-broom sensor designed to cover a wide swath of space with its linear detector array as the satellites move.

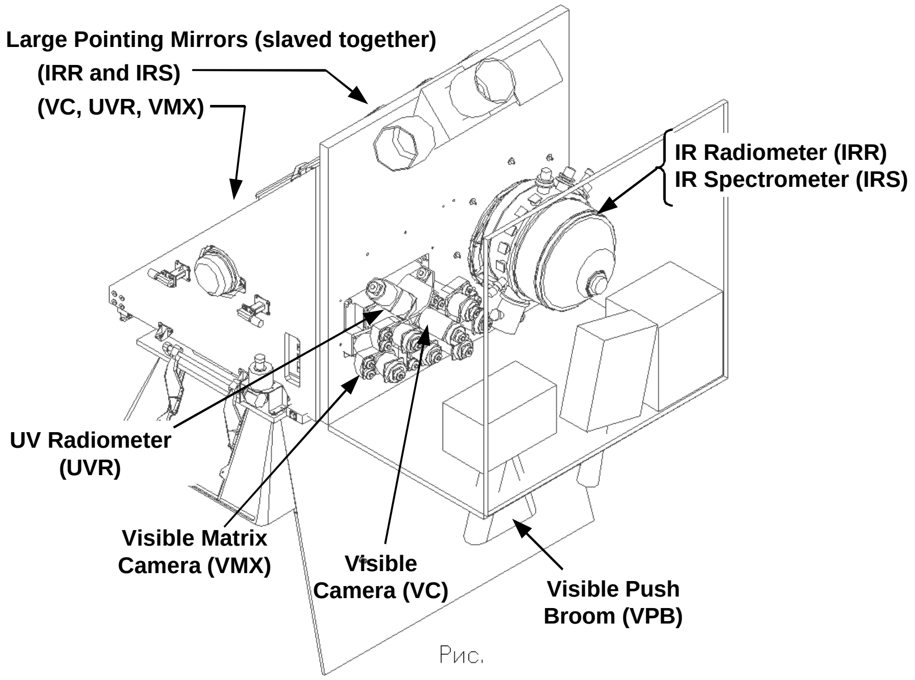

Figure 2: Proposed sensor suite configuration will feature high resolution payload sensors designed to support a vide variety of experiments. Nearly identical set of payload sensors on the two are grouped on two mirrors. The first mirror will point IR radiometer/polarimeter on Satellite 1 (IR radiometer/spectrometer on Satellite 2). The second mirror will support wide FOV matrix camera, visible camera and UV radiometer, and. a push-broom scanner camera is body mounted.

Table 1. RAMOS Payload Configuration.

Two Satellites (Both Active) – Two ROKOT Launchers		
	Satellite #1	Satellite #2
Pointing System #1	Infrared Radiometer/ *Polarimeter*	Infrared Radiometer/ *Spectrometer*
Pointing System #2	High Speed Visible Camera	High Speed Visible Camera
	Wide Field Visible Cameras	Wide Field Visible Cameras
	Ultraviolet Radiometer	Ultraviolet Radiometer
Body Mounted	Visible Push-broom Scanner	Visible Push-broom Scanner

