RAMOS Near Term Observations

Cynthia J. Beeler
[1]Visidyne, Inc.
10 Corporate Place, S. Bedford St.
Burlington, MA 01803
617 273-2820
beeler@bur.visidyne.com

Charles H. Humphrey[1]
gardner@bur.visidyne.com

Andrew J. LePage[1]
lepage@bur.visidyne.com

Mary E. Pitkanen[1].
pitkanen@bur.visidyne.com

Orr Shepherd[1]
shepherd@bur.visidyne.com

Captain Barry Tilton
SAF/RESPO
11781 Lee Jackson Highway, Suite 500
Fairfax, VA 22033
Pager: 800 759-8255 PIN: 2832955
tiltonba@sgate.com

Abstract--The Russian American Observational Satellites (RAMOS) program is a joint US-Russian experiment designed to collect simultaneous stereo imagery in the visible and IR wavelength regions in support of clutter measurements and environmental monitoring. The classic RAMOS experiment utilizes complementary sensors on board two dedicated, extended-lifetime satellites, an American Observational Satellite (AOS) and a Russian Observational Satellite (ROS), which are in the same low Earth orbit. In preparation for the launch of these dedicated satellites, the RAMOS program is currently making use of existing US and Russian assets in a series of near term observations. These observations are designed to accomplish the milestones that lead RAMOS to its goals of developing a data base of three-dimensional background radiance and spatial structure statistics, and of obtaining the ability to monitor environmental trends and specific atmospheric events, such as hurricanes. The intermediate goals of the RAMOS program and how they will be accomplished through these near-term observations are discussed in this paper. The first set of assets used for these observations is the NASA-owned WB-57 aircraft for the U.S. and either one of two Russian satellites, Resource 1 or MIR. Two simultaneous data collection events have occurred thus far. The U.S. sensors include an infrared multi-spectral imager, IR imagers, and visible cameras. The Russian satellites feature visible line scanners, visible and IR imagers, and video cameras. Future U.S. assets to be used for RAMOS near-term observations

include the Midcourse Space Experiment (MSX) and Miniature Sensor Technology Integration (MSTI 3) satellites. This paper includes discussions of both recent and future RAMOS near-term data collections and analysis, and presents data collected during the recent simultaneous measurements.

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1. INTRODUCTION

The Russian American Observational Satellites (RAMOS) program has the unique capability of real-time stereoscopic measurements in both the visible and infrared wavelengths. Therefore, RAMOS will be able to collect valuable scientific data on a number of dynamical atmospheric phenomena. RAMOS has a mission that includes both measurement of atmospheric phenomena and environmental monitoring. The program's scientific objectives are to demonstrate the ability to measure hurricane intensities, cloud polarization and solar albedo, with the use of stereo imagery, as well as to collect an Earth backgrounds data [1].

The "classic" RAMOS experiment [2], consists of two dedicated satellites, the American Observation Satellite (AOS) and the Russian Observation Satellite (ROS), designed specifically to meet the requirements dictated by the RAMOS science objectives. However there are several milestones, which, if accomplished prior to the implementation of the classic RAMOS experiment, would greatly increase the success and utility of RAMOS.

These milestones are being accomplished by a series of RAMOS near-term observations that make use of existing U.S. and Russian assets. The goals of these near-term observations are both programmatic and technical. The programmatic goal refers to the fact that the Russian and American teams have to establish and exercise the mission operations procedures as well as work out the details of the data/technology transfer procedures and requirements in order to insure successful simultaneous data collection. The technical goals are to demonstrate the ability to create three-dimensional scenes from imagery acquired by disparate sensors by first exercising the techniques on data collected over well-surveyed topographical areas, and then by applying these verified techniques to data containing high altitude clouds and other sources of spatial structure.

2. RAMOS NEAR-TERM GOALS

The RAMOS program has a well-defined set of science objectives that the team has broken down into a series of intermediate goals to be accomplished by sets of near-term observations. These goals will aid in the development and testing of processing and analysis techniques to be applied to the data. In addition, they will provide valuable information to be used as input to the design of the classic RAMOS experiment and sensors.

The first set of goals for these near-term observations is to construct stereoscopic imagery from simultaneously acquired data using existing U.S. and Russian sensors (visible and infrared). The ability to construct such three-dimensional scenes will be demonstrated in steps: first by observing sites with well surveyed terrain structure, i.e., cloud-free mountain peaks, and then by observing sites, or scenes that consist of a combination of structured clouds and terrain. The successful demonstration of the stereoscopic processing technique, using these types of observation scenes, will lend more confidence to the ability to create three-dimensional scenes of cloud decks and hurricanes complete with accurate cloud height and hurricane intensity information.

