MSTI-3 BACKGROUND DATA-COLLECTION EXPERIMENTS

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Abstract

The ability to detect and track targets against the structured earth and earthlimb backgrounds is a fundamental requirement of many space-based surveillance systems. Knowledge of the background structure is critical for the determination of sensor design characteristics, such as spectral bandpass, sensor field-of-view/footprint, detector sensitivity, and signal processor sizing and algorithm selection. The current background database in the critical SWIR (2.7 μm) and MWIR (4.3 μm) bands is limited. The MSTI-3 mission provides a unique opportunity to collect this needed background data to develop and validate predictive infrared radiance structure codes and to develop an understanding of the statistics of background structure.

The primary objective of the measurement modes described in this paper are to provide data to characterize:

- spatial structure within a waveband
- band-to-band spatial correlation
- two-dimensional spatial structures, and
- temporal structures.

For below-the-horizon (BTH) and above-the-horizon (ATH) geometries and dependence on:

- solar zenith angle
- solar scattering angle
- tangent height (ATH), and
- cloud and surface properties (BTH)

will be assessed. The year-long MSTI-3 mission will provide a statistically significant survey of short-wave and mid-wave infrared backgrounds essential to the design of space-based surveillance systems.

I. Background

a. Data Need

Infrared Tactical Warning and Attack Assessment (IR TW/AA) sensors in general operate by detecting the plume of the ballistic missile against the earth's background. In the infrared, ballistic missile plumes, since they are the product of a combustion process, are composed primarily of water, carbon dioxide, carbon monoxide, and nitrogen. These molecules emit strongly in the 2.7 μm region (water), the 4.3 μm region (carbon dioxide), and the 4.7 μm region (carbon monoxide). Thus, IR TW/AA sensors operate in the short-wave infrared (SWIR) or mid-wave infrared (MWIR). However, the atmosphere contains significant amounts of water and carbon dioxide, and thus absorbs infrared radiation in these spectral regions. The trick, then, to performing the TW/AA mission is to work at the edges of these atmospheric absorption regions, and look deep enough in the atmosphere to detect the target in a timely manner, yet not so deep that clutter from ground sources and clouds causes excessive false alarms. In general, the most important clutter source in the SWIR is solar reflections from clouds at altitudes greater than about six kilometers (a common occurrence), and in the MWIR from a combination of solar reflections, temperature differences between clouds and the ground, and upper atmospheric processes.

In addition to missile plume detection, proposals have been made to fly satellites (e.g., Brilliant Eyes) that continue to track warheads into the midcourse phase, in order to cue a terminal defense. These targets radiate thermally, in a continuum manner, and can be quite dim. Because many short-range ballistic missiles will be tracked by these sensors below the horizon, the desire is to widen the band as much as possible, in order to maximize the detected target signal, while at the same time operating in atmospheric absorption regions, in order to minimize clutter. For these reasons, the MWIR is the most likely region for this mission.

The cost of an IR surveillance and tracking system is determined *primarily* by the number of detectors in the sensor (and hence spatial footprint on the ground for a given revisit time), and by the size of the optics. Ground footprint is governed by a number of performance requirements, not the least of which is clutter suppression. Optical aperture is primarily determined by sensitivity requirements, which in turn must be based on a balance between sensor noise and false returns due to clutter. Thus, clutter is a significant systems cost driver.

The degree to which clutter is an issue is, of course, driven by the performance requirements of the system. Obviously, it is possible to build a sensor with the same performance characteristics as those of the current TW/AA sensor (the Defense Support Program, or DSP), and at a higher revisit rate without the collection of additional data. However, the DSP design, although clearly functional, is certainly not optimal, and a small investment in data collection could lead to substantial cost savings (for example, the footprint could be increased, thus reducing the number of detectors). In addition, the desire may develop, at some future time, to grow proposed follow-ons to DSP (i.e., ALARM) to high sensitivity, or to full on-board processing; these requirements would imply a very low tolerance to clutter and uncertainties in its character. Furthermore, tracking dim MWIR midcourse targets against the earth background is an obviously stressing mission that is relatively intolerant of uncertainties in the background.

