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**AIR COMBAT TARGETING/ELECTRO-OPTICAL
SIMULATION (ACT/EOS)**

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55 Walkers Brook Drive
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December 1995

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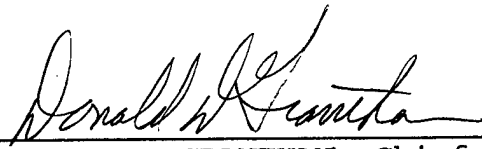
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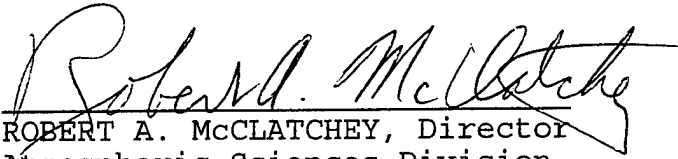


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13. ABSTRACT (Maximum 200 words) ACT/EOS focused on improving support to users of FLIR weapon systems by developing improved performance prediction capabilities. TASC's role in the ACT/EOS program focused on three activity areas: scene visualization, model evaluation, and atmospheric transmission modeling. TASC developed an interactive scene builder and visualization capability using 3-D terrain and target models. The system relies on output from ACT/EOS physical models including thermal contrast, atmospheric effects, and sensor effects models. TASC developed an assessment plan for evaluating the ACT/EOS physical models through comparison with field data. The plan was used to set up a very successful field experiment. Finally, TASC developed an efficient atmospheric transmission and path radiance interpolation algorithm using MODTRAN to incorporate atmospheric effects into infrared scene visualizations.			
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1. INTRODUCTION

This final report provides an overview of TASC activities in support of the Air Combat Targeting/Electro-Optical Simulation (ACT/EOS) program. The goal of the ACT/EOS program is to develop fourth-generation decision aids to support DoD air interdiction operations employing precision guided munitions. ACT/EOS is aimed at providing military mission planners, tacticians and pilots with weapon system performance predictions critical to their decision making. When fully developed, ACT/EOS will be capable of producing realistic battlefield visualizations of infrared scenes to enhance pilot situational awareness. Ultimately, the prototype system developed under the ACT/EOS program will be incorporated into operational Mission Support Systems.

TASC's role in the ACT/EOS program is to provide research and development and engineering support to the Phillips Laboratory (PL) for development of the ACT/EOS system. In coordination with PL, TASC identified work in four task areas which are briefly summarized below.

Task 1. Visualization. Develop a Scene Builder and Viewer (SBV) interface to the ACT/EOS scientific models. The SBV will allow populating background scenes with menu targets and displaying the composite scenes as simulated thermal imagery.

Task 2. MODTRAN Quick-look. Identify the requirements for atmospheric transmission modeling in support of ACT/EOS and optimize the use of MODTRAN for scene visualization.

Task 3. Calibration Support. Assist PL in developing a model assessment plan.

Task 4. Sensor Effects Modeling. Develop a model to incorporate sensor subsystem effects on scene visualization.

In late 1994, the government elected not to proceed with Task 4 and to continue the work on Task 2. This change in emphasis was negotiated in March 1995. A high-level schedule for all tasks, indicating the actual performance periods, is provided in Figure 1.

During the course of the project, detailed technical reports were developed in each of the major task areas (see References 1, 2 and 3). As a result, only summaries of activities are described here. The reader is encouraged to contact PL to obtain these reports if the detailed technical descriptions are desired.

Activity Name	1993		1994				1995				1996	
	Third	Fourth	First	Second	Third	Fourth	First	Second	Third	Fourth	First	Second
Kick-off Meeting	◆											
1. Visualization Task	▶											
2. MODTRAN Quick-look Task			▶				▶ Contract Extension					
3. Calibration Support Task	▶											
R&D Status Reports	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Visualization Software and Report					◆							
MODTRAN QL Software and Report											◆	
Assessment Plan			◆ Draft								◆ Re-issue	
Final Report										◆ Draft	◆ Final	
	Third	Fourth	First	Second	Third	Fourth	First	Second	Third	Fourth	First	Second

Figure 1 ACT/EOS Schedule

This report is divided into five major sections. Following this introduction, activities in Tasks 2 through 4 are described in Sections 2 through 4, respectively. Section 5 contains a summary. Section 6 contains references.

2. TASK 1: VISUALIZATION

2.1 OBJECTIVES OF TASK

The objective of the Visualization task was to develop a sophisticated and user-friendly interface to the ACT/EOS physical models, with emphasis on scene visualization. This led to the development of the Scene Builder and Viewer (SBV) system. Consistent with the design goals at that time, the software was developed in the NeXTStep development environment and used the Renderman visualization software supported by NeXTStep. The SBV was developed in the first year of the project; it allows the user to build scenes through the use of terrain databases and target geometry files and to view the constructed scenes in a number of different ways. The software can support shading of scene elements using brightness temperature output from the thermal contrast model (TCM2), false-color shading based on object type, and wire frame rendering of the scene. Developed scenes can be saved and accessed at a later time.

2.2 SUMMARY OF TECHNICAL DEVELOPMENT

A strawman design concept for the SBV was presented at the ACT/EOS kickoff meeting held at the Phillips Laboratory, Hanscom AFB, on 2 and 3 September 1993. Minor design changes were made as a result of discussions at the meeting, but the overall concept was accepted. Following acceptance of the strawman design concept, work was initiated on the System Concept Design. The System Concept Design provided detailed descriptions in the following areas: statement of requirements, concept of operations, functional decomposition, data and user interface flow descriptions, object class identification and derivation, and etc. During the November timeframe, TASC received the GFE computer equipment and software, and began exploring the capabilities of the NeXT Renderman scene visualization application.

The System Concept Design was briefed to Mr. Jeff Yopez, the COTR at the time, on 10 December 1993. Based on discussions at that meeting, some details of the System Concept Design were revised. An important capability that was added was the capability to aggregate individual terrain elements in the scene, based on proximity, background type, and geometry. Only the aggregated list of background types was to be presented to

TCM2, thus reducing the computational load on the thermal model. At the same time, file formats for exchanging information between the SBV, TCM2, the atmospheric transmission model (ATM), and the sensor performance model (SPM) were coordinated with the other ACT/EOS contractors (KRC and HSTX). In parallel with the system design, TASC initiated development of certain lower level models (e.g., software to render target objects based on TCM2 target geometry files).

The System Concept Design was reviewed at a technical exchange meeting held at PL on 27 and 28 January 1994, which resulted in minor changes to the design. Software development of the SBV was in full swing at this time, and much of the desired functionality was incorporated by the end of April 1994. The software was demonstrated to PL in late May and was very well received. During June and July, TASC continued to fine-tune the product, and initiated development of a technical report to describe the system design. The software was demonstrated at the ACT/EOS contractors meeting held at PL on August 3 and 4, 1994. The software and documentation were formally delivered on 22 August 1994.

The SBV system was not utilized by PL. Shortly after the system was delivered, the technical management of the ACT/EOS program changed and with it the goals and direction of the ACT/EOS program changed significantly. In particular, the target environment for developing the ACT/EOS system was changed from NeXTStep to UNIX. In addition, whereas the SBV was designed to support model evaluation and field tests as a first priority, the later emphasis was focused more towards the longer-range goal of developing realistic scenes to enhance pilot situational awareness. Consequently, the SBV served as a prototype and demonstratable capability, but was never utilized to the extent initially intended.

