DIRSIG Cloud Modeling Capabilities; A Parametric Study

Kristen Powers
powers.kristen@gmail.com

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Objective

The objective of this paper is to study how DIRSIG could be used to radiometrically model clouds. The intent was to use spatially uniform results from MODTRAN as truth values which could be used to verify DIRSIG cloud modeling capabilities. The evaluation was completed as a parametric study in which the various parameters and inputs that are utilized by DIRSIG to model clouds were evaluated not only at the expected truth values, but also at a wide range of other values. 34 DIRSIG runs were completed in support of the parametric study.

Background

The DIRSIG version used for this study was version 4.2.0. Modtran 4 was used.

Study Case

That study case for this evaluation is a stratus cloud. While other clouds were used at different points in the study, the results were similar as to what was observed for the stratus cloud. The current MODTRAN software version contains 5 default cloud cases. While MODTRAN allows users to create their own cloud to specific parameters, the utilized default cloud parameters for a stratus cloud were used. The table below, which was taken from the MODTRAN User's Manual, shows the five default clouds and their associated properties.

Properties of the MODTRAN Cumulus and Stratus Type Model Clouds

ICLD	Cloud Type	Thickness (km)	Base (km)	0.55 um Ext. (km-1)	Column Amt (kg gm /m^3)
1	Cumulus	2.34	0.66	92.6	1.6640
2	Altostratus	0.60	2.40	128.1	0.3450
3	Stratus	0.67	0.33	56.9	0.2010
4	Stratus/Stratocumulus	1.34	0.66	38.7	0.2165
5	Nimbostratus	0.50	0.16	92.0	0.3460

Table 1: Properties of the MODTRAN Cumulus and Stratus Type Model Clouds

The properties listed in the above table represent the vertical thickness of the cloud, where the base of the cloud starts, the extinction property of the cloud, and the column amount of water vapor.

DIRSIG Scene Geometry and Materials

The geometry of the DIRSIG scene can be seen below, in image form. The scene consists of a ground plane of 18% reflectance, a hemisphere protruding from the ground plane, and a cloud, which partially covers the hemisphere. The sensor is directly overheard of the scene, and the sun in at a 30.6666 declination angle.

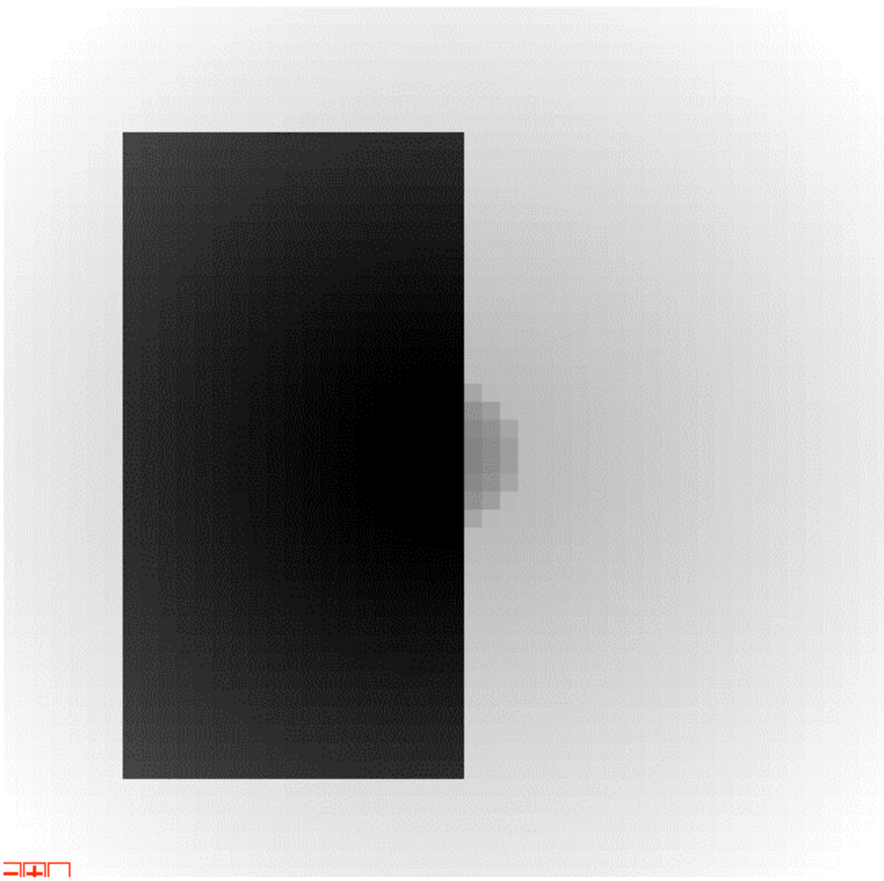

Figure 1: Sample Stratus Cloud Scene

The details of the scene can also be obtained from the DIRSIG geometry file (.ODB file). The details in that file can be viewed below.

```
************************************
 DIRSIG_ODB = 1.0

SPHERE {
   CENTER = 0, 0, 0
   RADIUS = 330
   MATERIAL_IDS = 1
```

```
}

GROUND_PLANE {
   X_SLOPE = 0
   Y_SLOPE = 0
   ANCHOR = 0, 0, 0
   MATERIAL_ID = 48
}

BOX {
   LOWER_EXTENT = -1300, -1300, 330
   UPPER_EXTENT = 65, 1300, 1000
   MATERIAL_IDS = 101
}
*****************************************************
```

Figure 2: Stratus Cloud Scene Object Database (.ODB)

The units in the Object Database are meters, so therefore we note that the sphere has a radius of 330 meters, and the stratus cloud (represented by the "BOX" in the .ODB), has dimensions which vary from -1300 to 65 in the x-dimension, so therefore has a length of 1365 meters, and vary from -1300 to 1300 so has a width of 2600 meters, and also has a floor at 330 meters and a ceiling of 1000 meters, which therefore indicated the stratus cloud base is at 330 meters and the cloud depth is 670 meters. Converting these values into km, it can be noted that the cloud base is at .33 km, and the cloud thickness is .67 km which corresponds exactly to the default stratus cloud case shown in Table 1.