Unfortunately, the database needed to determine clutter performance is, depending on the spectral passband, either sparse or nonexistent. The lack of clutter data has been well known within the phenomenology community for several decades.

Since the optical effect due to absorption from the atmospheric water tends to die out at around 10 km altitude, it is possible to collect clutter data in the SWIR from aircraft. However, the optical effects of carbon dioxide are significant up to altitudes of about 70 km, and thus, in the MWIR space-based clutter measurements are required.

Without this data, it is impossible to predict the performance of IR TW/AA and midcourse tracking systems. Specifically, design trades are, to a large degree, based on conjecture. This tends to lead to significant over-design; satellite stability requirements, numbers of detectors, optical aperture, and finally constellation size, cost, and weight on orbit are certain to be suboptimal. Even with over-design, it is likely that the system will not perform as advertised (and as paid for).

b. Previous Missions

While many field programs have been conducted in support of the TW/AA mission, most are of limited utility due to poor sensitivity, limited geometry/scattering angles, excessive footprint, different spectral bandpass, and non-representative scenes.

A notable measurement program conducted some 30 years ago, the A.D. Little U-2 flights, contributed useful data on radiance as a function of SWIR band for small-angle solar scattering and on solar glint from the ocean[1,2]. In order to extend the data to allow analyses of frequency of occurrence, the RM-19 satellite was launched into a polar orbit and collected data in 1971. Its MWIR sensitivity was limited to approximately one µflick (10^{-6} W/cm^2-sr-µm), however; RM-20, its more capable successor, was destroyed by range safety as it veered off course. Teal Ruby, which also could have provided critical data, was canceled for fiscal reasons. Consequently the precise data required to develop a SW/MWIR TW/AA system is still unavailable. However, there are some intriguing data from the CIRRIS 1a[3] and IBSS[4] sensors flown on STS-39 in April/May 1991.

Although originally intended for ATH measurements, the CIRRIS 1a sensor had sufficient dynamic range to measure BTH.

Some 15 minutes of data were collected over the US and Canada by both the CIRRIS 1a radiometer and interferometer and compared with similar data from the IBSS radiometer. Surprisingly, the narrow IBSS 4.3 μm filter showed structure content and the CIRRIS 1a radiometer and interferometer also both measured structure in the heart of the 4.3 μm band. While the narrow IBSS filter may have some spectral leakage and will have its out-of-band rejection transmission remeasured shortly, no such effects are thought to be present in the CIRRIS 1a data. Table 1 shows CIRRIS 1a data. The first three rows are calculated from interferometer data integrated over the spectral region shown, and the fourth row calculated using the radiometer data; the bandpasses for rows three and four are identical. A comparison of rows three and four shows good agreement between the two data sets and the first row shows a surprising percentage (standard deviation/mean) for this narrow 4.22-4.30 μm band. Consequently, addressing this question will be a priority for MSTI-3.

Band (μm)	Mean (W/cm^2-sr)	Std. Dev. (W/cm^2-sr)	%
4.22-4.30	9.19×10^{-7}	5.17×10^{-8}	5.6
4.22-4.40	1.63×10^{-6}	6.91×10^{-8}	4.2
4.09-4.51	4.69×10^{-6}	9.33×10^{-7}	19.9
Radiometer	4.38×10^{-6}	8.58×10^{-7}	19.6

Table 1. CIRRIS 1a Data.