Three-dimensional structured scenes in the visible can be used as a first approximation in determining the source of infrared structure, i.e., cloud temperatures can be inferred from cloud altitude. However, some of the near-term observations are designed to include measurements in the LWIR thermal wavelength regions, allowing for more accurate cloud temperature determination, which will aid in spatial structure analysis.

Part of the stereoscopic demonstration is the ability to merge data collected by disparate sensors. For example, the sensor imagery will have different footprint sizes and resolutions, and will represent radiation in different wavelength regions. These corrections are non-trivial, and the techniques for handling them will be refined during the data analysis of the near-term observations.

These RAMOS near-term goals also include test experiments for the cloud polarization experiment, wind field at altitude measurements, and other dynamic atmospheric phenomena. All of these near-term goals will be accomplished by the successful acquisition, processing, and analysis of simultaneous data over carefully selected observational sites and under the appropriate observational conditions using available instrumentation.

3. U.S. INSTRUMENTATION

The near-term observations planned for RAMOS will make use of various existing U.S. sensors and sensor platforms. The three most accessible platforms for these simultaneous measurements are the NASA-owned ARES WB-57F aircraft, BMDO-sponsored MSX (Mid-Course Space Experiment) satellite, and the Air Force's MSTI (Miniature Sensor Technology Integration) satellite. Each of these platforms will provide high resolution, multi-spectral imagery in the infrared wavelengths. A description of these platforms and their on board sensors is provided below.

ARES

The Airborne Remote Earth Sensing (ARES) Program is the only high altitude short/medium wave infrared (S/MWIR) spectral collection capability currently operating in the US. The program consists of a WB-57F aircraft operated for the Air Force by NASA Johnson Space Center, Houston, and a Lockheed Martin (LM) IR spectral imager, operated by LM's Palo Alto Research Labs and the Air Force.

Platform Overview--The WB-57 airplane is capable of normal flight operation between 8,000 - 65,000 feet, with about 7 hours of flight duration. It is a highly modified version of the old B-57 Canberra used in Vietnam. General Dynamics modified the aircraft in the early 1960's for high altitude (65,000 ft) missions. The WB-57F has a crew of two (Pilot & Navigator/Payload Operator), permitting sensor operation by a dedicated flight crewmember. Aircraft main bay payload volume is 250 ft^3, and it can carry up to a 4000 lb payload. Additionally, the nose can carry a 250 lb payload (volume - 25 ft^3). The main bay is unpressurized, but the nose bay can be either pressurized or not. Currently two flyable WB-57's exist, the other one is owned by the National Center for Atmospheric Research in Boulder, CO.

Sensor Overview--The ARES sensor may be operated as either a 4-band radiometer or as a 75-channel imaging spectrometer in the 2.0 - 6.4 μm IR bands. These spectral bands are given in Table 1 along with the noise equivalent spectral radiance. This system has an Indium doped Silicon 45 × 90 element focal plane, and operates at a 10, 20, 40 or 80 Hz data rates. Data is collected and recorded digitally at an instantaneous dynamic range of 12 bits.

Operating Modes--As stated previously, the sensor has two operating modes. The radiometer mode makes use of two filter wheels, one with four narrow bandpass filters and the other with four neutral density filters plus an open position. A rotation between filter combinations requires one second. The spectrometer mode (Figure 1) uses optical scanning of the image across a fixed reflecting slit. The slit image is spectrally dispersed by a bi-prism and the resulting 75 spectral channels are imaged by means of the same refractive camera onto the same detector as used in the radiometer mode. Sensor reconfiguration is by means of a slide mirror. The change requires only a few seconds and is routinely done in flight. (Note: Radiometric and Spectral data cannot be taken simultaneously.)

Data Recording--The infrared focal plane data is digitally encoded to 12 bits and recorded in real time, along with the aircraft INS data (aircraft position, pitch, roll, & yaw), pointing mirror readouts, and GPS information onto one of two onboard tape recorders. The data from the onboard calibration system is also recorded as infrared focal plane data. The continuous imaging sequences from the infrared imaging

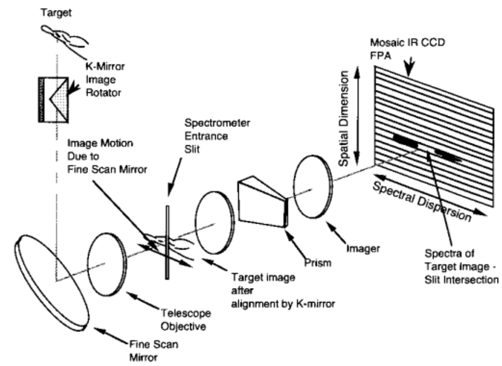

Figure 1 ARES Spectrometer Operation Mode

tracker and the RTDS (Real Time Display System displays IR focal plane image) are recorded onto their own systems which include separate VHS tape recorders. Further, the output of the payload operator's video monitor, which displays the output chosen from either one of two visible cameras (wide FOV black and white & narrow NTSC color FOV) , the IR camera, or the RTDS, is recorded in-flight onto its own VHS recorder.