The materials which are referenced in the object database are a sphere, of material=1, a ground plane of material = 48, and a cloud of material =101. The materials file can be examined to determine the meaning of each of these values. It should be noted that as this is a parametric study, some the parameters in the materials file (.MAT) are varied across the runs. As such each run has its own materials file. The sample shown below is from run 1. Any of the parameters which could change in subsequent runs are italicized.

```
*******************************************************
MATERIAL_ENTRY {
   NAME = kodak_grey_card
   ID = 48
   SPECIFIC_HEAT = 1.0000
   THERMAL_CONDUCTIVITY = 0.0000
   MASS_DENSITY = 1.0000
   SPECULARITY = 0.00
   VISIBLE_EMISSIVITY = 0.82
   THERMAL_EMISSIVITY = 0.82
   EXPOSED_AREA = 0.17
   OPTICAL_DESCRIPTION = OPAQUE
```

```
   EMISSIVITY_FILE = ./kodak_grey_card.ems
   EDITOR_COLOR = 0.2, 0.2, 0.2
}
MATERIAL_ENTRY {
   NAME = diffuse
   ID = 1
   EDITOR_COLOR = 1.0000, 1.0000, 1.0000
   DOUBLE_SIDED = FALSE
   SURFACE_PROPERTIES {
      REFLECTANCE_PROP_NAME = WardBRDF
      REFLECTANCE_PROP {
         DS_WEIGHTS = 0.15 0.0
      }
   }
RAD_SOLVER_NAME = Generic
   RAD_SOLVER {
      INITIAL_SAMPLE_COUNT = 10
      MAX_BOUNCES = 2
      SAMPLE_DECAY_RATE = 1
      MIN_QUAD_SAMPLES = 3
      MU_SAMPLES = 10
      PHI_SAMPLES = 20
         }
}
MATERIAL_ENTRY {
   NAME = cloud
   ID = 101
   EDITOR_COLOR = 1.0, 1.0, 1.0
   DOUBLE_SIDED = TRUE
   SURFACE_PROPERTIES {
      REFLECTANCE_PROP_NAME = PMFresnelBRDF
      REFLECTANCE_PROP {
      }
      TRANSMITTANCE_PROP_NAME = PMFresnelBTDF
      TRANSMITTANCE_PROP {
      }
   }
   RAD_SOLVER_NAME = Null
   RAD_SOLVER {
   }
   BACK_MAT_ID = 1010
}

MATERIAL_ENTRY {
   NAME = cloudvolume
   ID = 1010
```

```
   BULK_PROPERTIES {
      IOP_MODEL {
         BASE_MEDIUM = air
         ADD_ABSORPTION_MODEL{
            TYPE = constant
            ABS = 0.002845
         }
         ADD_SCATTERING_MODEL{
            TYPE = constant
            SCAT = 0.054055
         }
         ADD_PHASE_FUNCTION_MODEL {
            TYPE = uniform
         }
      }
   }
   RAD_SOLVER_NAME = Medium
    RAD_SOLVER {
   PHOTON_MAP = cloud_map_run1
   SEGMENT_LENGTH = 134.0
   SPECTRAL_SEARCH_RADIUS = 100
   DISABLE_MAP = FALSE
   CORE_SEARCH_FRACTION = 1.00
}
}

*******************************************
```

Figure 3: Sample Materials File (.MAT)

While each of the italicized values above will be discussed in great detail in the following section, there are some static values which are representative of the scene. The ground plane (Material =48) is an 18% opaque reflector. The sphere is a 15% diffuse reflector. The values for the cloud volume vary within the parametric study and are discussed in detail in the following section.

DIRSIG Parameter Properties for Parametric Study

The following properties are the primary properties which DIRSIG relies upon for modeling clouds. For each of the values the definition of the parameter is listed as well as the Stratus Cloud Default Assumed Value. This value represents the number which would most realistically be used for the stratus cloud study. (I.e. this is the truth for a stratus cloud) As this was a parametric study, a DIRSIG run was completed at not only the Stratus Cloud Study Assumed value, but also at variations which differed from the assumed value. These differing values are the Min Value Modeled, Low Value Modeled, High Value Modeled, and Max Value Modeled. By modeling not just at the assumed value, but at values higher and lower, it should be possible to see how the variation of each of these parameters drives the final result.

MAX_SOURCE_PHOTONS:

Definition: The maximum number of photons shot from sources.
Stratus Cloud Study Assumed Value: 5,000,000. This represents a reasonably high value which would be needed to compensate to a cloud of the volume being modeled. Added more photons would increase the processing time. A number too low could result in the photons 'clumping' in the photon map and not being properly distributed.
Min Value Modeled: 1,250,000
Low Value Modeled: 2,500,000
High Value Modeled: 7,500,000
Max Value Modeled: 10,000,000

MAX_BOUNCE:

Definition: The maximum scattering order of the propagation process. The default is 100 (very high), and a lower value (under 10) would smooth out the distributions.
Stratus Cloud Study Assumed Value: 50. This represents a good mid-range value.
Min Value Modeled: 3
Low Value Modeled: 25
High Value Modeled: 75
Max Value Modeled: 100

MAX_PHOTON:

Definition: The maximum number of photons which are modeled at any time.
Stratus Cloud Study Assumed Value: 500,000. This represents a reasonably high number for modeling within the cloud volume.
Min Value Modeled: 125,000
Low Value Modeled: 250, 000
High Value Modeled: 500,000
Max Value Modeled: 1,000,000

B_a:

Definition: Extinction coefficient of absorption (The number of photons which are absorbed within a 1 meter length)
Stratus Cloud Study Assumed Value: 0.002845 /m.
The assumed value from this are obtained from a combination of the MODTRAN default value for a stratus cloud as well as some standard literature. MODTRAN only gives a standard extinction coefficient, rather than giving a coefficient for both absorption and scattering. The value which MODTRAN lists as the Extinction for the stratus cloud is 56.9 / km, or 0.0926 / m. Standard literature lists that the ratio between scattering and

absorption as 0.95. As such the assumed absorption is set as 0.002845/m, while the scattering is set to 0.54055/m. For the parametric study, however two parameters are varied to show their effect on the results. The first is the total extinction (given a constant ration of 95/5 for scattering to absorption), while the second varies the ratio of scattering to absorption given a constant total extinction of 56.9 /km as given by MODTRAN.
Min Value Modeled (constant ratio): 0.000711/m
Min Value Modeled (constant extinction, ratio = 0/100): 0.0569/m
Low Value Modeled (constant ratio): 0.001423/m
Low Value Modeled (constant extinction, ratio = 50/50): 0.02845/m
High Value Modeled (constant ratio): 0.004268/m
High Value Modeled (constant extinction, ratio = 99/1): 0.000569/m
Max Value Modeled (constant ratio): 0.008535/m
Max Value Modeled (constant extinction, ratio = 100/0): 0.0000/m

B_s:

Definition: Extinction coefficient of scattering (The number of photons which are scattered within a 1 meter length).
Stratus Cloud Study Assumed Value: 0.054055/m
See the discussion above regarding ratio of scattering to absorption and parameter variations for the status cloud study.
Min Value Modeled (constant ratio): 0. 013514/m
Min Value Modeled (constant extinction, ratio = 0/100): 0.0000 /m
Low Value Modeled (constant ratio): 0.027028/m
Low Value Modeled (constant extinction, ratio = 50/50): 0028450 /m
High Value Modeled (constant ratio): 0.081083 /m
High Value Modeled (constant extinction, ratio = 99/1): 0.056331 /m
Max Value Modeled (constant ratio): 0.162165 /m
Max Value Modeled (constant extinction, ratio = 100/0): 0.0569 /m

Scattering Phase Model:

Definition: Within DIRSIG IOP models, which scattering phase model is utilized.
Stratus Cloud Study Assumed Value: Uniform model with constant scattering
Min Value Modeled: N/A (only two possibilities modeled)
Low Value Modeled: N/A (only two possibilities modeled)
High Value Modeled: Henyey-Greenstein Model,G= 0, W: 1
Max Value Modeled: N/A (only two possibilities modeled)

Segment Length:

Definition: The integration step size along the path of the ray. (The length in which the properties of the volume are assumed to be constant.)
Stratus Cloud Study Assumed Value: 134 m
The cloud being modeled in our case has completely homogeneous properties, so the expectation is that varying this parameter will have no effect on the outcome.