II. MSTI-3 Requirements

a. Overview

Requirements for measuring the background structure were driven by (1) the target signature against which the operational sensor must be able to perform, (2) the need for spectral resolution to explore atmospheric absorption band edges, and (3) the expected operational spatial resolutions. It is very important to understand that the sensitivity required of the measurement sensor is driven by the required target. If the background structure is so dim that no clutter can compete with the expected target, then there is no need to measure it. Thus, to set sensitivity requirements for MSTI-3, the most stressing target was determined from an analysis of the targets that might be of interest for the foreseeable future. Since the MSTI-3 background measurements are supposed to provide a database that stands up over the next few decades, we assumed extremely stressing target signatures that should satisfy long-term data needs. It was assumed that the operational sensor would have its threshold set to a value ~2–3 times less than that minimum target. Finally, since the goal of the sensor on MSTI-3 is to measure background structure at that threshold rather than sensor noise, a signal-to-noise ratio requirement of 6–10 was imposed, yielding a MSTI-3 noise equivalent target (NET). In all cases of interest the target may be considered a point source. Spectral resolution requirements were determined from the structure of both the target signature and the atmospheric absorption band. Finally, spatial resolution requirements were determined from an analysis of system requirements; a TW/AA sensor with a requirement for wide-area surveillance will typically have a footprint ~2 km square, while a cued midcourse sensor can have a much smaller (~100 m) footprint. Specifically, for MSTI-3, the spatial resolution requirement is driven by Brilliant Eyes' system needs for midcourse tracking, and thus the MSTI-3 requirement is that the modulation transfer function (MTF), including effects due to sensor line of sight motion, be, for all spatial frequencies, greater than or equal to the MTF of a diffraction-limited, otherwise perfect, sensor with a 100 m nadir footprint.

b. MWIR

In the MWIR, it was considered unlikely that BTH targets much dimmer than 30 W/sr-μm, which is typical of a booster in midcourse, would be attempted by realistic space-based tracking systems. Assuming a system threshold ~1/2 that value, and a desire to measure background structure at that threshold with a S/N of about 6, then the MSTI-3 NET should be better than 3 W/sr-μm. For nominal sensor footprint of 100 m, this leads to a noise equivalent spectral radiance (NESR) of 3×10^{-8} W/cm^2-sr-μm, or 0.03 μflicks. A further stressing target would be a dim upper-stage plume; we assumed that signals less than about ~3000 W/sr-μm would not be likely for wide-area warning systems. This leads to a measurement sensor NET specification of better than 300 W/sr-μm. However, sensors designed to track this class of target may be used for global surveillance, and thus footprints of ~1 km can be expected. A radiance fluctuation of about 0.2 μflicks that subtends the full 1 km operational footprint would cause a threshold crossing, and therefore a measurement sensor such as MSTI-3 would need an NESR of, again, 0.03 μflicks or better to collect background structure data relevant to such an operational sensor. Note, however, that this NESR need only be achieved at the 1 km spatial resolution, and thus even better performance can be achieved by taking advantage of the sensitivity gain from spatial co-adding of pixels. Nevertheless, the MSTI-3 sensitivity requirements in the MWIR have been set under the assumption of at best low-efficiency spatial co-addition gain.

The spectral filters chosen for the MWIR are listed in Table 2:

λ>0%	λ<5%	λ<50%	λ>50%	λ>5%	λ<0%
4.21	4.23	4.24	4.44	4.45	4.47
4.21	4.23	4.24	4.42	4.43	4.45
4.21	4.23	4.24	4.40	4.41	4.43
4.21	4.23	4.24	4.38	4.39	4.41
4.21	4.23	4.24	4.34	4.35	4.37
4.21	4.23	4.24	4.30	4.31	4.33
3.43	3.53	N/A	N/A	4.04	4.16

$$\left.\frac{dT}{d\lambda}\right|_{5-50\%} = 4500$$

Table 2. MWIR Filter Specifications (μm)

The last filter, 3.53-4.04 μm, is for cloud temperature determination and mimics the NOAA AVHRR cloud-temperature band.

The two narrowest bands were chosen so that cloud-generated structure would not be an issue. The 4.21-4.31 μm band is so narrow as to guarantee that only the highest altitudes of the atmosphere will be sampled; it is also as narrow as filter and sensor design might be expected to reasonably allow. The 4.21-4.35 μm band should allow more target photons while having the same clutter phenomenology as the narrower band. However, both are included from a decision-theoretic perspective: if unexpectedly high clutter is seen in the wider band, then there would be intense interest in the narrow band data, while if benign structure is seen in the narrow band, then the wider band measurements would be needed for system design. The remaining MWIR bands were selected with a focus on sampling structure that just leaks in from higher altitude clouds; only one arguably wide (low altitude) band is included, the rationale being that aircraft measurements can collect data in the transmission regions of the atmosphere. The rationale for going to space for this type of measurement is, after all, to explore the opaque regions and their edges.