Fields-of-view--Both the radiometer and spectrometer make use of the same 45 × 90 pixel focal plane. The radiometer uses a subset of 45 × 45 pixels whereas the spectrometer uses 45 × 75 pixels. The IFOV per pixel in the radiometer mode is defined by the pixel size giving 1.12 mrad (about 20 m at 20 km altitude) with a total IFOV of 2.58 × 2.58 degrees subtended by the subset square array. The long axis of the slit is imaged across the 45 pixels subtending the short dimension of the area while the spectrum is imaged across 75 detector elements parallel with the long axis of the array. The short axis FOV is a function of frame rate and forward scan velocity. It is generally accurate to assume an equivalent IFOV approximately one half of the pixel pitch IFOV. Using the onboard GPS, the center of the FOV

Table 1: ARES Instrument Parameters

Radiometer Mode		
Filter Center Wavelength (μm)	Bandwidth (μm)	Noise Equivalent Spectral Radiance (μW/cm^2-sr-μm) @ 80 Hz
2.23	0.054	0.402
2.84	0.256	0.053
3.78	0.120	0.073
4.48	0.146	0.189
Spectrometer Mode		
Center Wavelength of Selected Channels (75 total) (μm)	Bandwidth (mm)	Noise Equivalent Spectral Radiance (μW/cm^2-sr-μm) @ 80 Hz
2.23	0.028	2.71
2.84	0.049	1.45
3.82	0.067	0.46
4.59	0.070	0.41
5.32	0.065	0.54
6.30	0.059	1.42

can be pointed to any location on the ground to an accuracy of better than 30 feet.

Spectral Coverage--The wavelength coverage is limited on the short end by the Germanium camera lens to 1.8 μm and by the detector doping to about 7 μm on the long end (This spans part of the SWIR and all the MWIR of the infrared). The detector material is Indium Doped Silicon (In:Si) and evolved from the HiCamp detector except the chip was not irradiated by neutrons. Historically it has generated a much higher level of calibration and stability than the HiCamp parentage.

Calibration--The instrument is absolutely calibrated using a traceable NBS secondary standard whenever the payload in removed from the plane and located in the laboratory. This calibration is transferred to a standard blackbody that the sensor looks at when parked in the hanger. This activity is usually performed immediately before or after a data flight. The entire optical path is monitored for changes by looking at two onboard blackbodies held at fixed temperatures. Absolute calibration is consistently good to the 5-10% level whereas relative calibration is repeatable to the 1% level. These levels are due in part to the inherent long-term (months) stability of the extrinsic doped silicon, to the constant in-flight optical path monitoring, and to the total elimination of in-flight ice contamination on the optics and detector.

MSX

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) integrated the MSX spacecraft and sensors. The MSX primary mission is to serve as a long duration data collection platform for Earth, Earthlimb, and celestial backgrounds, as well as for target detection and tracking, however it is available for collecting data in support of RAMOS near-term observations.

The spacecraft is scheduled for launch in 1996 from Vandenberg Air Force Base , California into a sun-synchronous orbit at an altitude of 898 km and an inclination of 99.16 degrees. The satellite measures 510 cm in length, has a square cross section of 150×150 cm, excluding the two solar arrays, and weighs approximately 2700 kg. The spacecraft has an expected lifetime of approximately 18 months.

The primary instruments on board the MSX spacecraft are the SPIRIT III (Space Infrared Imaging Telescope) instrument, built by the Space Dynamics Laboratory at Utah State University (USU/SDL), the UVISI (Ultraviolet and Visible Imagers and Spectrographic Imagers), the SBV (Space-Based Visible) Instrument, and the OSDP (On-board Signal and Data Processor) [3].

The principal instrument of interest for the RAMOS near-term observations is the SPIRIT III instrument which includes a five band, high spatial resolution scanning radiometer, and a six-channel (17.2 - 28.0 μm, 2.6 - 4.9 μm, 5.8 - 8.9 μm, 4.0 - 28.0 μm, 10.6 - 13.0 μm, and 2.5 - 24.0 μm), high spectral resolution Fourier-transform spectrometer.