Min Value Modeled: 33.5 m
Low Value Modeled: 67.0 m
High Value Modeled: 201.0 m
Max Value Modeled: 268.0 m

Spectral_Search_Radius:

Definition: The maximum distance from the ray that "photons" are collected from. This maximum distance is used to build the spectral distribution of radiance.
Stratus Cloud Study Assumed Value: 100 m
This represents a reasonable value for a volume of the size that is being modeled. Also since this study is being done at a very small spectral bandwidth, it is not expected that this parameter will have any effect on the outcome.
Min Value Modeled: 25 m
Low Value Modeled: 50 m
High Value Modeled: 100 m
Max Value Modeled: 200 m

Core_Search_Fraction:

Definition: Defines a smaller region (than the spectral search radius) which is used to determine the mean radiance contribution (i.e. spectrally average). This parameter uses a smaller volume for the "brightness", while the spectral search radius uses a larger region for the "spectral shape".
Stratus Cloud Study Assumed Value: 1
This is not expected to have any effect on the outcome due to the fact that only a small spectral bandpass is being examined.
Min Value Modeled: 0.00
Low Value Modeled: 0.25
High Value Modeled: 0.50
Max Value Modeled: 0.75

All the parameters listed above and their respected values can be seen in the table below.

Parameter (units)	Min Value	Low Value	Stratus Assumed Value	High Value	Max Value
MAX_SOURCE_PHOTONS (# photons)	1250000	2500000	5,000,000	7500000	10000000
MAX_BOUNCE (# bounces)	3	25	50	75	100
MAX_PHOTONS (# photons)	125000	250000	500000	750000	1000000
Total Extinction w/ Varying Extinction w/ Constant Ratio between absorption and scattering	14.225	28.45	56.9	85.35	170.7

B[a]_95_5 (1/m)	0.000711	0.001423	0.002845	0.004268	0.008535
B[s]_95_5 (1/m)	0.013514	0.027028	0.054055	0.081083	0.162165
Total Extinction w/ Constant Extinction w/ Varying Ratio between absorption and scattering	56.9	56.9	56.9	56.9	56.9
Ratio Scattering/Absorption	0/100	50/50	95/5	99/1	100/0
B[a] (1/m)	0.056900	0.028450	0.002845	0.000569	0.000000
B[s] (1/m)	0.000000	0.028450	0.054055	FALSE	0.056900
Scattering Phase Model	N/A	N/A	Uniform Model ID: "uniform" SCATID: "constant"	Henyey-Greenstein Model ID: "hgpf" G: 0 W: 1 SCATID: "constant"	N/A
SEGMENT LENGTH (m)	33.5	67	134	201	268
SPECTRAL_SEARCH_RADIUS (m)	25	50	100	150	200
CORE_SEARCH_FRACTION (unitless)	0	0.25	1	0.5	0.75

Table 2: Parameters and associated values utilized in study

After the stratus assumed values, as well as the variations from the assumed values, for each parameter are determined, the next step was to assign each of the parameters and variations to a specific DIRSIG run in the parametric study. In each of the runs default values of the "Status Assumed Values" are used while varying one of the parameters from the assumed base value. Each of the DIRSIG runs and the associated parameters for the run can be seen in the table below.

Run Number	Run Name	MAX_SOURCE_PHOTONS	MAX_BOUNCE	MAX_PHOTONS	B[a]	B[s]	Scattering Phase Model	SEGMENT LENGTH [m]	SPECTRAL_SEARCH_RADIUS	CORE_SEARCH_FRACTION
Run 1	STRATUS ASSUMED	5000000	50	500000	0.002845	0.054055	Uniform	134	100	1
Run 2	MAX_SOURCE_PHOTONS_MIN	1250000	50	500000	0.002845	0.054055	Uniform	134	100	1
Run 3	MAX_SOURCE_PHOTONS_LOW	2500000	50	500000	0.002845	0.054055	Uniform	134	100	1
Run 4	MAX_SOURCE_PHOTONS_HIGH	7500000	50	500000	0.002845	0.054055	Uniform	134	100	1
Run 5	MAX_SOURCE_PHOTONS_MAX	10000000	50	500000	0.002845	0.054055	Uniform	134	100	1
Run 6	MAX_BOUNCE_PHOTONS_MIN	5000000	3	500000	0.002845	0.054055	Uniform	134	100	1
Run 7	MAX_BOUNCE_PHOTONS_LOW	5000000	25	500000	0.002845	0.054055	Uniform	134	100	1
Run 8	MAX_BOUNCE_PHOTONS_HIGH	5000000	75	500000	0.002845	0.054055	Uniform	134	100	1
Run 9	MAX_BOUNCE_PHOTONS_MAX	5000000	100	500000	0.002845	0.054055	Uniform	134	100	1
Run 10	MAX_PHOTONS_PHOTONS_MIN	5000000	50	125000	0.002845	0.054055	Uniform	134	100	1
Run 11	MAX_PHOTONS_PHOTONS_LOW	5000000	50	250000	0.002845	0.054055	Uniform	134	100	1
Run 12	MAX_PHOTONS_PHOTONS_HIGH	5000000	50	750000	0.002845	0.054055	Uniform	134	100	1
Run 13	MAX_PHOTONS_PHOTONS_MAX	5000000	50	1000000	0.002845	0.054055	Uniform	134	100	1
Run 14	B[as1]_MIN	5000000	50	500000	0.000711	0.0135138	Uniform	134	100	1
Run 15	B[as1]_LOW	5000000	50	500000	0.001423	0.0270275	Uniform	134	100	1
Run 16	B[as1]_HIGH	5000000	50	500000	0.004268	0.0810825	Uniform	134	100	1
Run 17	B[as1]_MAX	5000000	50	500000	0.008535	0.162165	Uniform	134	100	1
Run 18	B[as2]_MIN	5000000	50	500000	0.056900	0.000000	Uniform	134	100	1
Run 19	B[as2]_LOW	5000000	50	500000	0.028450	0.028450	Uniform	134	100	1
Run 20	B[as2]_HIGH	5000000	50	500000	0.000569	0.056331	Uniform	134	100	1
Run 21	B[as2]_MAX	5000000	50	500000	0.000000	0.056900	Uniform	134	100	1
Run 22	SPM_MIN	5000000	50	500000	0.002845	0.054055	HG	134	100	1
Run 23	SL_MIN	5000000	50	500000	0.002845	0.054055	Uniform	33.5	100	1
Run 24	SL_LOW	5000000	50	500000	0.002845	0.054055	Uniform	67	100	1
Run 25	SL_HIGH	5000000	50	500000	0.002845	0.054055	Uniform	201	100	1
Run 26	SL_MAX	5000000	50	500000	0.002845	0.054055	Uniform	268	100	1
Run 27	SSR_MIN	5000000	50	500000	0.002845	0.054055	Uniform	134	25	1
Run 28	SSR_LOW	5000000	50	500000	0.002845	0.054055	Uniform	134	50	1
Run 29	SSR_HIGH	5000000	50	500000	0.002845	0.054055	Uniform	134	150	1
Run 30	SSR_MAX	5000000	50	500000	0.002845	0.054055	Uniform	134	200	1
Run 31	CSF_MIN	5000000	50	500000	0.002845	0.054055	Uniform	134	100	0.01
Run 32	CSF_LOW	5000000	50	500000	0.002845	0.054055	Uniform	134	100	0.25
Run 33	CSF_HIGH	5000000	50	500000	0.002845	0.054055	Uniform	134	100	0.5
Run 34	CSF_MAX	5000000	50	500000	0.002845	0.054055	Uniform	134	100	0.75

Table 3: Parametric Study Run Configurations

As seen in the table above, 34 runs were completed to determine not only the accuracy of the stratus assumed case, but also the effects of varying each of the input parameters. The input files, from each of these run showing the usage of the above listed parameters can found in the attached Appendix A: DIRSIG Parametric Cloud Study Configuration Files.