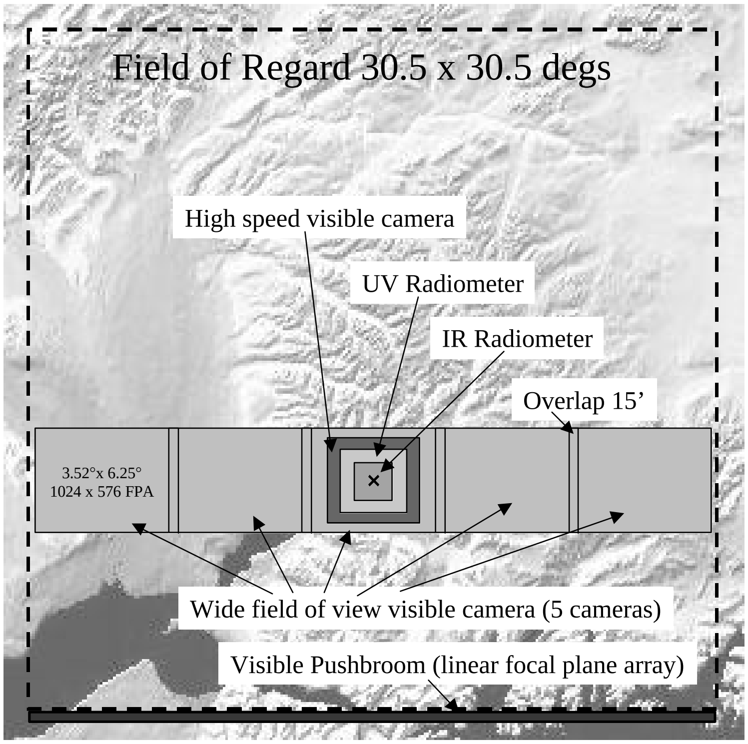

Figure 3: The payload sensor footprints can be pointed anywhere in a 30.5º by 30.5º field of regard, form a configuration with (1) 1º x 1º IR radiometer in the center, (2) a co-aligned variable FOV ultraviolet photometer, (3) a co-aligned 3º x 3º high speed visible camera, (4) a co-aligned wide field 3.52º x 30.5º visible camera system consisting of 5 cameras, and (5) a 30º wide FOV visible push-broom sensor that will cover the entire field of regard if the satellite moves in vertical direction on this figure.

3. RESEARCH AND PREPARATION

RAMOS benefits from a number of past experiments in which both Russian and American teams participated. These experiments were designed to produce a better understanding of the use of stereo-optical measurements, polarization measurements, atmospheric observations, solar scattering and numerous other phenomena. A number of joint projects were undertaken to prepare for and define parameters of the RAMOS mission.

In 1996, U.S. and Russian remote sensing measurements were made in the region surrounding Mt. Erebus, Antarctica[2,3]. The data were obtained from the US Midcourse Space Experiment (MSX) satellite and Russian Resurs-O 1 Earth Resources Satellite. Over 1,200 multi-spectral images and other data were obtained by the satellites. This program demonstrated the ability for stereoscopic analysis of scene data from two separate observation platforms with sensors of totally different design. A number of techniques were developed for generic stereo processing that were applied not only to data from this experiment, but were applicable to future joint observations as well.

From 1997 until 2000 a series of flights by the US Flying Infrared Signatures Technology Aircraft (FISTA) obtained spectral and polarization imagery (Fig. 4). The FISTA program allowed continuous modifications to be made to the instruments and the experiment design over the course of these flights, improving the quality of the data collected and leading to a more detailed view of the environment observed.

In 1997 and 1998 FISTA obtained polarization measurements of solar radiation scattered from clouds in a number of infrared and visible wavelength bands simultaneously. The purpose of this investigation was to obtain the data required to characterize the polarization properties of various atmospheric phenomena with applications to background clutter mitigation, the ability to differentiate between clouds of various compositions (e.g., ice versus water clouds), and the verification of theoretical polarization models. The data gathered during the FISTA flights has yielded a large body of usable polarization data.

An analysis of the FISTA data indicated that the degree of polarization from an apparently homogeneous deck of clouds can vary markedly at a given scattering angle[4]. This can arise from differences in the source of scene illumination, the spatial variability in scattering properties of the clouds, and wavelength-dependent contributions from scattering in the clear atmosphere above the cloud deck. Computer-based polarization models that were developed using single-scattering theory indicated that differences in cloud composition, for example, can be best determined by making polarization measurements at wavelength bands corresponding to the shoulders of infrared absorption bands of ice and water. These data were used to plan further experiments and to verify the computer models.

Figure 4: Flying Infrared Signatures Technology Aircraft (FISTA)

In 1998, additional FISTA flights studied atmospheric absorption[5] to obtain data to refine models of background clutter. These flights used a suite of instruments that included a Russian-built water band radiometer called the Aquameter. This instrument was designed to produce high spatial resolution imagery in four spectral bands in the M/LWIR. For these flights, three of the Aquameter's spectral channels made measurements in various parts of the water band from 5.4 to 7.2 µm, while the fourth channel observed to the ground in the 4.6 to 4.9 µm band. Significant and unexpected measurements in the water band were made of waves at 7 to 9 km in clear atmospheres. Small scale (~ 400 meter) waves were observed over the ocean and larger scale (~ 10 km) waves were observed over Utah and Colorado. The large amount of M/LWIR data gathered by the Aquameter during the FISTA 98 campaign presented a rich variety of atmospheric phenomena that was used to verify and refine predictions of background clutter properties made by existing simulation programs under a range of conditions.