In Figure 1 we show atmospheric absorption in the MWIR as a function of altitude. The blue edge of the MSTI-3 filters was chosen to be inside the atmospheric band edge at 4.21 μm. The red edges were chosen to, in effect, sound the atmosphere; the narrowest band will only penetrate the atmosphere down to altitudes of about 20 km, and, thus, is expected to see few clouds. Background structure in this band is expected to arise primarily from upper-atmospheric processes, but with a consequent loss of target signal (due to the narrow band), and with no capability to track targets deep in the atmosphere, such as boosting short-range ballistic missiles. The wider bands successively see first high-altitude clouds, then mid-altitude clouds, and finally ground clutter.

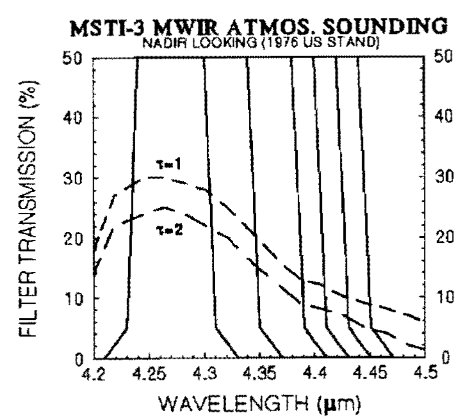

Fig. 1. MWIR Atmospheric Sounding

c. SWIR

We assume as unlikely SWIR targets dimmer than ~3000 W/sr-μm for operational sensors with footprints of about 1 km. Logic similar to that discussed above leads to a MSTI-3 requirement of 0.03 μflicks at 1 km footprint. Again, background structure relevant to operational systems with still larger footprints can be measured with some spatial co-adding.

Atmospheric transmission in this spectral region is shown in Figure 2.

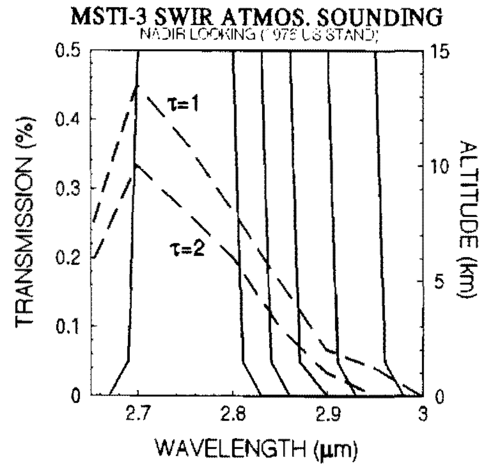

Fig. 2. SWIR Atmospheric Sounding

The rather complex spectral content of the target SWIR emission spectra makes passband selection more complicated than that in the MWIR. However, analysis[5] suggests the passbands shown in Table 3.

λ>0%	λ<5%	λ<50%	λ>50%	λ>5%	λ<0%
2.66	2.69	2.705	2.945	2.96	2.98
2.67	2.69	2.705	2.895	2.91	2.93
2.67	2.69	2.705	2.855	2.87	2.89
2.67	2.69	2.705	2.825	2.84	2.86
2.67	2.69	2.705	2.795	2.81	2.83
N/A	2.58	N/A	N/A	3.43	N/A
N/A	2.58	N/A	N/A	3.43	N/A

$$\left.\frac{dT}{d\lambda}\right|_{5-50\%} = 3000$$

Table 3. SWIR Filter Specification (μm)

III. MSTI-3 Observations

To address the above requirements, a number of detailed observations have been planned for the MSTI-3 satellite[6]. These observations make up the bulk of the MSTI-3 operations and will continue throughout the lifetime of the satellite. Much of the data will be correlated with cloud type and seasonal influences, which puts a substantial burden on the ancillary "truth" data which will be provided to the analysts.