DIRSIG Runs:

After the input files were established for each of the DIRSIG runs, the runs were executed. DIRSIG version 4.2.0 was used for each of the runs. Each of the DIRSIG runs shared some of the same files and input parameters. The file seen below represents a sample configuration file. The fields which are italicized represent parameters of files which changed over the runs while the non-italicized parameters and files represent values which did not change.

****

```
DIRSIG_CFG

PATHS {
```

```
    MATERIAL_PATH = ./
    MAPS_PATH = ./
    GDB_PATH = ./
    ODB_PATH = ./
}

SCENE {
    GDB_UNITS = METERS
    ODB_FILENAME = ./cloud_stratus.odb
    MATERIAL_FILENAME = ./cloud_stratus_run1.mat
    ADB_FILENAME = ./clouds_stratus_wo_cloud.adb
    GROUND_ALTITUDE = 0.000
    DATE = 08 18 2008
    GMT_OFFSET = 5.000
    GMT_TIME = 17.000
    LATITUDE = 43.000
    LONGITUDE = 78.000
}


ENVIRONMENT {
    TAPE5_FILENAME = ./cloud_stratus_wo_cloud.tp5
    ADB_FILENAME = ./cloud_stratus_wo_cloud.adb
    WEATHER_FILENAME = mls.wth

}

PLATFORM {
    INSTRUMENT {
        TYPE = FRAMING_ARRAY
        FOCAL_LENGTH = 10.000000
        BAND_LIST {
        BAND {
            NAME = Band #1
            MINIMUM_WAVELENGTH = 0.55
            MAXIMUM_WAVELENGTH = 0.57
            DELTA_WAVELENGTH   = 0.02
                  RESPONSE_FILENAME = SPECTRAL
                  X_PIXELS = 50
                  Y_PIXELS = 50
                  PIXEL_SIZE = 90
               IMAGE_FILENAME = ./clouds_stratus_run1.img
            }
        }
    }

     POSITION {
        TARGET_LOCATION = 0.000,0.000, 0.000
        PLATFORM_LOCATION = 0.000, 0.000, 9000.00
        AZIMUTH_ANGLE = -90
    }
}

OPTIONS {
    ENABLE_TRUTH_IMAGES = TRUE
    ENABLE_THERMAL_MODEL = FALSE
    ENABLE_BRDF = TRUE
```

```
    ENABLE_MAPS = TRUE
    ENABLE_SOURCES = FALSE
    ENABLE_PLUME = FALSE
    REMOVE_SENSOR_PATH = FALSE
    ENABLE_LINE_SKEW = FALSE
    ENABLE_EARTH_ROTATION = FALSE
    REGISTER_BANDS = FALSE
    REGISTER_DETECTORS = FALSE
    GENERATE_IMAGE_PER_SCAN = FALSE
    GENERATE_TRUTH_PER_SCAN = FALSE
    USE_SCENE_PLATFORM_ANGLES_TAG = FALSE
    ENABLE_APODIZATION = FALSE
    ENABLE_OFF_AXIS_ERROR = FALSE
    ENABLE_OPD_ERROR = FALSE
    USE_STEPWISE_PLUME = FALSE
}

TRUTH_IMAGES {
    MATERIAL_MAPS = TRUE
    SHADOW_MAPS = FALSE
    SHAPE_FACTOR_MAP = FALSE
    HIT_MAPS = TRUE
    PATH_ANGLE_MAPS = FALSE
    TEMPERATURE_MAPS = FALSE
    EMISSIVITY_MAPS = FALSE
    UPWELLED_RADIANCE_MAPS = TRUE
    DOWNWELLED_RADIANCE_MAPS = TRUE
    SOLAR_RADIANCE_MAPS = TRUE
    PATH_TRANSMISSION_MAP = TRUE
}


PHOTON_MAPS {
    MAX_SOURCE_PHOTONS = 5000000
    MAX_BOUNCE_COUNT = 50
    ENABLE_DEBUG_FILES = TRUE
    USER_MAP {
        NAME = cloud_map_run1
        SAVE_FILE = ./cloud_stratus_run1.sav
        BOUNDING_BOX = -1300.0, -1300.0, 330.0, 65.0, 1300.0, 1000.0
        MAX_PHOTONS = 500000

    }
}
**************************************************************
```

Figure 4: Sample DIRSIG Configuration File

As seen in the above sample configuration file, consistent scene geometry was used as discussed above, along with a simple framing array, examining narrow portion of the visible spectrum.

Also, as can be noted from the above sample file, configuration files changed per run, (cloud_stratus_run#.cfg) as well as materials file (cloud_stratus_run#.mat). The full file details for all the runs can be found in Appendix A: DIRSIG Parametric Cloud Study Configuration Files, and Appendix B: DIRSIG Parametric Cloud Study Material Files.

A final DIRSIG run was completed as an additional data point which was titled “Cloudless”. This run was computed in an identical manner to Run 1, but without the cloud in the .ODB file. The purpose of this run was to determine the error between the DIRSIG run and the MODTRAN results in the absence of a cloud.

Calculation of Sensor Reaching Radiance Truth Values for Cloudless & Stratus Cloud Scenes

Each DIRSIG run created a separate spectral radiance image. To determine the results the spectral radiance was averaged over the area spatially represented by the cloud (the center portion only – to negate any edge effects). This value then is then compared to the radiometrically correct value for a spatially uniform field, as determined by MODTRAN.

To determine the accuracy of each of the DIRSIG parametric study runs, the truth value needs to first be obtained through MODTRAN. Only one MODTRAN value is needed, in this case it is completed as computed utilizing the parameters from the “Assumed Value” for a stratus cloud. These are the default values MODTRAN gives to a stratus cloud.

Two separate MODTRAN & .ADB creation runs are used for the study. Each of the runs will be configured nearly identically, but one will include a stratus cloud, while other does not have one. The run that contains the stratus cloud is utilized to determine the truth value for sensor reaching radiance from a stratus cloud. The non-cloud run produces an .ADB which is then utilized by each of the parametric DIRSIG runs. These DIRSIG runs use the non-cloud baseline and then attempt to radiometrically model the cloud within DIRSIG vs. via MODTRAN.