In 1999, FISTA flights also assisted in obtaining polarization measurements of solar radiation scattered from water and ice-clouds across the 2.5 to 3.5 µm region as a function of solar scattering angle using the Space Dynamics Laboratory's Hyperspectral Imaging Polarimeter (HIP) instrument. The purposes of the experiment were to verify the expected strong sensitivity of polarization as a function of wavelength within this spectral band, to select the optimum wavelength for making remote diagnostic measurements of cloud compositions, and to verify theoretical polarization models. A complementary goal was studying polarization as a potential discriminator between naturally occurring solar-scatter backgrounds and man-made objects[4]. The polarization angle is largely dependent on the viewing geometry but also showed significant wavelength variation. These spectral measurements were valuable in understanding and modeling the processes taking place during scattering. The data produced with HIP largely matched the model at some frequencies but showed some deviation for some others[6]. Based on these results, polarization models were modified to include more complex ice grains and scattering processes, in order to more accurately model the effects of polarization induced through scattering from clouds.

These FISTA programs yielded a wealth of information that has been used to design RAMOS sensors, choose appropriate wavelength bands, and plan experiments.

4. ENVIRONMENTAL EXPERIMENT OBJECTIVES

RAMOS will conduct research and development of new technologies for monitoring global environmental phenomena and improving of space-based observation capabilities. Using stereo-optical observation, multiple wave bands, and a small footprint, RAMOS will evaluate the capability to measure and identify fast-changing environmental events such as volcano eruptions and forest fires. RAMOS will also demonstrate the capability to measure the wind velocity altitude profile by stereo-optically tracking cloud fragments, and the ability to determine the vertical distribution of water vapor in the atmosphere. These capabilities may assist in weather forecasting, such as predicting hurricane strength and movement. This section summarizes the proposed experiment types .

4.1 Predicting the strength of cyclones

Cyclones are the most destructive of natural calamities both in terms of loss of life and property (Fig. 5). Presently the strength of cyclones while far out at sea is crudely estimated from measurements inferred from satellite data, and more precisely near the East Coast of the United States by flights of the “Hurricane Hunter” aircraft into the storms. The latter are costly (~$30 million/year) and risky for aircraft and crew. RAMOS will demonstrate that the strength of the cyclone can be determined if one can measure the altitude of the turrets that protrude above the eye-wall of the of the cyclone to plus or minus 100 meters, and the temperature of these turrets to plus or minus a few degrees Kelvin. Such a successful demonstration could lead to a space-based system that could, in addition to providing world-wide civil warnings, also provide to the US Navy sufficient warning (coupled with the wind measurements discussed below) to permit their fleets to avoid these storms. These measurements will be validated where possible by targeting storms in the Atlantic where the Hurricane Hunter aircraft can provide reference data.

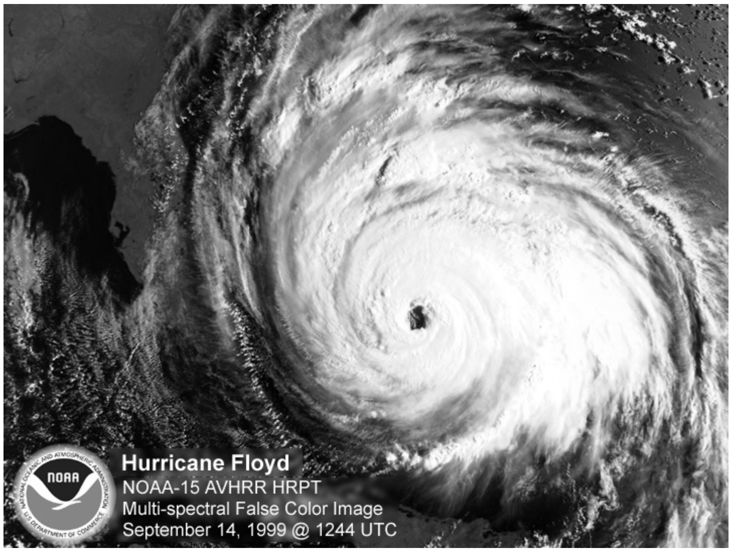

Figure 5. Satellite image of Hurricane Floyd

4.2 Support disaster control in observation of fire

Timely and accurate information on forest fires, industrial, pipeline, or oil field fires, and fires from accidents such as aircraft crashes is needed to support disaster control (Fig. 6). One objective of RAMOS is to demonstrate the ability to measure and identify these events and to report them in a timely fashion to both the National and Global Disaster Networks (NDIN and GDIN). The small footprints characteristic of the RAMOS sensors, the stereo viewing capability in three dimensions when combined with the temperature measurement capabilities are unique among satellite systems.