The radiometer has five Si:As focal plane arrays, each consisting of 8×192 pixels, four of which collect data in one wavelength band (6.0 - 10.9 μm, 11.1 - 13.2 μm, 13.5 - 16.0 μm, and 18.1 - 26.0 μm) and one of which is horizontally divided in half with one band, 4.22 - 4.36 μm, on one half, and another band, 4.24 - 4.45 μm, on the other. The spatial resolution of these arrays is approximately 80 meters (measured on the ground at nadir). The radiometer field-of-regard width is approximately 15 km (in the nadir) and can be scanned up to a length of approximately 50 km.

The Fourier-transform spectrometer has six Si:As detectors with programmable spectral resolutions of 2, 3.9, or 20 cm^{-1} over sample times of 4.2, 2.2, and 0.55 seconds.

MSTI

The MSTI satellite is the third of a series of satellites originally developed by BMDO, which is now supported by the Air Force. Phillips Laboratory/Space Experiments Directorate (PL/SX) integrated the satellite at Edwards AFB, CA and calibration was performed by USU/SDL. The satellite is planned for launch in early 1996 into a 425 km, sun-synchronous (6 a.m. - 6 p.m.) orbit with an inclination of 97.3 degrees.

The MSTI mission is to serve as a long-duration (one year), space-based data collection platform designed to collect valuable Earth and Earthlimb backgrounds data [4]. The primary MSTI instrument is a high spatial resolution staring radiometer. This sensor has two InSb focal plane arrays, one for SWIR and the other for MWIR wavelength detection. Both focal planes are 256×256 pixel arrays with spatial resolutions of approximately 43 meters and instantaneous field-of-regard of almost 11 km on a side. The sensor has a two-axis gimbaled mirror that can be pointed to include a 180-degree × 100 degree field-of-regard.

Both the SWIR and MWIR cameras have a selectable 7-position filter wheel located in its optical path. The wavelength bands for these filters are given in Tables 2 and 3 [5].

Table 2. MSTI SWIR filter bands

5 % cut-on λ	5 % cut-off λ
2.69	2.97
2.73	3.03
2.55	3.48
2.70	2.82
2.69	2.85
2.70	2.88
2.70	2.91

Table 3. MSTI MWIR filter bands

5 % cut-on λ	5 % cut-off λ
4.23	4.31
4.257	4.357
4.23	4.39
3.50	3.87
4.22	4.42
4.23	4.43
4.24	4.46

4. RUSSIAN INSTRUMENTATION

The RAMOS near-term observations are presently being planned to use existing Russian civilian remote sensing satellites. These satellites house a range of instrumentation suites that include both visible and infrared wavelength sensors. Detailed descriptions of these satellites and their sensor suites are available in open literature; however, the naming conventions slightly differ from one source to another. The Russian scientists on the RAMOS team have designated these available Russian satellites as Resource 1, and MIR. Below we provide a description of each of these Russian assets along with details of the available sensors.

Resource 1

This satellite is most commonly referred to in literature as one of the Resurs-O series remote sensing satellites. The mission of the Resurs-O series is to obtain multi-spectral image data for civilian remote sensing applications. Unlike other Russian remote sensing platforms such as the Resurs-F series, which rely on photographic film return, the Resurs-O returns its data via radio. As a result, the data are returned to Earth shortly after being taken and the spacecraft remains active in orbit for years instead of only for days or weeks. The role of this spacecraft is analogous to that of the Landsat or SPOT satellites used in the West [6,10]

The spacecraft is manufactured by the Russian company VNII Elekromekhaniki (All-Union Research Institute for Electro-Mechanics). Weighing 1,840 kilograms, this spacecraft consists of a sealed and pressurized cylinder about 1.5 meters in diameter and 5 meters long (see Figure 2). It is three-axis stabilized with its attitude fixed so that one end of the cylinder always points toward the nadir [7]. All of the Earth-scanning instruments are mounted at this end of the spacecraft, thus permitting a constant view of the Earth passing below.

Resurs-O 1 (Resource 1) was launched in November of 1994 and circles the Earth in a sun-synchronous orbit inclined 98 degrees to the equator at an altitude of approximately 660 km [8]. The satellite repeats its ground track about once every 33 days. The standard set of instruments carried by a Resurs-O spacecraft include a push broom CCD imager, a nadir-pointing conical scanner, a synthetic aperture radar (SAR) and a multi-band microwave radiometer. The RAMOS observations concentrate on data collected by the push broom imager and the conical scanner.