2.3 SUMMARY OF SBV CAPABILITIES

The SBV was developed as a powerful, user-friendly front-end to PL's Infra-red (IR) Weather Impact Decision Aids, under the ACT/EOS program. Having been built under the NeXTStep development environment, it takes full advantage of the NeXTStep foundations classes, including the "appkit" for the user interface and the 3D-kit for interactive access to Renderman. The main functions of the SBV are as follows:

- Construct 3D models of scenes
- Perform visualization of IR scenes

- Generate graphical displays of target/background contrast for these scenes.

The SBV user interface supports two major activities: 1) data ingest and 2) scene model construction and visualization. Data ingest refers to reading in data, representing either a background or a target, from external sources, and using that data to construct a 3D model that is readily usable by Renderman. Once held internally in this form, these models can be viewed and manipulated by the user. Any such models can then be archived in such a manner that they can be retrieved and restored to Renderman-ready format quickly.

The model archive is the source of model primitives for the scene construction activity. The user first selects a background model from among those in the background archive. Then, the user selects one or more targets from the target archive. Each selected target can be independently placed on the background, and given an arbitrary azimuth. The targets are automatically sloped to conform to the local terrain. Scenes constructed in this fashion can, themselves, be archived and retrieved. Retrieved scenes can then be the starting point for additional construction (i.e., adding more targets).

All models can be viewed in any one of four different modes, called "image types" on the user interface. These types are: point cloud, wire frame, faceted solids, and smoothed solids. The point cloud mode shows only the vertices of the model's facets. The wire frame mode shows these vertices connected by straight-line segments. The faceted solids mode shows the facets shaded in a realistic manner, with hidden surfaces removed. Finally, the smoothed solids mode is like the faceted solids mode (i.e., shaded with hidden surfaces removed), but the shading is such that the sharp edges at the borders between facets are less obvious.

All models can also be viewed using one of two shading options. A no-shading option uses white as the inherent color of all facets, and a pseudo-color option uses colors suggestive of the surface type of background facets, and a neutral gray as the inherent color of target facets. In addition, *scene* models can be viewed using a thermal shading option. This option shows grey values derived from thermal radiances obtained from the physical models. When this option is selected, the user has a choice of viewing gray values derived from inherent radiances or at-sensor radiances. The latter take in to account the effects of the intervening atmosphere.

The SBV is designed to use results from the ACT/EOS physical models (thermal and atmospheric transmission models) for the thermal shading. At the time of the SBV development, these models were encoded in the Mathematica language. Since that time, they have been re-written into the C programming language. The SBV is designed to access the physical models transparently, as needed. Specifically, whenever a new scene is constructed or an old scene is modified, the SBV is designed to communicate with TCM2 to obtain inherent radiances. Also, if the user selects the atmospheric effects option, the SBV is designed to communicate with the ATM to obtain parameters from which at-sensor radiances are computed. Movement of the sensor while in this mode results in a repetition of communication with the ATM and subsequent recomputation of at-sensor radiances.

Each time the SBV communicates with the ATM, it also obtains contrast histories (inherent temperature differences between target and background) for each target in the scene from the SPM. Subsequently, the user has the option to display these contrast histories in the form of a line graph. A single graph shows the contrast history of each target in a different color, so that the different histories may be directly compared.

The SBV and ACT/EOS physical models together form a loosely coupled system. That is, they pass each other required data via a prescribed set of files, as shown in Figure 2. The figure also shows the inputs, outputs, and user choices described above.

2.4 OVERVIEW OF TECHNICAL REPORT

The technical report, "ACT/EOS Scene Builder/Viewer Architecture and Maintenance Manual," Ref. 1, provides a complete description of the SBV architecture and design. An overview of the system is provided in Chapter 1 of that report. A general description of the SBV software architecture, as a cooperating collection of objects, is provided in Chapter 2. The chapter is intended to provide a basic understanding of how the SBV works. This is supplemented by detailed class descriptions in Chapter 3. Finally, Chapter 4 describes the SBV files and required directory structures. The reader is referred to this comprehensive technical report for further details of the SBV system design.

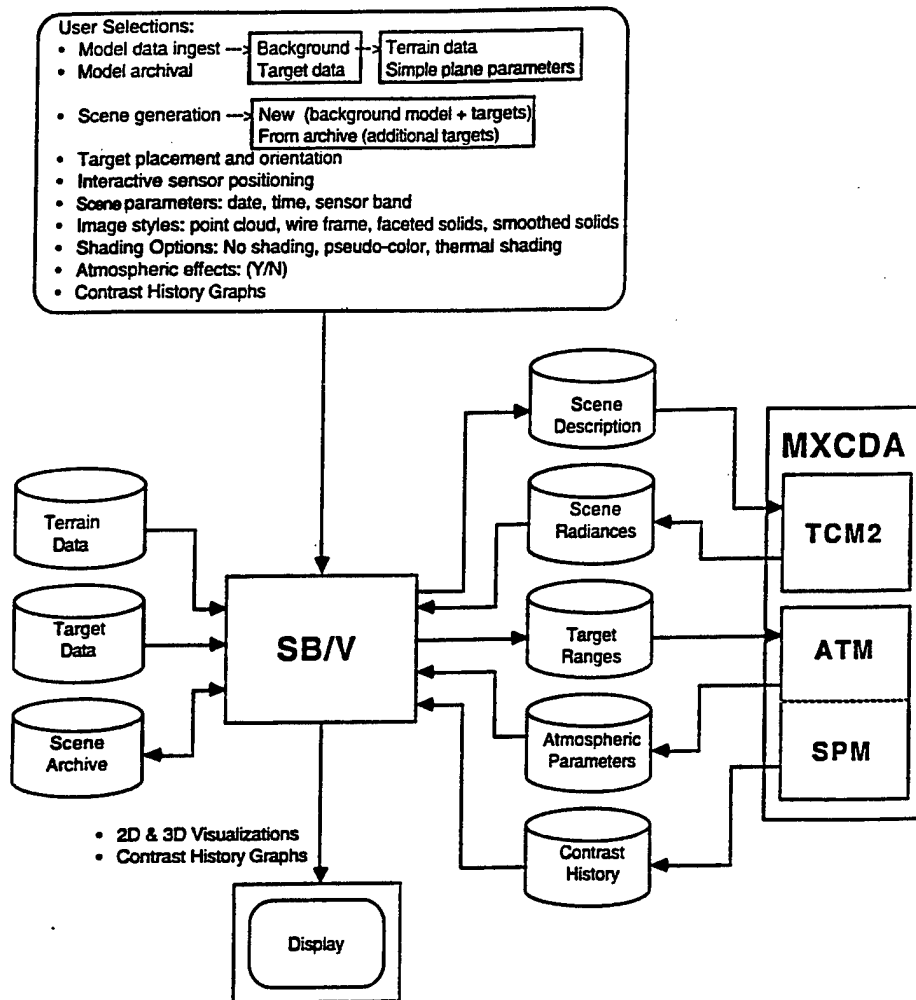


Figure 2 SBV Concept of Operations

3. TASK 2: MODTRAN QUICK-LOOK

3.1 OBJECTIVES OF TASK

The objective of Modtran Quick-look task was to develop an interpolation algorithm to efficiently estimate atmospheric path transmission and radiance to support infrared scene visualization. The method selected for ACT/EOS uses the MODTRAN atmospheric transmission model to compute atmospheric path transmission and radiance for user-selected scenario parameters and for a limited number of geometries, dependent on the scenario parameters. Scaling laws and interpolation provide estimates of these parameters for other desired geometries corresponding to the locations of scene elements, yielding a significant time savings relative to executing MODTRAN for every desired geometry.