4.3 Three-dimensional volcanic plume measurements

Using the data from one or both satellites, RAMOS intends to demonstrate the ability 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 nevertheless still poses a threat to jet aircraft that might penetrate the cloud, or may affect weather patterns (Fig. 7). Defining the top and bottom altitudes of the plume, as well as the width, is crucial. The approach will be to use tomographic methods with data from each satellite and then correlate the two views to assist in the spatial definition. Observations of aircraft contrails will serve as a fiducial calculations, where the altitude and width of these trails are observed from ground stations.

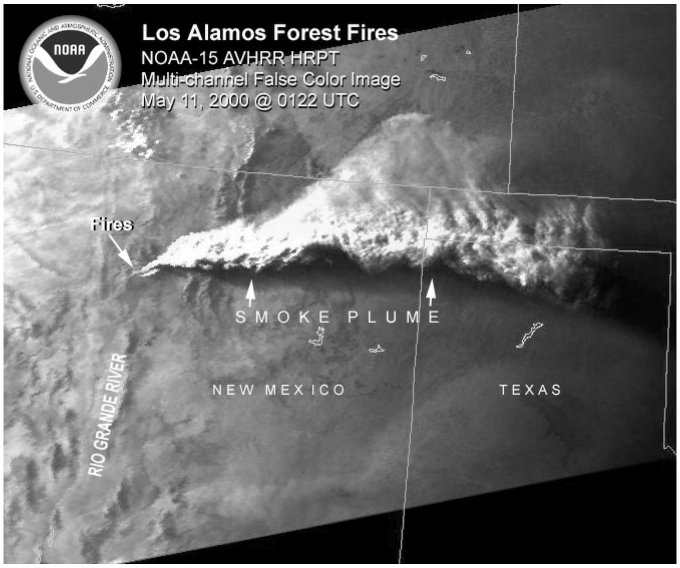

Figure 6: Smoke plume over New Mexico and Texas from the forest fire near Los Alamos, NM.

4.4 Three-dimensional wind velocity/altitude profile measurements

An important scientific objective of RAMOS is to demonstrate, using the stereo capability of this system, the ability to unambiguously measure wind velocity versus altitude by tracking cloud fragments over a period of several minutes (Fig. 8). These measurements can affect numerical weather forecasting far removed from land-based observation sites and provide information on the winds that steer cyclones as an assist to the cyclone strength measurements. These measurements will be conducted when possible in conjunction with "ground truth" measurements being made by other agencies.

Figure 7: Satellite image of Mount Etna eruption

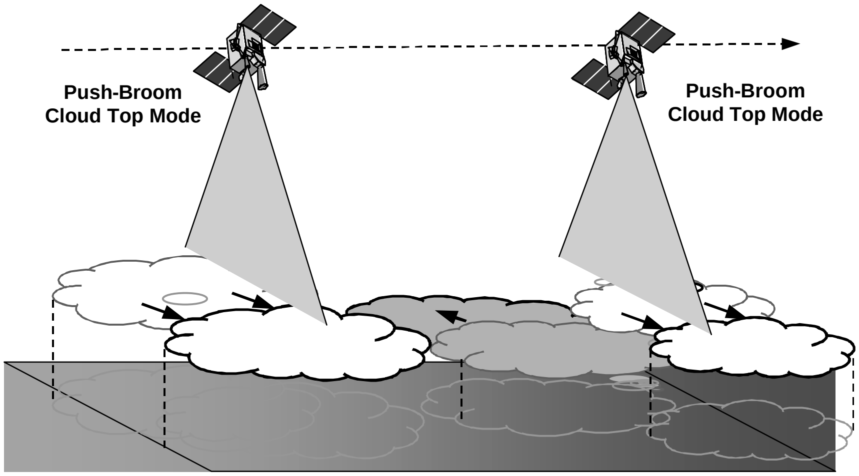

Figure 8: Wind Field Distribution. Visible push broom scanners are the primary sensors providing uniform measurements of time-dependent, wide-field 3-D distributions using "cloud top" filters.

4.5 Small-scale three-dimensional water vapor profiles

The scientific objective of this series of experiments is to use the multi- and hyper-spectral capability of RAMOS to measure the vertical distribution of water vapor in the atmosphere, especially near the tropopause and in the 0 to 3 km altitude range. These measurements, at a spatial scale of less than 100 meters, will demonstrate capability and potential value in forecasting climate change and weather. The key sensor is the dual channel spectrometer which permits simultaneous sounding for temperature in the MWIR (4.3 – 4.6 micrometers) and for water vapor in the MLWIR (4.7 – 7.5 micrometers).