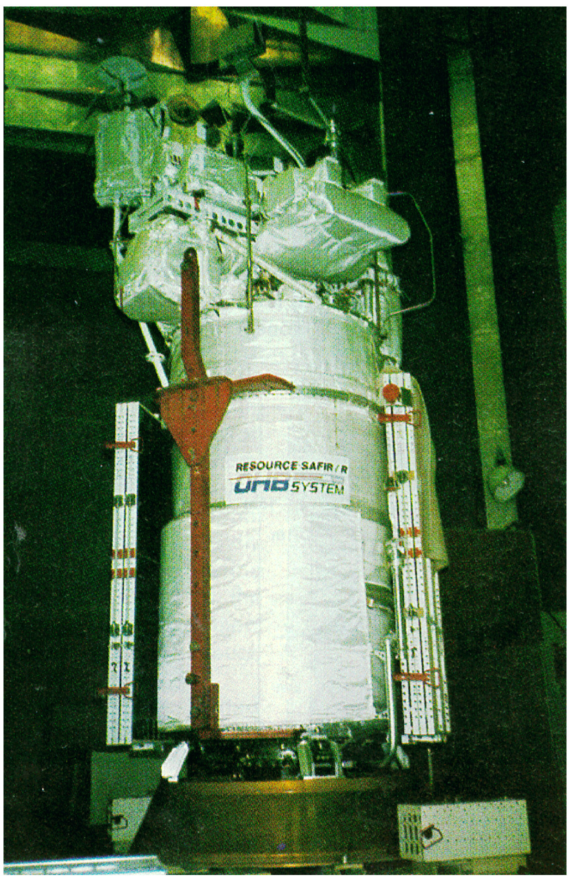

Figure 2 The Resurs-O 1 Spacecraft

The push broom CCD imager (MSU-E) is capable of imaging in three bands ranging from 0.5 to 1.0 microns (0.5 - 0.67 μm, 0.65 - 0.8 μm, and 0.8 - 1.0 μm). The sensor can be pointed up to 30 degrees or 350 km from nadir and produces images with a resolution of 34 × 45 meters. Its nominal swath width is 45 km and its swath length is limited to approximately 105 km.

The conical scanner (MSU-SK) is nadir pointing only and is capable of producing images in four bands between 0.5 and 1.1 microns (0.5 - 0.6 mm, 0.6 - 0.8 μm, 0.7 - 0.8 μm, and 0.8 - 1.1 μm) as well as an additional channel in the LWIR range (10.4 - 12.6 μm). The resolution of this instrument is approximately 160 meters in the visible to near IR wavelength regions, and 600 meters in the LWIR. The nominal swath width is 600 km and it is limited to swath lengths of 210 km [6,7,9].

MIR

The Mir space station is the latest in the DOS-7K series of civilian space stations that started with the launch of the Soviet Union's Salyut 1 in 1971 [11]. Since the launch of the core module in 1986, Mir has been the only permanently crewed space station in the world. It is equipped with six docking ports allowing specialized modules to be attached to the station while accommodating up to two Soyuz-TM crew ferries or Progress-M automated cargo craft. These expansion modules are based on the TKS spacecraft series originally designed to support the Soviet military's OPS Almaz crewed space station program of the 1970s [12, 13].

Each module, which are as large as the Mir core, weighs about 20 metric tons and is largely dedicated to a particular field of investigation such as material processing, astrophysics, or remote sensing. Once the last expansion module is attached by the end of 1995, Mir will consist of a core module and five expansion modules with a total mass of about 140 metric tons.

Mir's orbit is about 375 km high and is inclined

52.6 degrees to the equator. From this orbit it can survey a selected area for 25 days at two to three day intervals. Lighting conditions of a selected area repeat every 56 days [14].

The Mir space station carries a wide range of remote sensing instruments. Two of the recently launched expansion modules, Spektr and Priroda, are dedicated to studying the Earth's surface and atmosphere. Each is equipped with a variety of spectrometers, radiometers and other sensors to accomplish their tasks. Two of the other large expansion modules, Kvant 2 and Kristall launched in 1989 and 1990 respectively, carry large format panchromatic and multi-spectral photographic cameras such as the KAP-350, MKF-6MA, and Priroda 5 [15]. In addition, Mir also carries a KATE-140 topographic camera that was salvaged from the Salyut 7 space station before it was abandoned in 1986. These cameras have already exceeded their original design lives and are either no longer available or are used only on a limited basis to meet Russia's domestic remote sensing needs.

Mounted on the exterior of the Kvant 2 module is the ASP-G-M video-spectral platform. This steerable platform was developed in Czechoslovakia and was designed to provide a means of pointing a package of spectrometers used to study the Earth's atmosphere. The platform can be pointed with an accuracy of one degree and carries a television camera to aid in targeting its other sensors [15]. It possesses a five degree wide field-of-view and has 100 meter ground resolution. During its in-orbit lifetime, several new instruments have been added to this platform including the Gemma-2 video spectro-polarimetric system [16].