3.2 SUMMARY OF TECHNICAL DEVELOPMENT

According to plans, work on the MODTRAN Quick-look task began in May 1994 with a requirements analysis. An overview of the requirements for the MODTRAN Quick-look algorithms is provided below:

- Sensor bandpass: 8–12 μm
- Sensor altitudes: 0 to 1.0 km
- Sensor zenith angles: 45 to 180 degrees
- Sensor to target range: normally 0–25 km, maximum 50 km
- Target (scene element) altitude: 0 to 2 km
- Meteorological scenarios: user specified; test using MODTRAN climatologies and variations
- Interpolation error goals: average 1K or less for apparent temperature; average 10% or less for atmospheric transmission and path radiance.

In the initial phase of the effort, between May and August 1994, the focus was on sensor zenith angles ranging between 90 (horizontal) and 180 degrees (nadir). These paths are downward-looking and generally intersect the earth's surface.

The requirements analysis was followed by a sensitivity analysis that sought to identify potential sampling techniques, scaling laws, and interpolation approaches that might

be used to estimate path transmission and radiance over an entire scene. During the next few months, a candidate list of scaling laws and interpolation methods were examined. Results of this study were briefed at the ACT/EOS contractors meeting held at PL on August 3 and 4, 1994. By that time, most of the initial funding for ACT/EOS was expended. Shortly after the meeting, work was suspended until additional funds were allocated to the task.

Work on the ACT/EOS project resumed in late March 1995, after a contract extension went into effect. The contract extension continued activity on the MODTRAN Quick-look task (Task 2).

Four sub-tasks were identified as follows:

1. Complete MODTRAN Quick-look analysis for downward looking paths
2. Extend the analysis to upward-looking paths
3. Integrate results of the first two subtasks and develop deliverable software
4. Develop technical report describing the MODTRAN Quick-look algorithms.

In April 1995, TASC met with PL representatives to coordinate requirements for the software to be delivered at the end of the contract. At that meeting, it was determined that the delivered software would be developed in ANSI C and would be run at PL under UNIX on an SGI workstation. The software would consist of two main components: a series of executable programs to set up the required MODTRAN runs, execute MODTRAN, and output results to an intermediate data file; a second callable function would perform the actual interpolation of path transmission and radiance for paths specified by the user. Required input would be specified via data files. PL requested that TASC provide a commented version of the code in progress, along with any design specifications, towards the end of August.

Subtasks 1 through 3 were conducted in parallel over the next few months. A detailed design document was provided to PL in late July and a first draft copy of the software was provided to PL in late August. Feedback on both products was positive. From September through most of December, the software was developed and the algorithms tested over a variety of conditions. The algorithms and software are briefly described below, and in much more detail in the technical report "Atmospheric Effects Interpolation Algorithm — Technical and Software Description," (Ref. 2).

3.3 MODTRAN QUICK-LOOK ALGORITHMS

3.3.1 Introduction

An important component of the physical modeling required to produce realistic scene visualizations in the 8–12 μm band is the treatment of atmospheric effects. The radiation emitted by a scene element is attenuated by the atmospheric volume along the path between the scene element and the sensor. At the same time, path emission along the atmospheric path contributes to the radiance reaching the sensor. Both effects must be considered for realistic scene visualizations.

In support of the atmospheric effects modeling for ACT/EOS, an interpolation algorithm was developed to efficiently estimate atmospheric path transmission and radiance to support infrared scene visualization. The method uses MODTRAN to compute atmospheric path transmission and radiance for user-selected scenario parameters and for a limited number of geometries, dependent on the scenario parameters. Scaling laws and interpolation provide estimates of these quantities for other desired geometries corresponding to the locations of scene elements, yielding a significant time savings relative to executing MODTRAN for every desired geometry. Estimates of interpolation error for the atmospheric quantities as well as for apparent temperature are provided below.

The MODTRAN atmospheric effects model is frequently used to estimate line-of-sight path transmission and radiance for specified scenario and atmospheric conditions. The amount of time required to execute MODTRAN in support of scene visualization can be very large, however, if MODTRAN is used to compute path transmission and radiance for every scene element or every displayed pixel. For example, if MODTRAN were executed for every pixel of a 1024×800 display, a total of 819,200 computations would be required.

Fortunately, a very large number of executions is not required in most cases. However, a sufficient number of executions is needed to properly “characterize” the scene. Figure 3a and b illustrate a visualized scene that includes terrain features, a POL storage tank, and the sky. From the perspective of executing MODTRAN, a wide range of viewing geometries and scenarios are present in this single scene. Some scene elements are located close to the sensor, while others are located a great distance away. Some paths intersect the ground, other paths do not. The atmospheric effects model must be capable of providing accurate estimates of path transmission and radiance for all of these paths.