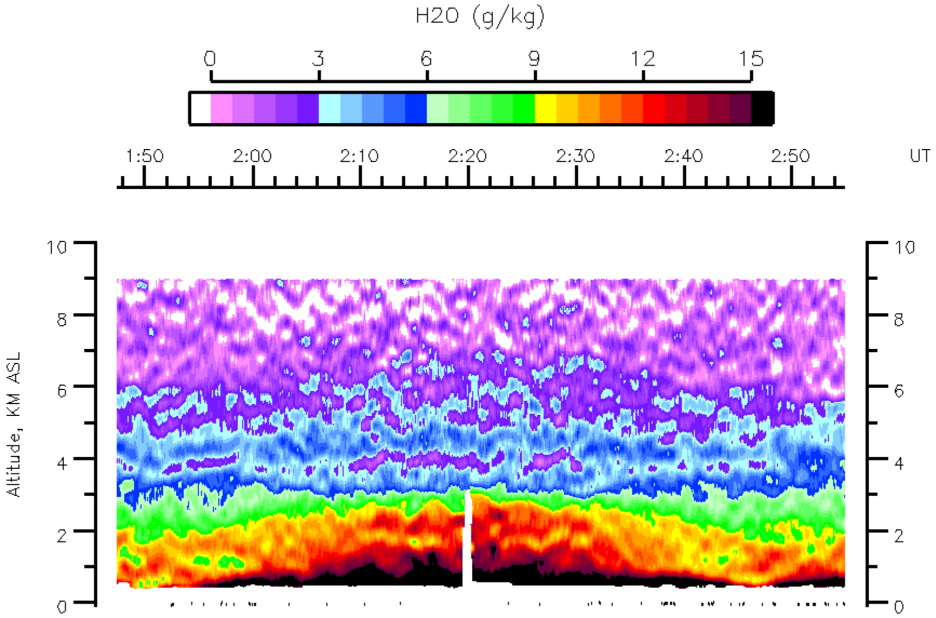

Figure 9: Water vapor profile demonstrates complicated distribution in the atmosphere.

4.6 Multispectral, polarization and stereo-optical backgrounds

The objective of this experiment is to acquire a spatial/temporal data base of the MLWIR and MWIR earth backgrounds taken simultaneously (Fig. 10). The visible camera will also be used for co-registration and 3-D reconstruction because of the dynamic scene detail. These data bases will be a function of geographic location, seasonal and diurnal times. They will also include temporal variations arising from atmospheric motions, temperature fluctuations, and water vapor variations. The visible push-broom measurements and the stereo-optical capability of RAMOS will allow the background sources (altitude and temperature of clouds) and the nature of the clutter to be defined as a function of the angle from the nadir. Using two-dimensional detector arrays and operating in a step-stare mode, RAMOS can meet the requirement of providing mosaic scenes thousands of kilometers in length to register backgrounds for uses such as object track simulation. Near-horizon views will provide the backgrounds where most observations from low-altitude satellites would take place. Of great importance to modeling and understanding the backgrounds and clutter will be the role of water vapor in the atmosphere and the fall-off of the IR emissions near cloud edges to determine the sharpness of cloud edges and their effect on the observed clutter. The role of the spectrometer will be crucial in measuring water vapor along the line of sight, particularly near horizon.

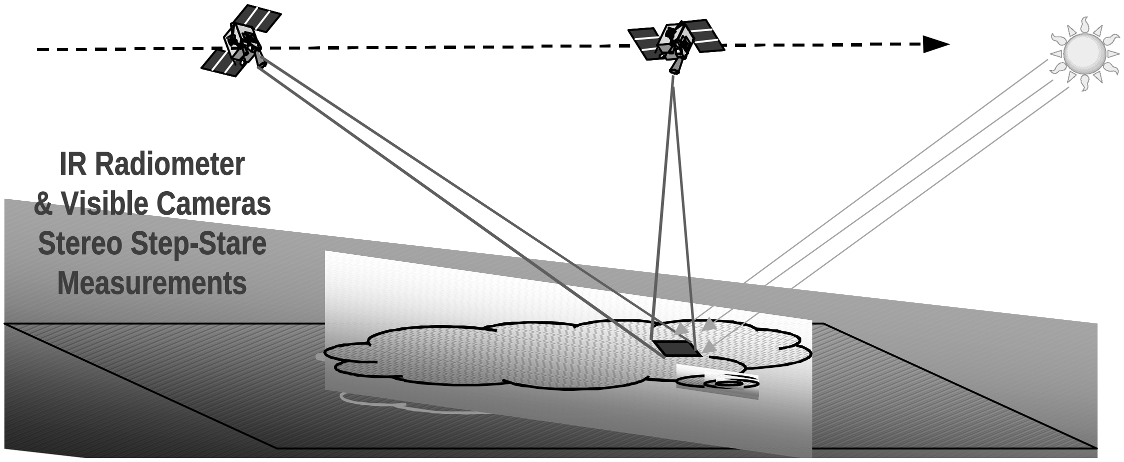

Figure 10: Experiment is to measure solar glint and polarization in the visible and SWIR atmospheric absorption band.