Each of the observations have been prioritized in importance to the early warning community and the ability of MSTI-3 to address the fundamental uncertainties. Based upon the inputs from that community, the priorities are:

a) Solar scattering (diffuse and specular)
b) Survey large regions (statistical data base)
c) 3-D structure
d) Earth limb
e) Temporal variation
f) Reference scenes
g) Aurora (BTH and ATH)
h) Jetstream & strat-warming
i) High-altitude airglow

In this section of the paper we will describe in detail the observational plans for each of these tasks as well as the truth data which will be provided.

a. Solar Scattering (Diffuse & Specular)

By far the largest contribution to background clutter in the SWIR is due to solar scattering. This contribution ranges from a general increase in background radiance to solar specular points which will overwhelm the signal from any terrestrial target. The impact of solar scattering in the MWIR (in the heart of the absorption region) is less certain and needs to be ascertained prior to the development of the next generation of surveillance systems.

The solar scattering angle, θ, is defined by the following diagram:

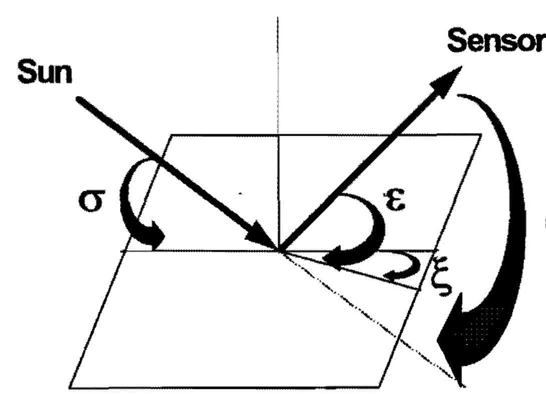

Fig. 3. Solar Scattering Geometry

The solar photons striking a scattering surface at incidence angle, σ, are scattered into reflectance angle, ε, and azimuth angle, ξ, towards the observer. The specular point is defined where the incidence angle equals the reflectance angle (i.e., $\sigma = \varepsilon$, $\xi = 0$).

This experiment will measure the two-dimensional spatial structure of the background scene at varying solar scattering angles and spatial resolution. These measurements require a variety of scenes with features such as high-altitude clouds and cloud edges, oceans, snow and terrain that create stressing backgrounds due to solar scattering. These observations can be conducted over geographic regions known for high probability of the types of cloud cover required for scattering.

Table 4 outlines the highest priority measurements in terms of solar scattering angles and latitudes of interest:

Priority	Latitudes	Priority	Scattering Angle
1	20-50°	1	< 30°
2	0-20°	2	30-60°
3	50-90°	3	>60°

Table 4. Prioritized Measurements for MSTI-3 Solar Scattering Observations.

The latitudes were prioritized according to the location of the majority of regional areas of interest, and the scattering angles were prioritized based upon the likelihood and severity of solar scattering angles predicted for low-earth-orbiting surveillance systems.

The solar specular measurements will concentrate on those regions which cause outage problems for surveillance system sensors. The observations will measure the radiance levels and spatial structure of the specular region. Similar to the scattering observations described above, the content of the scene is essential. For these observations, high-altitude clouds with ice crystals or bodies of water are contained in the scenes of primary interest.

Given that the MSTI-3 satellite will be in a sun-synchronous orbit with an approximately 6:40 equatorial crossing time, certain constraints exist for the accessible solar scattering angle as a function of time of year. Since we want to map out the radiant intensity as a function of latitude, scattering angle, and season, understanding the limitations based upon the orbit is critical. Figure 2 presents the solar scattering angles accessible at the equator as function of day in the year for the MSTI-3 proposed orbit. The symbols represent the minimum and maximum scattering angle accessible each day (i.e., there are two symbols in the chart for each of the 365 days represented). From Figure 4 we see that scattering angles <30° are available every week of the year at the equator, with typically minimum solar scattering angles of 10-20° possible.