In addition to these instruments mounted in or on the various Mir modules, a variety of hand held still and video cameras are also carried. These cameras can be pointed towards the Earth using special view ports. These view ports use high quality optical glass and are covered by a shutter when not in use. This limits the damaging effects of micro-meteors, space debris, and normal space station operations.

5. Simultaneous Data Collection

The typical flight pattern that has been developed for these WB-57 aircraft RAMOS measurements is a three-leg pattern over the observational site. The first leg is the coincident leg, i.e., the leg flown at the same time as the Russian satellite observation, and is flown on the opposite side of the site as the Russian satellite. In general, the geometry of the measurement is designed for optimum stereo, i.e., 90 degrees between the two lines-of-sight of the sensors. An example is a 45 degree nadir angle for both sensors (135 degree azimuth). These viewing angles are adjusted for each individual RAMOS mission in order to accommodate the viewing conditions of the Russian satellite.

The WB-57 aircraft flies a course heading parallel to that of the satellite in order to maximize the amount of overlapping measured area. The next leg flown by the aircraft is directly overhead of the site and parallel to the first and the last leg is also flown parallel but on the opposite side of the site as the first leg. This third leg viewing geometry is set up so as to provide an adequate stereo viewing angle with the first leg. This allows stereo imagery of between two of the ARES legs as well as between the Russian sensor with leg #1.

Lamont,Oklahoma

On the 27th of July, 1995 at 16:38 GMT, the ARES aircraft (WB-57) and the Russian

Resource 1 satellite collected simultaneous data of the ARM (Atmospheric Radiation Measurement) site in Lamont, Oklahoma marking both the first RAMOS near-term observation, and the first Russian-American coordinated, simultaneous data collection event in history. The experiment met all of its mission objectives. The primary objective of this flight was to demonstrate the ability to coordinate a simultaneous measurement between the U.S. and Russian teams. The location of the ARM site was chosen for this first RAMOS near-term observation partly for its ease in scheduling, but mostly because the ARM site can provide informative "ground truth data" including data from LIDARs, spectrometers, radiosondes, and all-sky cameras.

The ARES aircraft flew leg #1 of the planned flight pattern within 8 seconds of the specified time of conjunction at an altitude of 48,000 ft. The nadir-viewing angle was 45 degrees (approximately 15 km East of the ARM site), and the ground course was directly North-South. There were 210 seconds of simultaneous data (1 km _ 30 km) collected on this leg. The second leg was flown twice in order to insure high quality data, and the leg #3 collected the stereo pair of leg #1. All three legs were cloud free, which is unfortunate because the terrain at the ARM site is very flat, so the measurement offers little topographical structure with which to practice stereo image processing. However, there are geographical features and buildings that will be used for registration. Also, as mentioned above, the primary mission objective was to successfully coordinate and acquire simultaneous data with the Russian sensor, and that was accomplished.

Mt. Whitney, California

On the 5th of October 1995 at 17:59:20 GMT, the second RAMOS near-term observation was executed over Mt. Whitney, California using the ARES and Resource 1 sensors. The primary objective of this measurement was to collect simultaneous imagery of Mt. Whitney, a well-surveyed, topographical region.

The viewing geometry of both leg #1 and leg #3 were at a nadir angle of 45 degrees, and a course of 193.1 degrees (from North). The altitude of the aircraft was 60,000 ft, and was flown at a distance of 13.9 km on either side of the site for a track length of approximately 30 km. The first leg was flown within 20 seconds of the planned time of conjunction; however, the sensor was experiencing pointing difficulties and that leg was abandoned. Legs #2 and #3 were flown, and then Leg #1 was repeated at the proper viewing geometry. Because Leg#1 was repeated after the other two legs were flown, the spatially coincident ARES data was not collected at the same time as the Resource 1 data. In fact, there is approximately a 20-minute delay. This delay will not be significant however, because with the exception of a few vertical thin cirrus clouds in some of the images, there were no time varying features in the images, so the only source of three-dimensional structure in the scenes was the mountain peak itself.

Figures 3 and 4 are examples of preliminary data collected by the ARES multi-spectral imager over Mt. Whitney during the 5 October 1995 RAMOS near term observation. The top figure is a mid wave infrared (approximately 4.2 microns) push broom scan (nadir view) over the site, and the bottom figure is the same scan in one of the short wave channels (approximately 3.7 microns). Once the data has been fully calibrated by Lockheed, the data analysis will begin at Visidyne, Inc. according to the analysis plan described below.

6. DATA ANALYSIS PLANS

The data analysis plan is similar for all RAMOS near -term observations and consists of analysis of the two data bases (Russian and American) separately as well as analysis of the merged databases. For this reason, the analysis of the ARES data acquired during the 27 July and 5 October RAMOS near term observations can begin before the U.S.- Russian data exchange takes place.