MODTRAN Inputs and Atmospheric Database Creation for Cloudless Scene & Calculation of Associated Sensor Reaching Radiance

The version of the .ADB which is utilized by the parametric runs does not have a cloud in it. The details of the tape5 file which was used for the non-cloud run can be seen below:

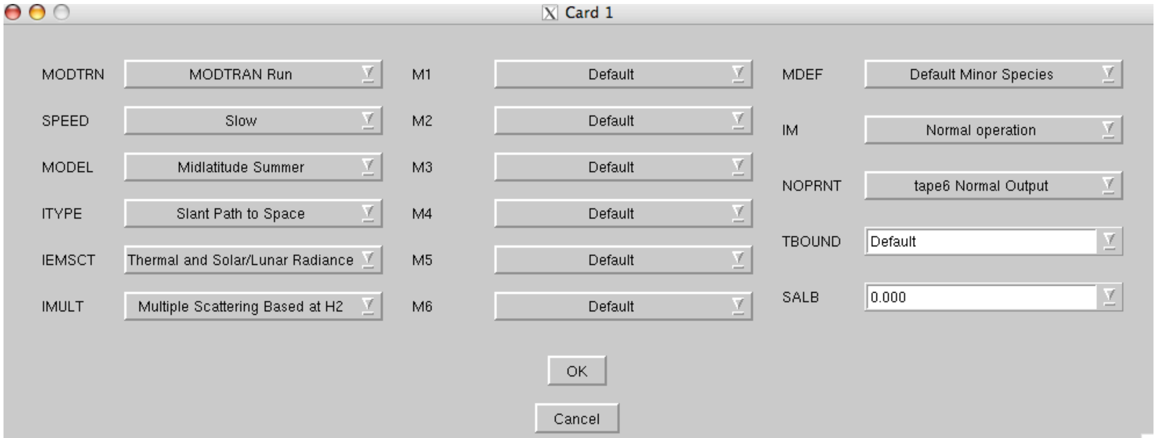

Figure 5: Cloudless Scene, Card 1

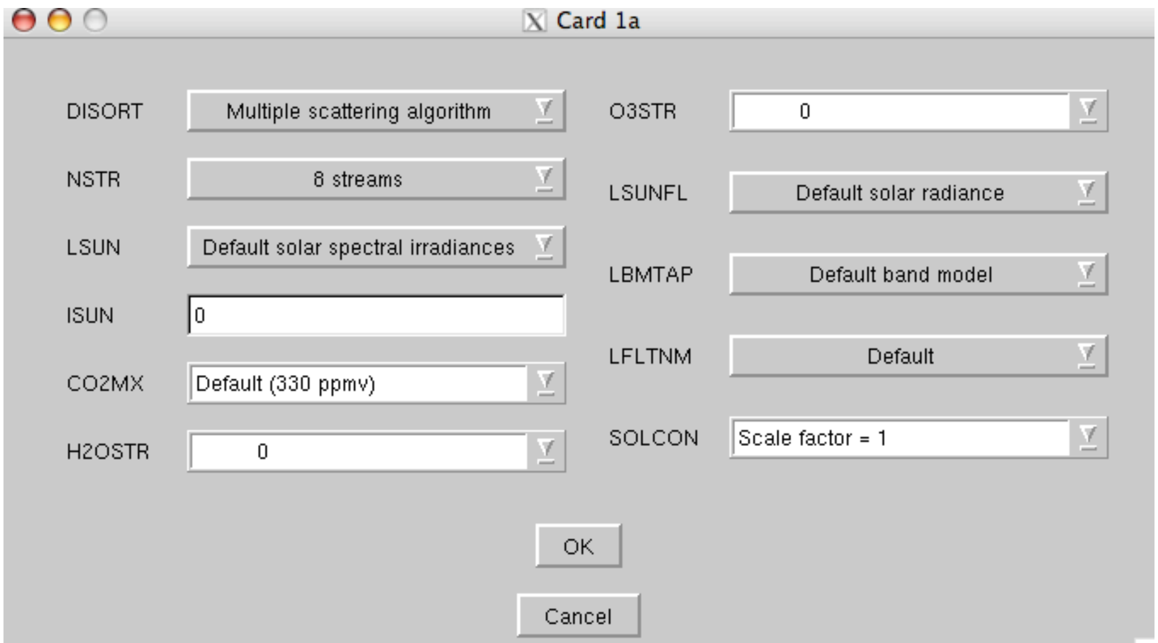

Figure 6: Cloudless Scene, Card 1a

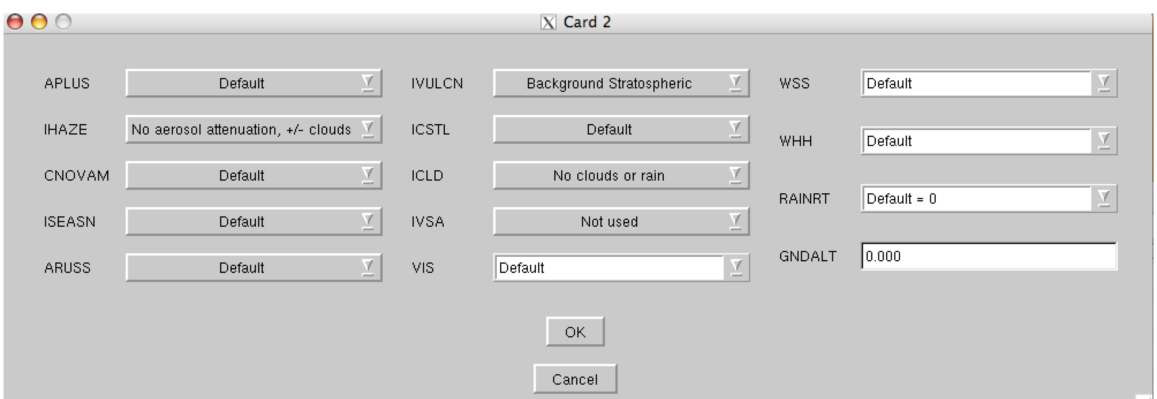

Figure 7: Cloudless Scene, Card 2

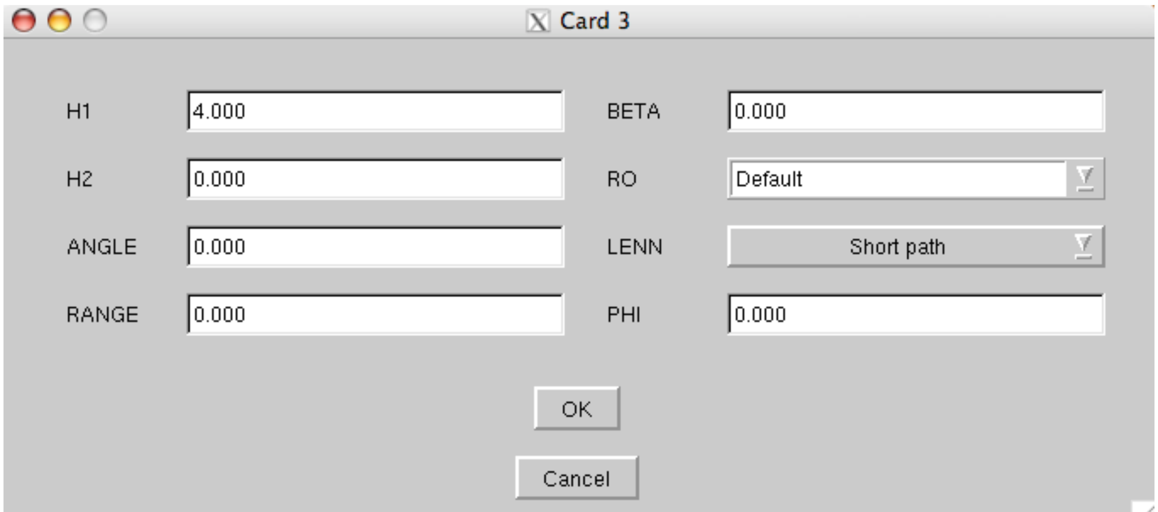

Figure 8: Cloudless Scene, Card 3

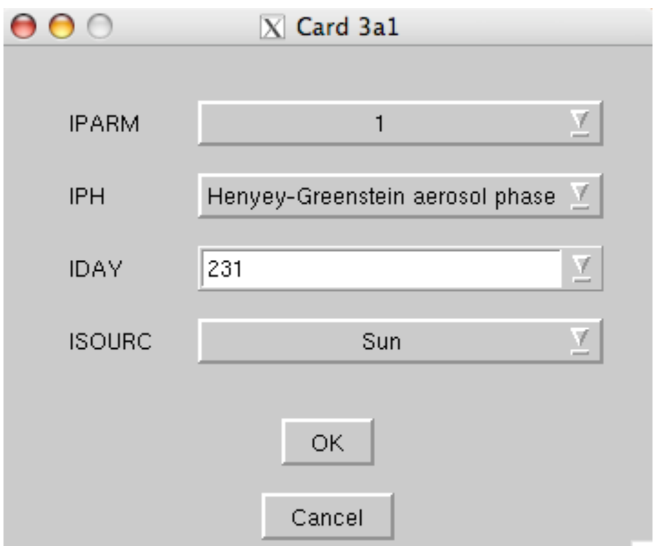

Figure 9: Cloudless Scene, Card 3a1

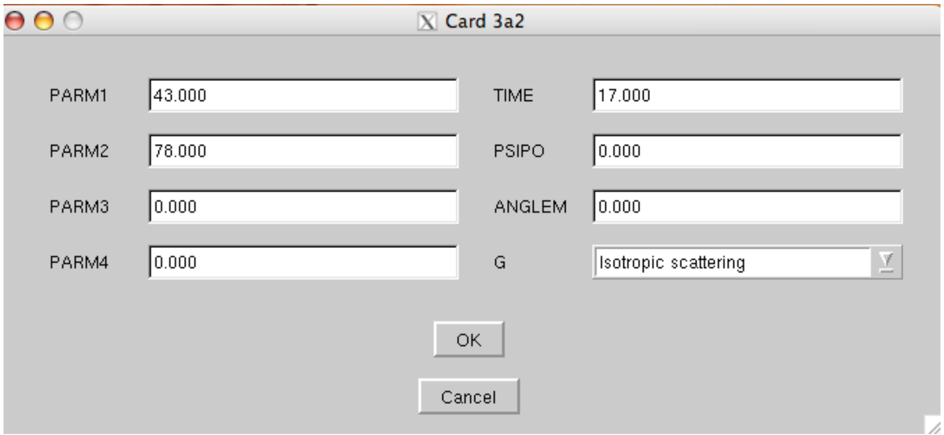

Figure 10: Cloudless Scene, Card 3a2

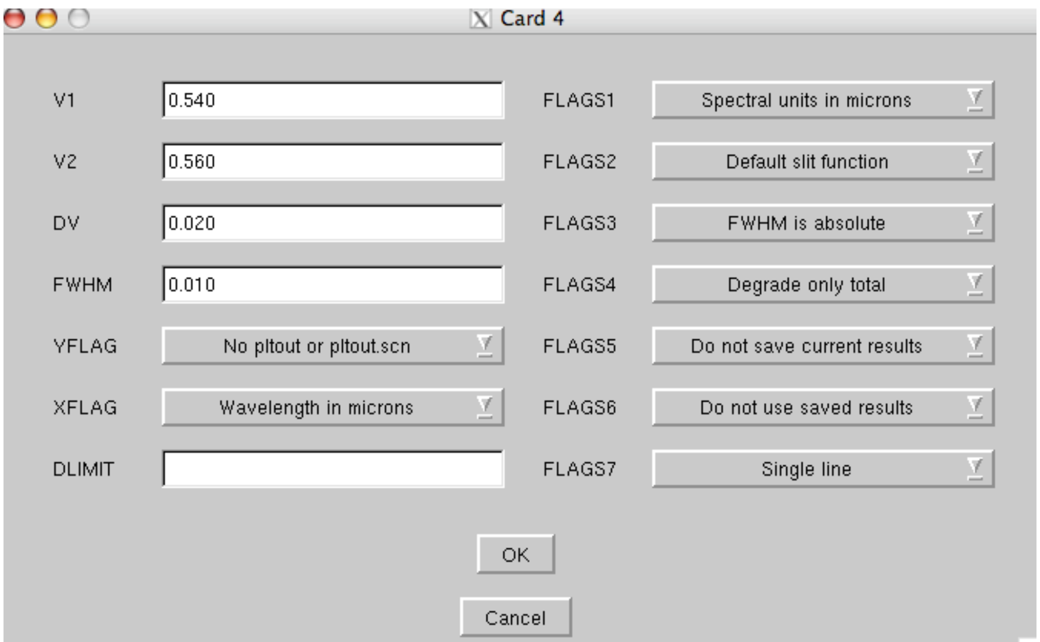

Figure 11: Cloudless Scene, Card 4

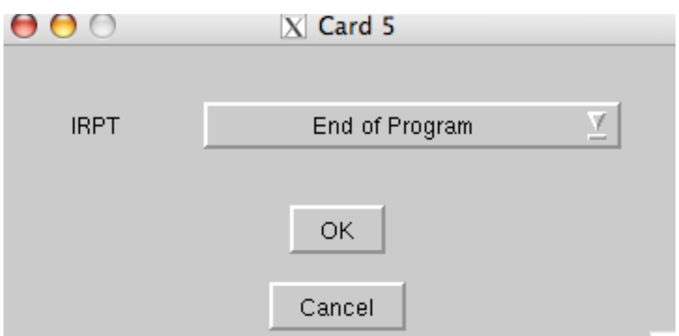

Figure 12: Cloudless Scene, Card 5

The tape5 file is represented as clouds_stratus_wo_cloud.tp5. As seen from the above cards this is a standard tape5 which mirrors the geometry and sensor properties as shown in the configuration file. As is standard for tape5 creation, many of the above parameters are iteratively changed in the creation process of the .ADB file, so the values shown above will be updated throughout the make_adb process.

The next step is to create the .ADB from this tape5 file. The results of the .ADB run can be seen below:

```
*****************************************************************
llama [30]% /dirs/pkg/dirsig3/bin/make_adb-4.2.0 cloud_stratus_run1.cfg
DIRSIG 4.2.0
Build Date: Jul 17 2008 08:56:47

DIRSIG3 File Reader: Warning!
  DOWNWELLED_RADIANCE_MAPS are not available in DIRSIG4!

DIRSIG3 File Reader: Warning!
  SOLAR_RADIANCE_MAPS are not available in DIRSIG4!

Initializing classic platform model:
Using static position method #1:
   Platform Location = [0, 0, 9000] (supplied)
   Target Location = [0, 0, 0] (supplied)
   Declination Angle = 0 (computed)
   Azimuth Angle = -0 degrees, clockwise from +Y  (supplied)
   Range to Target = 9000 (computed)

Initializing imaging platform:
   Master clock rate = 1 [Hz]
Initializing static instrument mount ... done.
Initializing Band #1:
   Using raw capture method

Initializing truth collectors:
Material truth
Intersection truth
Path transmission truth
Path radiance truth

Creating unique focal plane groups ... done (identified 1 groups).
Focal Plane Group #1:
   Band #1

Adjusting model atmosphere to match weather data ... done
   Set boundary layer temperature to 300.70 C
```

Summary of instrument focal planes:
  Band #1:
    Spectral Bandpass: 0.550 - 0.570 [microns]

General simulation geometry:
  Average ground altitude = 0.0000 km.
  Average sensor altitude = 9.0000 km.