The background observations will measure the polarization in the SWIR atmospheric absorption band of the solar glint: a) off clouds near the horizon; b) off clouds near the solar specular area; and c) from the pathological very bright returns that commonly occur far removed from the specular area. Measurements must be made to scattering angles less than 10 degrees from the sun, to address optimum earth coverage from satellite geometries. Sufficient measurements must be obtained to bound the problem. Polarization returns measured by the FISTA aircraft experiments provided insight needed to support this experiment. Using two near-IR bands will identify ice crystals, water droplets, and mixed-phase clouds for correlation with the polarization measurements. SWIR polarization from high altitude cirrus clouds, an important source of clutter, will be measured (Fig 11). The visible push-broom scanner returns, using the visible polarization filter, will be correlated with those in the SWIR. Multiple SWIR spectral bands will be used.

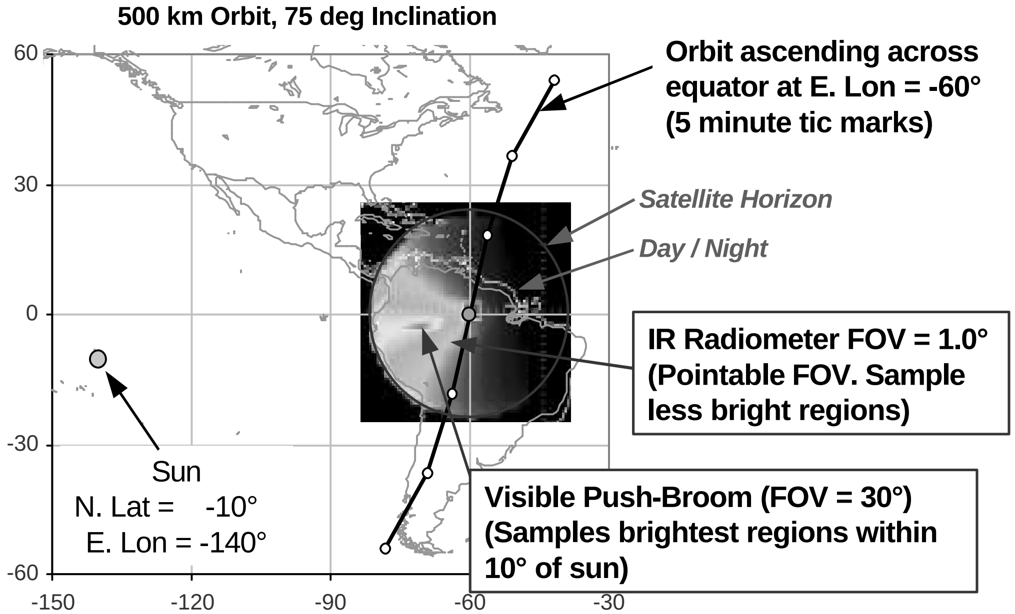

Figure 11: Polarization experiments in the visible and SWIR atmospheric absorption band will be able to measure scattering angles less than 10 degrees from the sun to address optimum earth coverage from satellite geometries.

5. CONCLUSIONS

The RAMOS program, a joint US-Russian experiment, will conduct research into and development of new technologies to study the global environment. The international RAMOS team has developed a number of unique experiments directed at this fundamental interest. This research was supported by modeling and simulation efforts to determine trade-offs for the experiments. It is also supported by the use of satellite, airborne, and laboratory experiments to provide truth data for creating, improving and validating models, and for designing space instruments. The acquisition of space-based data with simultaneous observations of two satellites will create numerous important scientific databases that will benefit international research.

This project has raised the level of cooperation and trust between various American and Russian organizations. It has demonstrated the ability of the two nations to work together in important research using space-based and other assets in a program that includes joint experiment planning, comparison of cooperative instrumentation, the exchange of experimental data, and the comparison of results.

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