The analysis of the ARES multi-spectral imagery will begin with the receipt of the visible video and the IR imaging spectrometer data. The data collected in a push broom fashion by the imaging spectrometer represent a 30 km long track approximately 1 km in width, for every spectral channel. The first and third tracks of the ARES flight are designed to be optimum stereo pairs, however, the combination of each of the first and third tracks with the second (nadir) track also provide sets of stereo pairs. The stereo imaging algorithms will be exercised with all three sets of stereo pairs thus providing an interesting sensitivity analysis of the algorithms to the observation geometry. A spectral region containing a reasonable amount of spatial structure, i.e., a wavelength in one of the window bands, will be chosen to construct a structured three-dimensional scene. The resultant stereo imagery will then be correlated with topographical maps of the observation area. This process will validate the stereo imaging algorithms. Next, other wavelength regions, namely bands in the absorption regions, which do not "see to the ground", will be chosen and stereo imagery will be constructed using the same, tested algorithms. Cloud heights can be determined from these derived three-dimensional scenes, and thus, temperature maps can be inferred. In the case of data collected over the ARM site in Oklahoma, this inferred temperature map can be evaluated with respect to the "ground truth" data collected.

Upon receipt of the Russian data for these coordinated measurements, the Russian data will need to be registered and pieced together in order to create continuous swaths of data to be analyzed with the ARES data. The Russian and ARES databases will be co-registered and footprint matched. This will require degradation of the finer resolution data to match the courser resolution data. At this point, the U.S. and Russian databases can be used to create three-dimensional structured scenes using the validated algorithms developed using the ARES database. The data from both visible cameras (U.S. and Russian) will be used as stereo pairs, and the S/MWIR U.S. data will be paired with both the Russian visible and LWIR data from Resource 1.

Next, a spectral/thermal data analysis will be performed. Temperature maps will be constructed independently using the U.S. MWIR data and the Russian LWIR data. The LWIR calculations should be somewhat less complicated since there is far less spatial structure in those bands than there is in the MWIR wavelength regions. Comparison of these temperature determinations to each other will yield a cross-calibration of the U.S. and Russian sensors, and likewise, a comparison to truth data will result in an absolute radiometric calibration of both sensors.

Completion of these describes analyses for all of the data collected during the RAMOS near-term observations will largely impact the success of the classic RAMOS experiment.

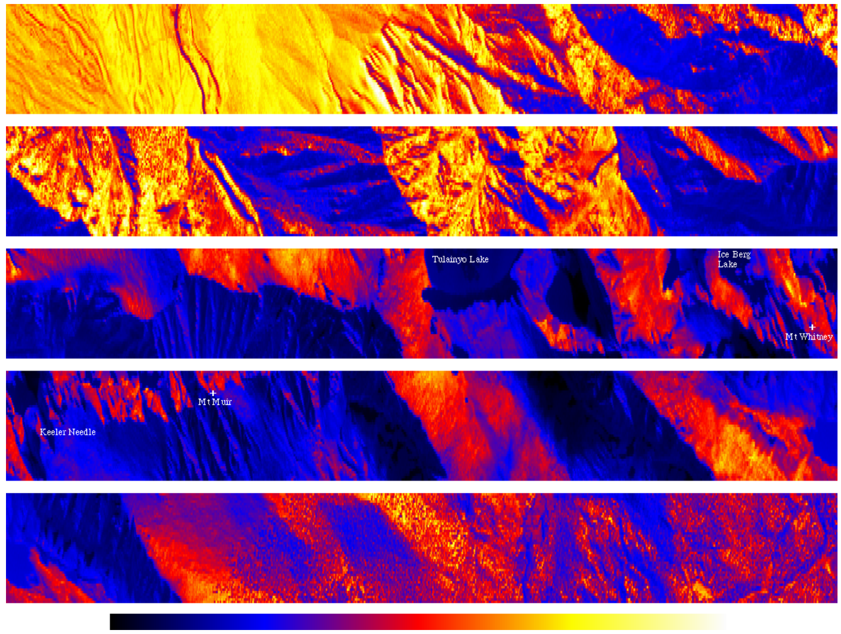

Figure 4 MWIR (~4.2 microns) ARES data collected 5 October 1195 over Mt. Whitney, CA in conjunction with Resource 1. *Photo supplied*