Computing total field-of-view ... done.
Sensor View Summary:
  Zenith = 0.0000 (from vertical)
  Azimuth = 0.0000 (East of North)
  Field-of-view = [0.0000, 18.0000]

Exoatmospheric source summary:
  Sun position = 30.37 declination, 262.42 azimuth
  Sub-Solar location = 32.66 +N Latitude, -114.53 +E Longitude

  Moon position = 134.81 declination, 416.01 azimuth
  Sub-Lunar location = -10.98 +N Latitude, -138.82 +E Longitude
  Phase fraction = 87.66, Phase angle = 22.16

External Model Usage:
  MODTRAN is needed by at least one band in the simulation
  FASCODE is not needed for any bands in the simulation

Computing solar and lunar paths ... done.
Computing sensor paths .... done.
Computing downwelled paths .... done.
****

Figure 13: Log File from creation of cloudless .ADB

This is the .ADB from which all the other DIRSIG configuration files will now refer to. It represents the atmospheric properties without a cloud in the scene. From the .ADB it is possible to extract the magnitude of the sensor reaching radiance in the absence of a cloud.

sigma	30.366666
Hit Angle	0

	FROM .ADB SOURCES SECTION		FROM .ADB DOWNWELLED PATHS SECTION		IN DIRSIG .ODB & .MAT	FROM .ADB SENSOR PATHS SECTION		
	E_Sun	T_Sun	Total Downwelled Radiance	Calculated Incident Radiance (Direct + Downwelled) From ADB	Surface Reflectance	Path Trans	Path Radiance	Calculated Total Sensor Reaching Radiance
λ	$E'_{s\lambda}$	$\tau_1(\lambda)$	$L_{ds\lambda} + L_{d\varepsilon\lambda}$	$[E'_{s\lambda *}\cos(\sigma)*\tau_1(\lambda)*]/\pi + L_{ds\lambda} + L_{d\varepsilon\lambda}]$	$r(\lambda)$	$\tau_2(\lambda)$	$L_{us\lambda} + L_{u\varepsilon\lambda}$	$[E'_{s\lambda *}\cos(\sigma)*\tau_1(\lambda)*]/\pi + L_{ds\lambda} + L_{d\varepsilon\lambda}]*r(\lambda)*\tau_2(\lambda)+L_{us\lambda} + L_{u\varepsilon\lambda}$
0.54	1.85E-01	0.8564	2.79E-03	4.63E-02	1.80E-01	0.9273	1.32E-03	0.009051
0.56	1.82E-01	0.8628	2.36E-03	4.55E-02	1.80E-01	0.9362	1.11E-03	0.008778

Average Sensor Reaching Radiance: 0.008914 W/(cm^2 sr um)

Figure 14: Sensor Reaching Radiance for Cloudless Scene

The calculation details for this can be found in Appendix C: Calculation of Sensor Reaching Radiance, Cloudless Scene. This value would represent the total sensor reaching radiance with the same sensor & solar geometry, but in the absence of a cloud.

MODTRAN Inputs and Atmospheric Database Creation for Stratus Cloud Scene & Calculation of Associated Sensor Reaching Radiance (Truth Value)

The next part of the process is to complete a MODTRAN run with the stratus cloud included. This is to be the truth value for each of the parametric runs. This is done in an analogous manner to the run above, but this time utilizing a MODTRAN tape5 which contains values for a default stratus cloud. The associated MODTRAN cards can be seen below.