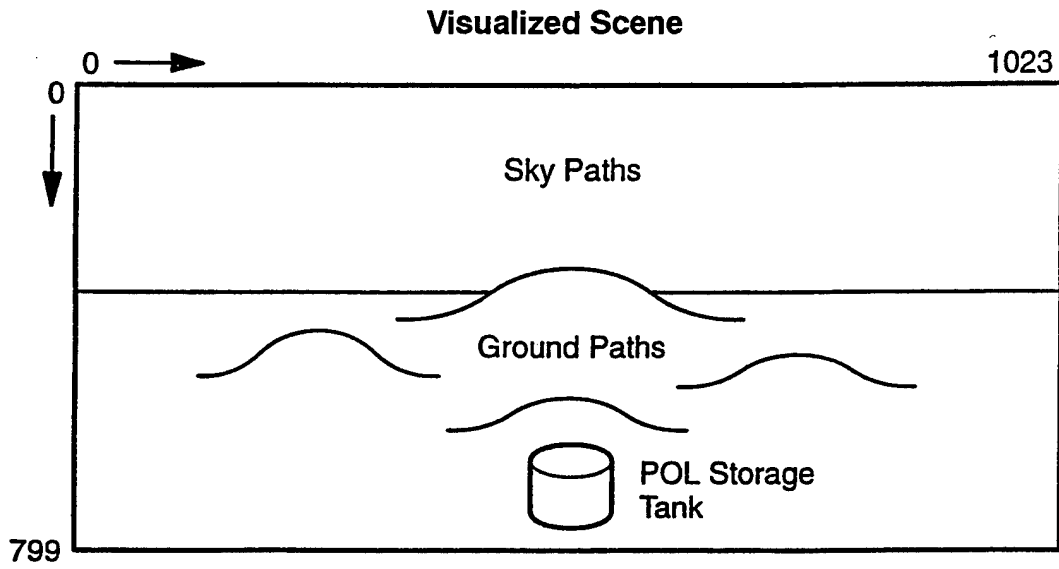


Figure 3a Notional sketch of a Visualized Scene on a 1024 × 800 Display

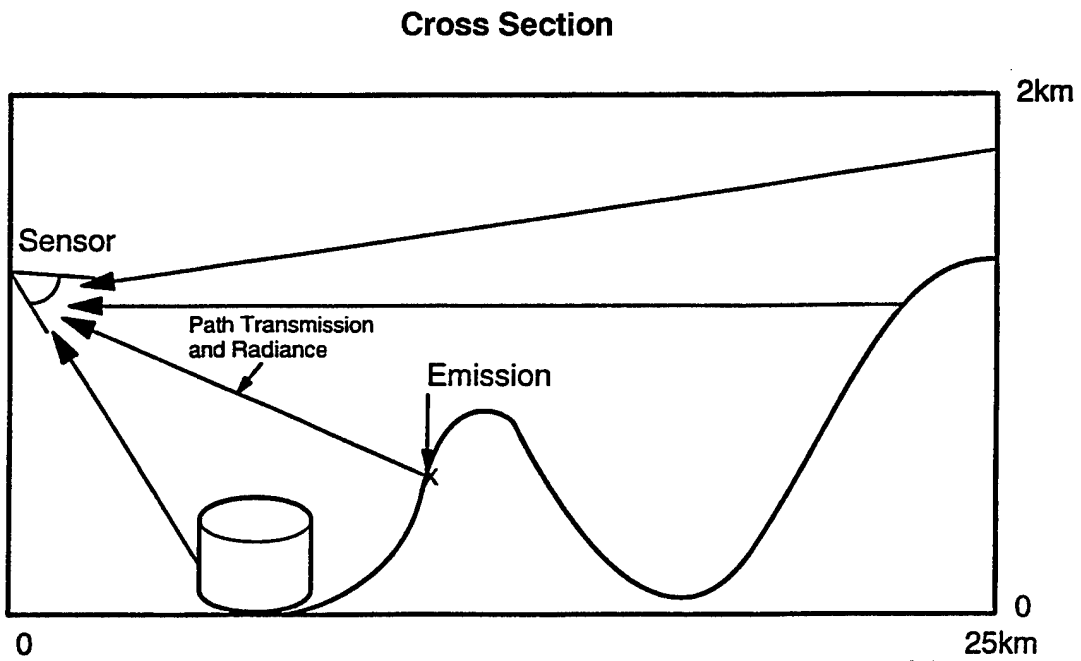


Figure 3b Cross Section Depicting Various Sky and Ground Paths

3.3.2 Approach

The approach selected for ACT/EOS is to use MODTRAN to compute path transmission and radiance for a limited number of geometries, effectively sampling the scene spatially. Estimates for all other required geometries are obtained through interpolation. The premise is that the bulk of the execution time is consumed by executing MODTRAN.

There are two classes of interpolation. For sky (infinite) paths, MODTRAN is executed for a series of zenith look angles and estimates of path radiance for intermediate zenith angles are obtained by linear interpolation. (Note: because no scene object is located at the endpoint of an infinite path, only path radiance is required for sky paths.) For ground paths (paths intersecting scene elements on the ground), MODTRAN is executed for a series of paths starting at the sensor and terminating at gridpoint locations specified as a function of ground range from the sensor and altitude above mean sea level. Bi-linear interpolation is used to provide values at intermediate points as discussed in more detail below. It is assumed that atmospheric effects are independent of azimuth angle. Regardless of interpolation method, the interpolation step size for zenith angle and path endpoint ground range and altitude may be set by the user, depending on his or her accuracy requirements.

For ground path cases, interpolation is performed with scaled parameters rather than the MODTRAN-computed values of atmospheric path transmission and radiance (see Figure 4). The scale parameter used for atmospheric path transmission is defined as follows:

$$B = \ln(\tau_{ave})/r \quad (3-1)$$

where

- B = scale parameter for path transmission
- τ_{ave} = atmospheric path transmission, averaged over sensor bandpass
- r = slant range

The scale parameter for path radiance is defined as follows:

$$R_{atm} = R_p/\epsilon_{atm} \quad (3-2)$$

where

- R_{atm} = scale parameter for path radiance
- R_p = path radiance, integrated over sensor bandpass
- $\epsilon_{atm} = (1 - \tau_{ave})$ (by definition)

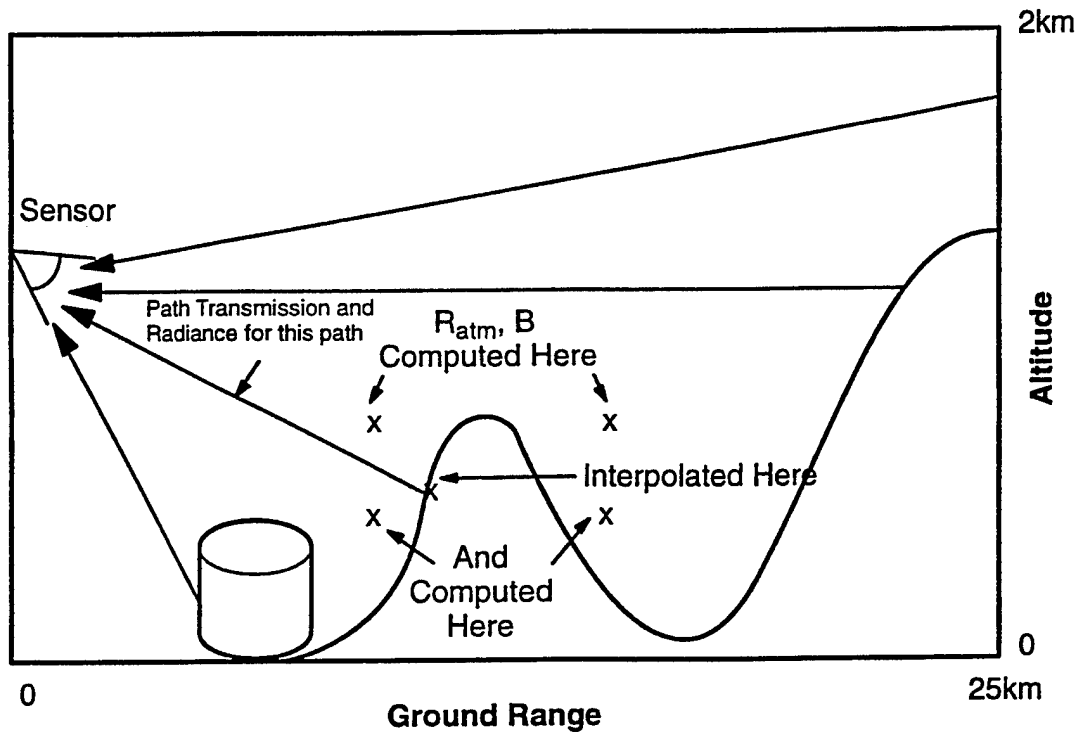


Figure 4 For Ground Paths, Interpolation is Performed Using the Scale Parameters. The Inverse Relationships are Used to Recover Path Transmission and Radiance.