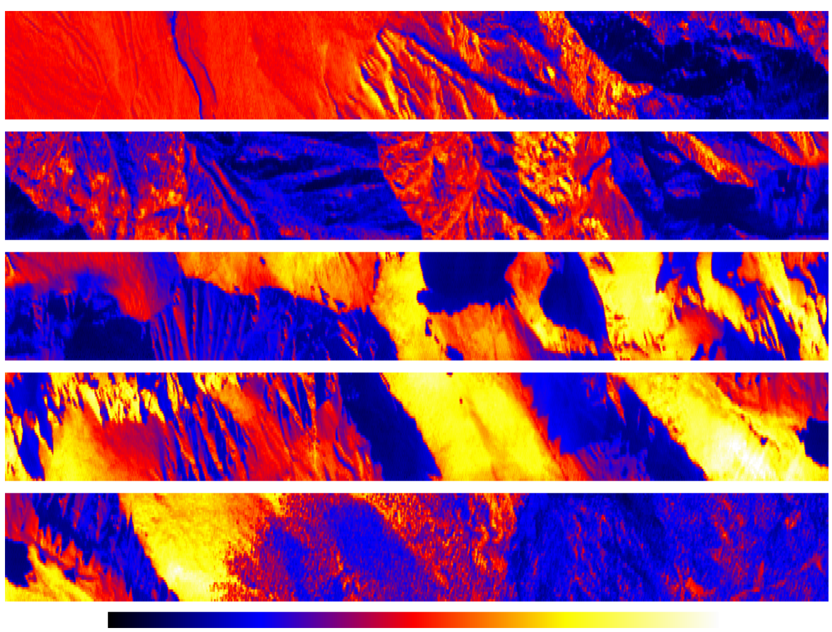

Figure 3 SWIR (~3.7 microns) ARES data collected 5 October 1995 over Mt. Whitney CA in conjunction with Resource 1. *Photo supplied by*

7. Future Observations

The RAMOS team has prepared a schedule of planned observations for the upcoming calendar year. These observations make use of the ARES instrumentation, the Russian MIR, Resource 1 and possibly other, to be specified, Russian spacecraft.

The first set of planned observations utilize the ARES and Resource 1 instruments. The first observation site is Wheeler Peak, NM in February 1996, and its objective is to collect data for cloud stereoscopy. These orographic clouds have little motion and therefore should not pose too difficult a set of imagery against which to exercise the stereo algorithms. This type of data collection is the logical "next step" in the series of near-term observations.

In April 1996, ARES and Resource 1 will again collect data over the ARM CART site in Lamont, OK. This data collection will occur during an ARM campaign when there will be many "ground truth" instruments and experiments taking place. This ground truth data will be used as discussed in Section 5. Targets of opportunity during this measurement are cirrus or cumulus clouds, which have spatial structure and can be used to attempt to measure wind fields at altitude. This measurement is unique to the RAMOS experiment because of its ability to measure simultaneous stereo imagery. Simultaneous stereo allows for the separate determination of cloud heights and velocities.

The next set of near-term observations planned in support of RAMOS makes use of MSX, MSTI and a Russian satellite (TBD). The first of these measurements will happen in May or June of 1996 over the Atacama Desert near the central Chilean coast. This region is an interesting observation site because it is a desert area with high mountains. Generally, there are clear lines of sight with very strong terrain relief for registration and processing of stereo scenes.

The second scheduled flight in this set of observations will be in June or July 1996 over the ARM site. The objectives of this flight are the same as the previous ARM flight scheduled in April 1996.

The third set of near-term observations is tentatively scheduled for 1997 using ARES and MIR. The goal of this flight, or set of flights, is to attempt measurements of cloud polarization and albedo. This measurement would require the addition of filters in either or both the ARES and MIR sensors [1]. Analysis of these measurements would include attempted correlation of the observations with ice clouds and water clouds, and thus to determine the criteria for locating cloud glaciation altitudes.

8. Conclusions

The RAMOS science teams, both U.S. and Russian, have carefully defined a set of near-term observations designed to lead the program to achieving its goals. Two such observations have recently been accomplished and data analysis of these first sets of data has just begun. Preliminary information implies success of both observations.

These near-term observations mark the first-ever coordinated, simultaneous measurements between the U.S. and Russia, and each observation is another step toward the success of the joint classic Russian-American Observational Satellites experiment.

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BIOGRAPHY

Cynthia J. Beeler is a Senior Scientist at Visidyne, Inc. and works in the area of infrared backgrounds phenomenology. Currently, Ms. Beeler is responsible for development of image processing and analysis software in support of SBIRS for the Backgrounds Experiments on the MSTI (Miniature Sensor Technology Integration) satellite series that will measure infrared spatial structure. The analysis of these data is focused on their application to present and future designs of BMDO and Air Force system elements. Previously, Ms. Beeler was a co-investigator for the IBSS Background Experiment and analyzed much of its radiometric MWIR spatial structure data in conjunction with data from CIRRIS-1A.