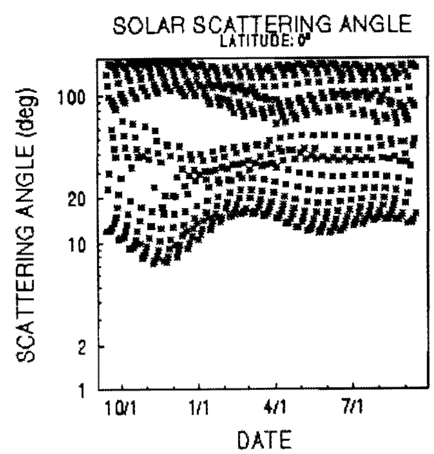

Figure 4. MSTI-3 Solar Scattering Angles Accessible at the Equator.

Figure 5 represents the solar scattering angle accessible to MSTI-3 for a latitude of 35°N. In this figure we note that the minimum angles in the winter can be quite small, whereas the minimum summer solar scattering angles tend to be much larger, with values typically around 20°. For both latitudes presented, MSTI-3 will be able to obtain the highest priority scattering angles any time of the year. Thus, the sun-synchronous orbit provides only a small restriction on the accessible solar scattering angles.

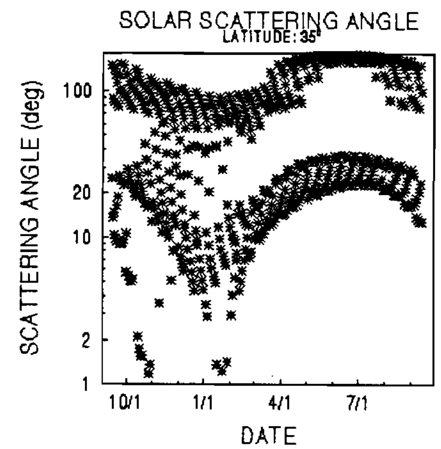

Fig. 5. MSTI-3 Solar Scattering Angles Accessible at 35°N Latitude.

b. Survey Large Regions (Statistical Data Base)

One of the most important products to come out of MSTI-3 will be a statistical data base representing the SWIR and MWIR clutter over large regions of the earth at different times of the year and meteorological conditions. This data will be used to characterize the nominal clutter conditions needed for designing the next generation space-surveillance systems. Understanding the probability of false alarms from statistical outliers in the clutter distribution is critical. In addition, the data will be used to design and test new spatial and spectral clutter-rejection algorithms to decrease the probability of false detection.

This observation will be accomplished by taking successive scenes which will form long contiguous swaths thousands of kilometers in length. Both step-stare and pushbroom pointing will be utilized. Step-stare pointing has the advantage of not requiring image coregistration, while pushbroom pointing reduces the effects of focal plane nonuniformity on the data.

Observations will be made repeatedly for different latitudes, seasons, and meteorological conditions. The data will be correlated with coincident measurements from DMSP, LANDSAT and NOAA satellites and other validation sensors. Data will also be taken as a function of grazing angle which will produce varying footprints and slightly different results depending upon the three-dimensional structure of the emitting region (i.e., we will start to become sensitive to an emitting volume as opposed to a surface). The priority measurements are summarized in Table 5.

Priority	Earth Grazing Angle	Footprint (m)
1	~ 0° (Nadir)	42.5
2	~30°	49.1
3	~60°	85.0

Table 5. Prioritized MSTI-3 Observations for Statistical Data Base.

c. 3-D Structure

Ascertaining the three-dimensional structure of the clutter emission region is important for extrapolating the results to the design of an operational system with different orbit and viewing geometry. This data will also be used to validate background models which attempt to simulate realistic environments.

The basic mode of operation will be to stare at a fixed latitude, longitude, and altitude and observe how the emission changes as the satellite moves and sweeps out large angular variations. The fixed point can either be along the velocity track of the satellite or orthogonal to the track (the former will sweep out a larger angular variation from MSTI-3 but with a smaller solar scattering angle variation than the latter).

A number of such observations will be made to assess the degree of homogeneity in the emission volume as functions of the basic parameters (meteorological conditions, solar scattering angle, and latitude).

d. Earthlimb

The importance in understanding the structure of the earthlimb arises from the typical viewing geometry that a low-earth-orbiting surveillance satellite will often have with respect to a target. To maintain a small constellation and hence lower cost, a satellite in LEO will have to plan for a large percentage of target engagements against the earthlimb. The structure in various wavebands and at different spatial scales will directly affect the operational capability of the asset. Thus, significant design trades need to be assessed - but insufficient data currently exists at the relevant spatial scales and sensitivity to impact the system designs. MSTI-3 should help fill in missing data.