The atmospheric transmission scale parameter, B , is essentially an average extinction coefficient for the path. The path radiance scale parameter, R_{atm} , is an estimate of the atmospheric blackbody radiance for the path, and is associated with thermal emission by the atmospheric volume along the path.

3.3.3 Example Results

Figure 5 and Figure 6 provide examples of path transmission and radiance results for the MODTRAN mid-latitude winter and summer atmospheric profiles, respectively. In this wavelength region, water vapor and aerosol extinction dominate. As anticipated, path transmission decreases exponentially as the path length increases. The decrease is more pronounced in the summer case because absolute humidity is greater in the mid-latitude summer moisture profile. The slant path terminating lower in the atmosphere is attenuated more because absolute humidity and aerosol concentration are greater at lower altitudes. Path radiance increases as the path length increases because the emitting volume increases. Path radiance is larger for the mid-latitude summer case because air temperature and absolute humidity are greater in the mid-latitude summer profile. Path

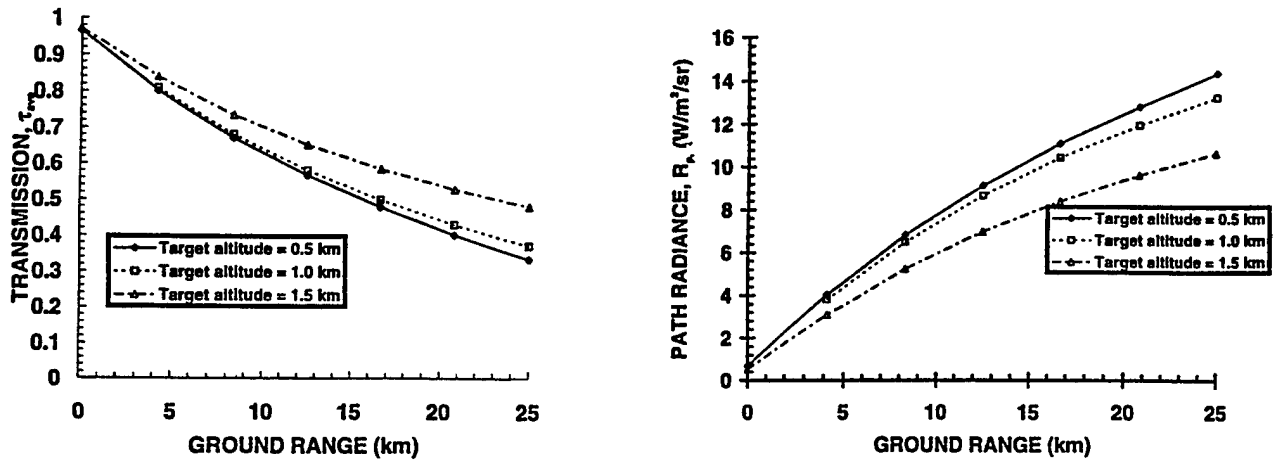


Figure 5 Path Transmission and Radiance for the Mid-Latitude Winter Case

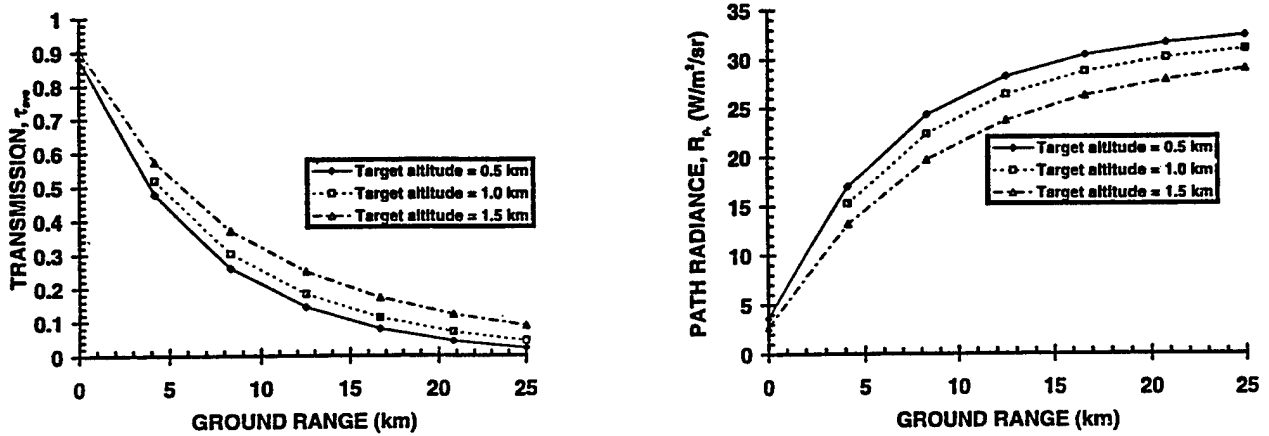


Figure 6 Path Transmission and Radiance for the Mid-Latitude Summer Case

radiance values are larger for the path terminating lower in the atmosphere because atmospheric temperature and emissivity are greater at lower altitudes.

Figure 7 and Figure 8 show the scale parameters for the two cases depicted in Figure 5 and Figure 6. The scale parameters exhibit little change as functions of ground range and vary smoothly with altitude. The mid-latitude winter case for B, however, shows more non-linear variation with altitude than the other cases. Overall, these characteristics of the scale parameters suggest that bi-linear interpolation is reasonable.

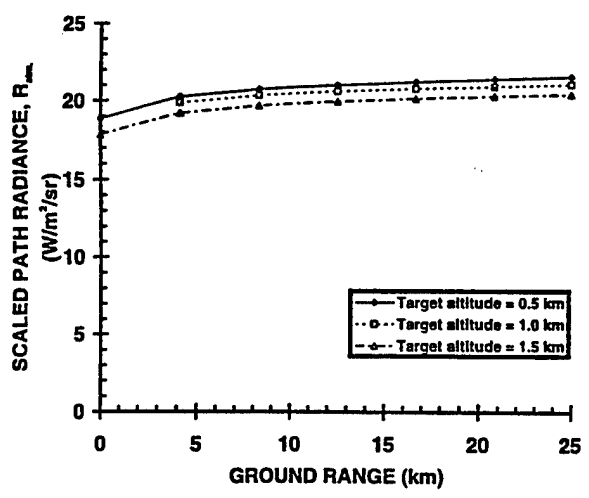
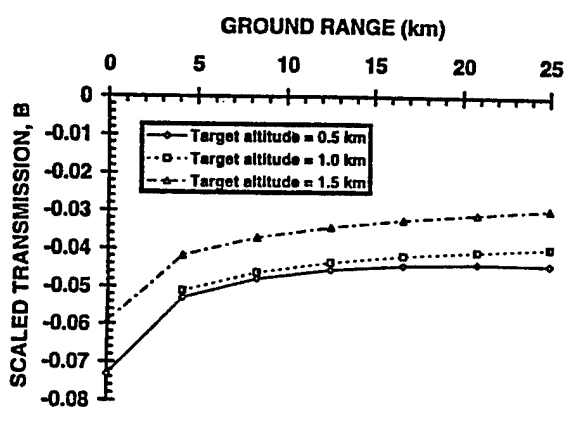