Figure 6 is an MWIR earthlimb picture taken by MSTI-2. The bandpass used was approximately 3.5-4.8 μm.

Fig. 6. MWIR Earthlimb Taken by MSTI-2.

For MSTI-3 observations of the earthlimb we will be concentrating on MWIR imagery from the horizon to approximately 100 km tangent altitude. The earthlimb observations include day, night, and terminator regions as well as repeating the observations for high, medium, and low latitudes. Several images will be taken in a step-stare pointing mode with sufficient overlap between images to insure adequate frame coregistration. Table 6 outlines the current viewing geometry plans:

Tangent Height (km)	Range (km)	Coverage (km)
10	2339	BTH-38.6
30	2284	2.1-57.9
50	2227	22.8-77.2
70	2168	43.5-96.5
90	2108	64.2-115.8
110	2046	85.0-135.0

Table 6. Coverage of MSTI-3 Earthlimb Observations.

e. Temporal Variations

Knowledge of the temporal characteristics of structured backgrounds is critical for accurately modeling background phenomena and in designing sensor signal-processing algorithms. The temporal variation experiment will exploit MSTI-3's capability to stare at an earth scene to gather data on the varying nature of the earth background over very short timescales.

Coordinated weather data from DMSP, NOAA, and other sources will be required for the observation so that stressing scenes can be identified and measured. The observation will measure scenes at small to moderate solar scattering angles, as well as at night.

To make the observation, the line-of-sight (LOS) will be fixed at a specified latitude, longitude, and altitude. Five seconds of data will be collected per filter in the SWIR and MWIR. The gimbal mirror will be commanded to backscan to compensate for the motion of the satellite. The data obtained will prove useful for assessing the trade-off between integration time and clutter suppression for LEO satellite systems.

f. Reference Scenes

The primary focus of the backgrounds observations is to collect data on stressing earth backgrounds for updating models and for assessing the impact of the data on sensor systems. Benign earth background scenes are needed to assess the severity of the stressing scenes taken in the solar scattering, specular point, and statistical data base observations.

The reference scene measurements will be made under three conditions: day (cloud-free), night (clouds), and night (cloud-free). The procedure for the reference scene measurements is as follows: the LOS pointing will be commanded to maintain a ground stare point. Multiple frames will then be taken in the SWIR and MWIR filters. The observations will be repeated for angles corresponding to those measured above in the other experiments.

DMSP, LANDSAT, and NOAA satellite images and other corroborating data will be required to schedule data collection events and verify the presence, or absence, of clouds.

g. Aurora (BTH and ATH)

Aurorae can produce extremely stressing infrared backgrounds in the high-latitude earthlimb. Enhanced emissions have been observed at 2.7 μm and 4.3 μm. All previous auroral measurements have been taken with scanning sensors, which cannot assess the auroral temporal dynamics important to staring sensors. The MSTI-3 sensor system has the capability of making the first such measurements.

A pre-planned mode of operation designed to stare at the evening-midnight sector of the auroral oval will be initiated during intense auroral activity. Auroral activity will be monitored in near real-time with DMSP imagery and regular reports from the worldwide magnetometer network. Once a measurement opportunity and its location are identified, a series of stares adjacent to each other in azimuth space (all centered at 95 km tangent height) will be taken as the MSTI-3 orbital motion moves the field of view through the high-priority region of the auroral oval.

The auroral observation will require collecting both SWIR and MWIR data. During the observation each filter will collect multiple images while staring at the target point. It is planned to schedule the nominal earthlimb data during favorable auroral access orbits with the idea of combining or substituting the auroral modes when geomagnetic and auroral conditions are favorable.

h. Jetstream and Strat-Warming

The jetstream region may provide an interesting opportunity to look for spatial clutter over a well-defined atmospheric boundary. The jet stream is continually monitored by meteorological stations, so its location is well known. The jet stream observation requires collecting multiple frames in the SWIR and MWIR in the appropriate filters which will see down to the level of the disturbance.