Figure 7 Scale Parameters for the Mid-Latitude Winter Case

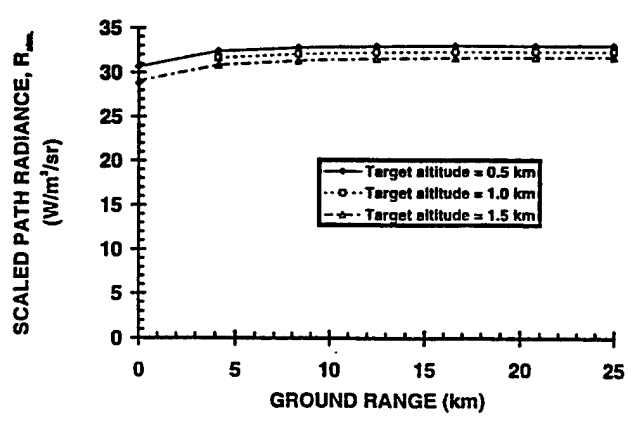
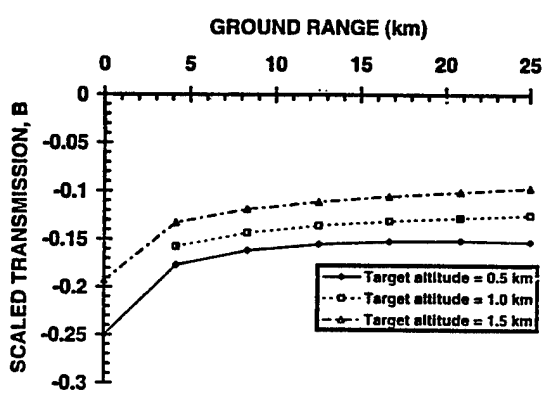


Figure 8 Scale Parameters for the Mid-Latitude Summer Case

Interpolated results were compared with direct MODTRAN computations for the midpoints between gridpoint locations. These comparisons were made for both path transmission and radiance. In addition, apparent blackbody radiance at the sensor was computed for paths between the sensor and each midpoint by assuming a 298K blackbody emission source at the midpoints. The following equation was used to compute apparent radiance:

$$R_{ap} = \tau_{ave} \int \epsilon R_o d\lambda + R_p \quad (3-3)$$

where

- R_{ap} = apparent radiance at sensor
- ϵ = emissivity of the surface (1.0 assumed)
- R_o = surface blackbody radiance
- λ = wavelength

Apparent blackbody radiance was converted to apparent blackbody temperature through application of Planck's equation.

Table 1 provides error statistics for the mid-latitude winter and summer cases, as well as run time estimates for a 66 Mhz Pentium class microcomputer. Two grid resolutions are shown. Obviously, errors can be reduced by decreasing the sampling interval, but at the expense of execution time. These run times can be considered near maximums, because the spectral resolution of the MODTRAN runs was fairly fine (20 cm^{-1}).

Table 1 Error Statistics and Run Time Data for Mid-Latitude Winter and Summer Cases

RMSE and Run time data
 Sampling domain: range 0-25 km; altitude 0-2 km
 *MODTRAN runtime per point: 9 seconds
 *Interpolation runtime per point: 0.005 seconds
 Time savings per point: 8.995 seconds

Sampling interval: 4.0 km range: 0.17 km altitude: 91 gridpoints, 72 test locations

	RMSE EBBT	Percentage of points w/ $ \Delta T < 1\text{K}$	Mean relative error in τ_{ave}	Percentage of points w/relative error <5%
Midlatitude Winter	0.97K	88%	1.3%	93%
Midlatitude Summer	0.37 K	97%	3.9%	86%

Sampling interval: 8.0 km range: 0.17 km altitude: 52 gridpoints, 72 test locations

	RMSE EBBT	Percentage of points w/ $ \Delta T < 1\text{K}$	Mean relative error in τ_{ave}	Percentage of points w/relative error <5%
Midlatitude Winter	1.2 K	50%	2.2%	94%
Midlatitude Summer	0.67 K	81%	7.0%	53%

*Executed on 66 MHz Pentium

Table 2 provides error statistics for a large number of cases and for the lower resolution grid spacing (52 gridpoints for ground paths). In addition, results for sky paths are

shown. For the sky paths, MODTRAN runs were made for every 2 degrees for zenith angles between 45 and 90 degrees. Interpolation errors are quite reasonable for these cases, and could be reduced by selecting finer grid spacing. In examining the detailed output for these runs, the largest errors take place near the sensor and for nearly horizontal lines-of-sight.

3.3.4 Software

A flexible driver program has been developed in ANSI C to automatically execute MODTRAN over the interpolation grid. The user can select the desired atmospheric scenario, sensor position, and sampling domain and resolution. A separate function applies the scaling laws and performs interpolation for paths between the sensor and any desired location within the sampling domain. A detailed description of the software, the algorithms, and error statistics can be found in the technical report (Ref. 2).

3.4 OVERVIEW OF TECHNICAL REPORT

The technical report "Atmospheric Effects Interpolation Algorithm - Technical and Software Description," Ref. 2, is divided into four parts. The first part contains an overview of the ACT/EOS program and the MODTRAN Quick-look activity. The second part describes the functionality of the delivered software. The third part provides a detailed technical description of the algorithms. The fourth and final part provides interpolation error statistics for the algorithms.

Table 2 Error Statistics for a Variety of MODTRAN Climatological Profiles, Aerosol Models, and Visibilities. The Sensor Altitude, Sampling Domain Data and Cloud Cases are Provided.

SCENARIO NUMBER	SENSOR HEIGHT (km)	MAXIMUM TARGET HEIGHT (km)	MAXIMUM GROUND RANGE (km)	MODEL ATMOS.	AEROSOL MODEL	SURFACE VISIBILITY (km)	PRECIP. MODEL	CLOUD MODEL	GRID RESOLUTION	GRID _{T_{err}} RMSE (K)	SKYPATH T _{err} RMSE (K)	GRID MEAN RELATIVE TRANS. ERROR (%)
1	1	2	25	Midlat. Summer	Rural	23	None	None	7 x 13	0.37	0.15	3.9
2	1	2	25	Midlat. Summer	Rural	5	None	None	7 x 13	0.35	0.13	5.2
3	1	2	25	Midlat. Summer	Rural	23	None	As	7 x 13	0.36	0.15	3.89
4	1	2	25	Midlat. Summer	Rural	23	None	Ci	7 x 13	0.37	0.39	3.9
5	1	2	25	Midlat. Winter	Rural	23	None	None	7 x 13	0.97	0.47	1.29
6	1	2	25	Midlat. Winter	Rural	5	None	None	7 x 13	0.76	0.43	2.33
7	1	2	25	Midlat. Winter	Rural	23	None	As	7 x 13	0.97	0.2	1.28
8	1	2	25	Midlat. Winter	Rural	23	None	Ci	7 x 13	0.97	0.84	1.29
9	1	2	25	Tropical	Rural	23	None	None	7 x 13	0.27	0.17	6.18
10	1	2	25	Tropical	Rural	23	None	As	7 x 13	0.27	0.15	5.55
11	1	2	25	Tropical	Rural	23	None	Ci	7 x 13	0.27	0.29	5.66
12	1	2	25	Subarctic Winter	Tropo	23	None	None	7 x 13	0.94	0.8	0.4
13	1	2	25	Subarctic Winter	Tropo	23	None	As	7 x 13	0.94	0.16	0.39
14	1	2	25	Subarctic Winter	Tropo	23	None	Ci	7 x 13	0.94	0.84	0.4
15	0	1	25	Midlat. Summer	Rural	23	None	None	7 x 13	0.32	0.15	3.74
16	0	1	25	Tropical	Rural	23	None	None	7 x 13	0.22	0.19	4.88
17	0	1	25	Subarctic Winter	Tropo	23	None	None	7 x 13	0.98	0.86	0.34
18	0	1	25	Midlat. Summer	Rural	.	None	Fog	7 x 13	0.06	0.12	*
19	0	1	25	Tropical	Rural	.	None	Fog	7 x 13	0.06	0.14	*
20	0	1	25	Subarctic Winter	Tropo	.	None	Fog	7 x 13	0.04	0.05	*