Primarily during the months of January and February, with some lower probability of occurrence in December and March, there is a phenomenon referred to as strat-warming that takes place only in high latitudes (> 50^{o}) in the northern hemisphere. During such an event the temperature of the stratosphere may, over about two weeks, rise approximately 60 K and remain peaked for several days. The largest temperature fluctuations usually occur near 40-50 km altitude and may extend over 100 km or more. The net effect of the strat-warming may be a rise in the background clutter level seen by several of the MSTI-3 filter bands.

Several sites have been set up to monitor the development of these strat-warming events. These sites will be monitored so that a measurement sequence will be conducted if a warming occurs. The observation will require sequencing through the filters while staring at a selected target point. The scenes of interest during the strat-warming will be near the center of the polar vortex and the edges of the warming, where there could be an increase in the spatial structure due to temperature variations.

i. High-Altitude Airglow

The hydroxyl (OH) airglow observable at 2.7 μm often reflects structure due to atmospheric dynamics. MSTI-3 will attempt to observe these features by pointing the center of the imaging array to a tangent height of 85 km and allowing the spacecraft motion to scan the array along the limb. Observations will be compared with measurements from ground-based sites and compared with models of high-altitude structure.

IV. Analysis Plans

The first task in the data analysis will be to generate calibrated images and to group them by data-collection experiment (see Section III). An extensive infrastructure for generating such images already has been established using MSTI-2 data. Consequently, calibrated MSTI-3 images are expected to be available to analysts shortly after launch.

The calibrated data from the model evaluation experiments will be analyzed by reconstructing within the CLOUDSIM model, using collateral and ground-truth data, the scenes from which the data was collected. These reconstructed scenes will then be compared to the data. Hypotheses on the cause of the observed discrepancies will be made, and follow-on experiments will be conducted (if, for example, other collateral data needs are determined). The model will then be upgraded, *based on the needs of the user*. Additionally, the uncertainties in the model will be quantified.

The statistical data will be binned synoptically (i.e., by solar geometric conditions, lat-long, zenith angle, etc.). Since scene gradient has been found to be a good indicator of the clutter content of the scene, scenes will be scored by taking gradients over various step sizes, and computing the 90th, 99th, etc. percentile bins. Furthermore, the scenes will be played against "canonical" filters (i.e., DSP-like, temporal, spatial) and scored by exceedance bin. The S/MWIR scenes will ultimately be classified as a function of synoptic parameters. Data/images to be used primarily for development/validation of predictive infrared atmospheric and terrestrial structure codes will be treated in a similar fashion.

The net result of this activity will be a statistical database in the SWIR and MWIR at the appropriate sensitivities and spatial resolutions, and the ability to generate validated model scenes of known content.

V. Conclusions

MSTI-3 demonstrates the tremendous utility which a properly instrumented small satellite can have for answering fundamental questions about the nature of earth's atmosphere and its structure. For more than twenty years, DoD has recognized the need for collecting the SWIR and MWIR clutter data, but for twenty years the data has remained uncollected. MSTI-3 has the best chance of addressing this data gap - and is the most inexpensive and fastest approach compared to all preceding efforts.

MSTI-3 will build a statistically significant database of background clutter in the atmospherically absorbed SWIR and MWIR bands. A satellite is the only practical means of obtaining the global coverage in the SWIR where the clutter is expected to be a function of cloud type, latitude, season, and solar scattering angle. In the MWIR, significant atmospheric absorption occurs up to 70 km, requiring a space-based asset to collect the data.

Detailed observation plans exist to exploit the capabilities of the MSTI-3 satellite and its orbit to insure that the highest priority measurements are made. The data collected will be analyzed to assess the optimal passbands, spatial resolution, and temporal resolution for future TW/AA sensors. Lacking this data forces the system designers into overdesigning the sensors to compensate for our uncertainty. This approach significantly increases the cost and complexity of a proposed system. MSTI-3 will enhance our knowledge of the background clutter and, hence, ultimately help to provide a more cost-effective early warning system.

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