*Transmission values were near zero and so a relative error was undefined.

4. TASK 3: CALIBRATION SUPPORT

4.1 OBJECTIVES OF TASK

The objective of the Calibration Support task was to provide a roadmap for evaluating the performance of the ACT/EOS physical models by comparing model results with field measurements collected by PL. The plan was intended to provide a starting point, recognizing that changes would be required as more experience was gained with the models and with the instrumentation and as model deficiencies were uncovered.

4.2 SUMMARY OF TECHNICAL DEVELOPMENT

Preliminary model assessment goals and potential experiments were presented at the ACT/EOS program kick-off meeting held at Hanscom AFB on 2 and 3 September 1993. The initial project schedule showed the calibration support task beginning late in FY94. Feedback received from PL during the kick-off meeting, however, suggested that the task should be initiated as soon as possible, to support PL in their analysis of instrumentation requirements. TASC supported this accelerated schedule and began work on the calibration support task almost immediately.

In October 1993, a draft outline for the Assessment Plan was prepared for review by PL. Also in October, TASC toured PL's ACT/EOS facilities and was shown existing instrumentation and computer equipment. During the tour, TASC obtained a copy of a technical report prepared by PL, describing in detail the in-house instrumentation potentially available to support the ACT/EOS project. That document was used to identify potential shortfalls in meeting requirements for assessing the models. By November, TASC had begun to design field experiments to assess the ACT/EOS physical model. TASC was directed by the COTR to place emphasis on evaluating the thermal model (TCM2).

Between December 1993 and January 1994, the Assessment Plan was completed. As a result of extensive technical discussions with PL and KRC, the ACT/EOS team decided to focus on simple flat plate targets to test the thermal model. KRC had success in testing the model with similar targets in the past. The flat plate targets possess simple geometrical properties and could be designed with materials for which physical properties

are well-known, simplifying both the modeling of the targets and the assessment process. The targets were eventually constructed by PL, with temperature sensors on the body of the plates. The experiments that were eventually conducted with these simple targets were very successful in revealing strengths and weaknesses of the thermal model.

The Assessment Plan was distributed to PL and ACT/EOS contractors for review in February 1994. TASC received feedback on the report in March and April. TASC prepared a written response to the feedback; this was distributed to PL, KRC, and HSTX. Only very minor changes to the report were required.

An issue that came up during the report evaluation period was appropriate designs for in-scene calibration sources. These sources would be used to calibrate the thermal imagery collected by the FLIR-2000 system used to observe the target scene. TASC put PL in contact with experts at Lincoln Laboratories, who had experience in designing and fabricating calibration sources. Contacts with these individuals, as well as with AF Wright Laboratories and KRC, led Tim Hiett (PL) to construct very reliable in-scene calibration sources for the experiments.

4.3 SUMMARY OF ASSESSMENT PLAN REPORT

This section presents a brief summary of the Assessment Plan report (Ref. 3). An overview of the requirements analysis is provided in Section 4.3.1. A review of recommendations regarding the evaluations of the TCM2, ATM, and SPM models is provided in Sections 4.3.2 through 4.3.4, respectively. Finally, the recommended approach for assessing the models is summarized in Section 4.3.5.

4.3.1 Requirements Analysis

A comparison was made between the measurements that could be provided by sensors available at PL in 1993 and 1994 and the input requirements and output products of the ACT/EOS scientific models. Collectively, these instruments were referred to as the Calibration Sensor Suite (CSS) Table 3 provides a general description of the instruments included in the CSS.

Table 3 Brief Description of the CSS Instruments

INSTRUMENT	DESCRIPTION
FLIR 2000	A scanning 8-12 μm FLIR
Whole Sky Imager (WSI)	A daytime viewing whole sky imager operating at visible wavelengths
MILOS 500 Weather Station	A system of meteorological sensors measuring wind speed and direction, air temperature, relative humidity, air pressure, rain rate, shortwave irradiance, and longwave irradiance.
Campbell Weather Station	A mobile system of meteorological sensors like the MILOS, but older, cruder and not expandable. Used to monitor meteorological conditions at the target location.
Present Weather Sensor (PWS)	An instrument containing a forward scattering nephelometer operating at visible wavelengths as well as other meteorological instruments. Used to estimate daytime visible range, air temperature, obstruction to visibility, precipitation particle count, precipitation water volume, and total extinction coefficient.

The ACT/EOS scientific models included in the evaluation were TCM2, ATM, and SPM. Model input and output parameters were identified for each model. For each model input parameter identified, the CSS sensor capable of providing the data was also identified. Similarly, for each identified model output product, the CSS sensor capable of providing collaborative data was identified. Only the environmental input requirements of the models were stressed in this evaluation. Other required input parameters, such as sensor position (e.g., altitude), target location, etc., were not addressed since they could be specified accurately.

The requirements analysis led to the development of recommendations regarding the assessment of the ACT/EOS physical models. These recommendations are summarized below. Please note that these recommendations reflect the capabilities of the models and instrumentation available in late 1993 and early 1994. Many of these recommendations have been implemented by PL since that time.

4.3.2 TCM2

Key observations and recommendations regarding TCM2 model input specification and output products are listed below. These observations and recommendations were contained in the original Assessment Plan, issued in February 1994.

TCM2 Environmental Input Requirements

- TCM2 should be tested using both measured and modeled insolation and sky irradiance data.
- The insolation and sky radiation models (INSOL and SKYRAD, respectively) should be evaluated independently. The total, direct and diffuse components of insolation should be measured and compared with INSOL computations.
- The broadband and sensor band sky temperatures required by TCM2 will have to be determined from pyrgeometer measurements of sky irradiance.
- Rain temperature will have to be determined from air temperature and dew point temperature.
- The cloud data that are required by the INSOL and SKYRAD models are not directly measured by any sensor in the CSS. These data will have to be obtained elsewhere, e.g., from observations taken at a nearby weather station, such as Hanscom Field. Unfortunately, aviation cloud observations do not generally provide all the cloud parameters required by these models.
- Shortwave background albedo, a required TCM2 input parameter, should be estimated from in-scene measurements of upwelling and downwelling solar irradiance as measured by two pyranometers. This will require the purchase of an additional pyranometer. The new pyranometer should operate in the same waveband as the current instrument.*
- Longwave background albedo (emissivity), a required TCM2 input parameter, should be estimated from in-scene measurements of upwelling and downwelling longwave radiation as measured by the two CSS pyrgeometers. The two pyrgeometers should operate in the same waveband.*

TCM2 Output Products

- As possible, thermocouple measurements of the skin temperature of target and background objects should be recorded.
- Apparent temperature should be measured using FLIR imagery. These data can be used to determine the inherent effective blackbody temperature of scene objects provided proper compensation is made for atmospheric and sensor effects.
- In-scene calibration sources are required for translating the FLIR imagery data into effective blackbody temperature. At least three known in-scene temperature sources should be provided for calibration. This will permit calibrating the FLIR measurements in cases where one of the sources is outside the dynamic range of the FLIR

*PL/GPAA disagrees with these requirements.

- Soil moisture and temperature probes should be used to measure the actual temperature and moisture gradients in the soil for initialization and comparison with values computed by TCM2. At a minimum, measurements should be made at two TBD depths in the soil.

4.3.3 ATM

Key observations and recommendations regarding ATM model input specification and output products are listed below. These comments refer to the IR EOTDA ATM, which was the ATM intended to be used at the time the Assessment Plan was prepared. These observations and recommendations were contained in the original Assessment Plan, issued in February 1994.

ATM Environmental Input Requirements

- As necessary, inversion height will have to be estimated or determined from radiosonde data obtained from a nearby weather station (e.g., Hansom Field). Inversion height is a parameter required by the IR EOTDA ATM. It defines the boundary between the two atmospheric layers modeled by the IR EOTDA ATM.
- Air mass type (aerosol index) will have to be inferred from meteorological observations taken at a nearby weather station and from the synoptic situation.
- 24-hour average windspeed will have to be computed from a time series of wind speed measurements if the Navy Maritime aerosol model is used.

ATM Output Products

- The CSS instruments do not measure atmospheric transmission. A transmissometer should be purchased by PL to measure atmospheric attenuation in the longwave IR wavelength region. The resulting measurements could be used to assess the ATM and perhaps MODTRAN.
- The existing EOTDA ATM offers no capability to estimate path radiance. The MODTRAN model could be used to estimate both path transmission and radiance.
- Currently, there is no capability to measure atmospheric path radiance. However, it should be possible to "back-out" path radiance from measurements of path transmission together with FLIR measurements of the apparent radiances of in-scene temperature sources.

4.3.4 SPM

Key observations and recommendations regarding SPM model input specification and output products are listed below. These observations and recommendations were contained in the original Assessment Plan, issued in February 1994.

SPM Environmental Input Requirements

- The SPM does not utilize any basic environmental input data. SPM input data are supplied by other ACT/EOS models.
- The Clutter Index, which is required by the SPM to compute detection range, must be estimated from scene characteristics.

SPM Output Products

- The primary SPM output product is detection range. This product cannot be verified with CSS instrumentation.
- It may be possible to modify the SPM to compute probability of detection (see Section 4 of the Assessment Plan report) and to design experiments to assess this product.

4.3.5 Experimental Framework

In the Assessment Plan, it was suggested that preliminary assessment activities should focus on evaluating the ACT/EOS models against simple examples of target and background types. Candidate targets and backgrounds were identified in Section 4 of the Assessment Plan. The candidate targets included a box target composed of aluminum panels and a water barrel target. Candidate backgrounds for the initial assessment activity include the composite foliage/soil models, asphalt and concrete.

As suggested in the Assessment Plan, a box target was constructed by PL; its simple geometry and material composition have facilitated testing of TCM2. A water barrel target has not yet been constructed. The water barrel target is analogous in many ways to TCM2's POL storage tank and represents a somewhat more complicated target type. Complications arise because the air and liquid inside the barrel must be modeled and the target geometry is more complicated than the box target.

The backgrounds identified in the Assessment Plan for initial assessment are among the first principle background models in TCM2. The five first principle background models included in TCM2 are: soil, foliage, water, concrete/asphalt, and snow. Examples of the soil, foliage, and concrete/asphalt models can be found on Hanscom AFB, in close proximity to the ACT/EOS facilities. During the winter months, opportunities to assess the snow model should occur. To our knowledge, only the composite foliage/soil models have been evaluated thus far.

The Assessment Plan advised that simple environmental scenarios be focused on initially, because it would be more difficult to isolate the causes of differences between model results and measurements during periods of highly variable meteorological conditions. The Assessment Plan also advised that the general meteorological scenario be described in words and through the use of synoptic weather maps. It was recommended that a meteorological observer be assigned to ACT/EOS during the assessments. Instances of frontal passages, fog, temperature inversion and changing weather conditions should be described and logged. These supplementary data provide useful information in the analysis of the data. The need for monitoring the status of the CSS instrumentation during tests was noted as well. Evidence of sun glint on sensors, dew/frost, and instrument failure should be noted. It was suggested that visible imagery of the target/background scene be recorded in addition to the FLIR imagery. Any routine maintenance of instruments should be accomplished before, after, and during the assessments, as necessary.

Finally, the Assessment Plan indicated that data collections be conducted over at least a two day period, to satisfy the requirements for antecedent environmental data for TCM2. Data should be collected over at least two diurnal cycles and TCM2 should be initialized with meteorological parameters representing average conditions over the *previous* 24-hours.

As it turns out, many of the suggestions made in the Assessment Plan have been implemented by PL since the time the report was written. PL has monitored a test site containing a flat panel (box) target at the location suggested in the Assessment Plan almost continuously for over a year.

4.4 OVERVIEW OF TECHNICAL REPORT

The Assessment Plan (Ref. 3) is divided into five major parts. Part 1 provides project and task background information. Part 2 describes the baseline instrumentation suite available at the time the Assessment Plan was being developed. Part 3 describes the ACT/EOS scientific models. Part 4 provides the high-level experiment design, the model assessment philosophy stressing uncomplicated scenarios, and identifies shortfalls in the CSS instrumentation relative to model requirements and output products. Part 4 also provides examples of target and background types that should be focused on in the initial assessments. Part 5 summarizes the report findings. Finally, a test plan for an initial experiment is provided in an Appendix.

5. SUMMARY

This report briefly summarizes TASC's work on the ACT/EOS program between September 1993 and December 1995. Only an overview of the work is presented here; detailed descriptions of work in the three major task areas are contained in References 1 through 3.

6. REFERENCES

1. Rubin, S.L.. ACT/EOS Scene Builder/Viewer Architecture and Maintenance Manual. TASC, 55 Walkers Brook Drive, Reading, Massachusetts 01867, TR-07163-3, 17 August 1994.
2. Hestand, P.D, M.J. Gouveia, G.J. Higgins, and M.S. Seablom. Atmospheric Effects Interpolation Algorithm — Technical and Software Description. TASC, 55 Walkers Brook Drive, Reading, MA 01867, TR-07163-4, December 1995.
3. Higgins, G.J. and P. Ramos-Johnson. ACT/EOS Assessment Plan. TASC, 55 Walkers Brook Drive, Reading, MA 01867, TR-07163-1, December 1995.