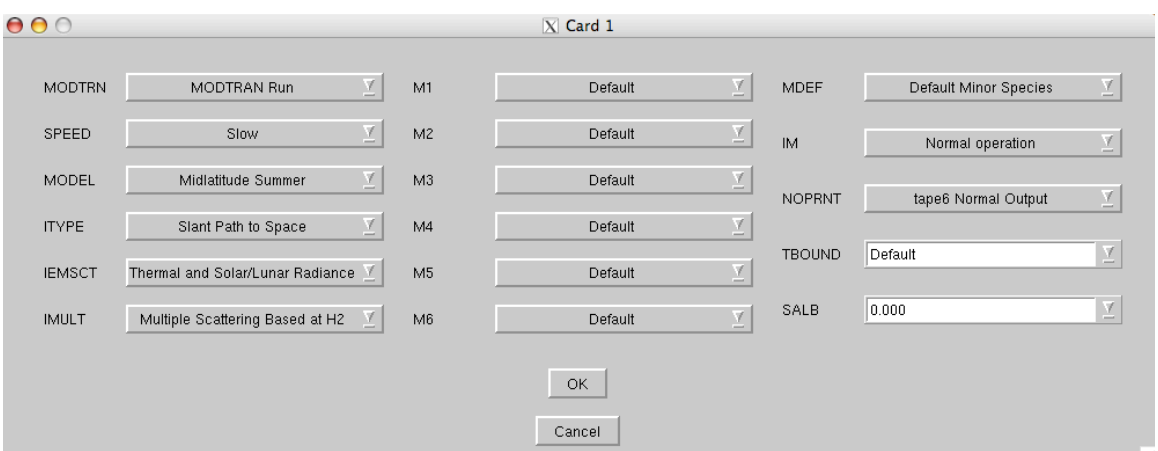

Figure 15: Stratus Cloud Scene, Card 1

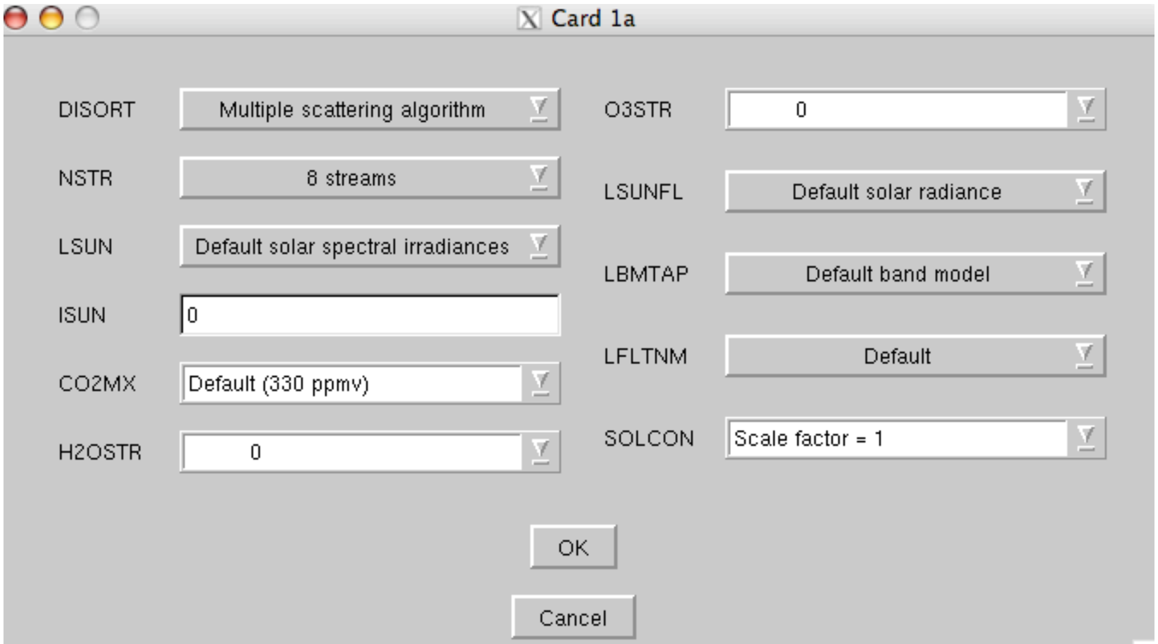

Figure 16: Stratus Cloud Scene, Card 1a

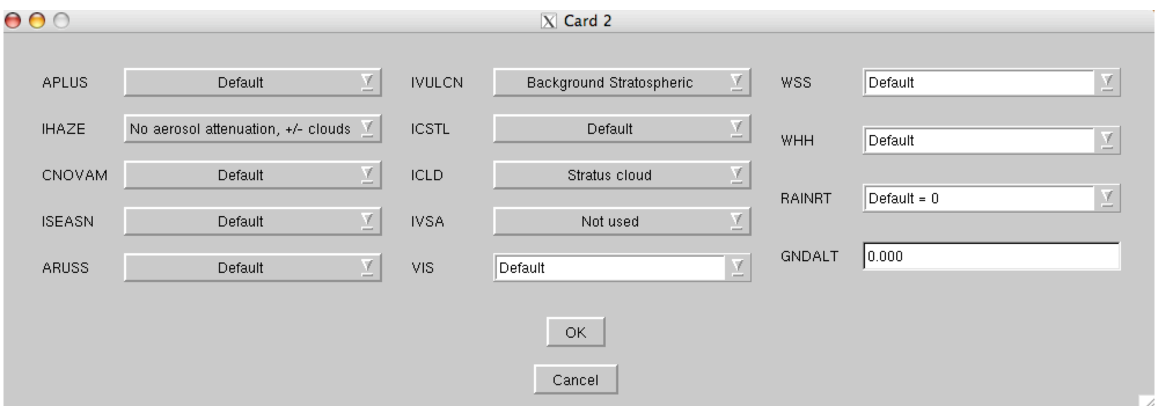

Figure 17: Stratus Cloud Scene, Card 2

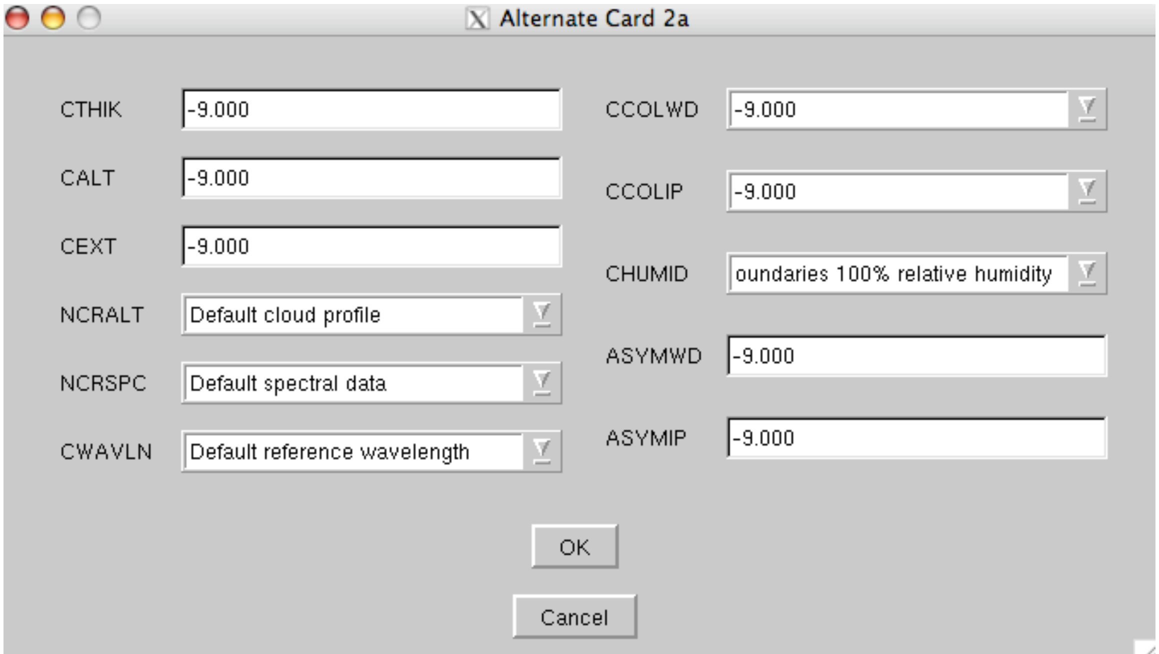

Figure 18: Stratus Cloud Scene, Alternate Card 2a

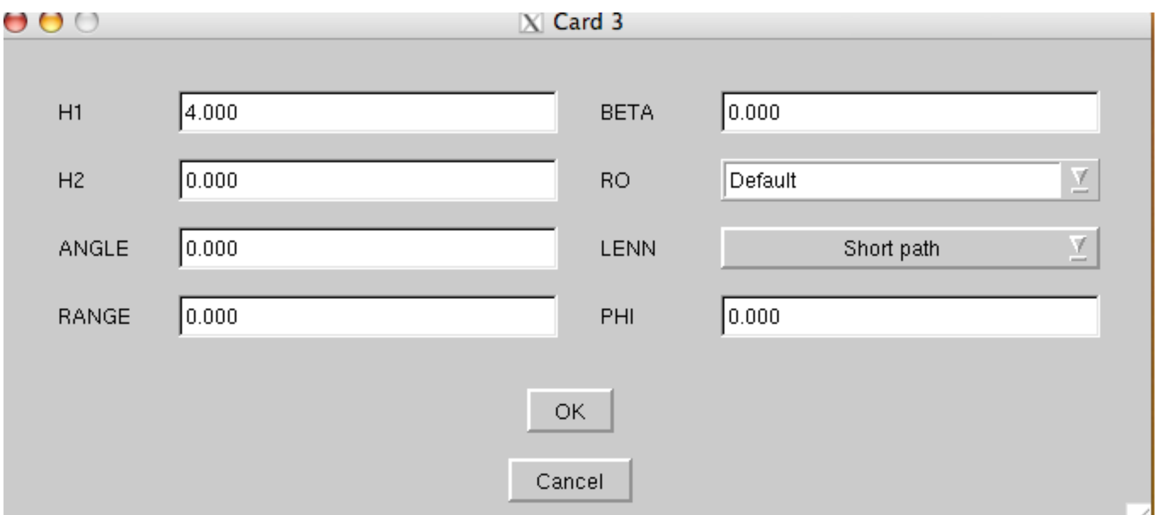

Figure 19: Stratus Cloud Scene, Card 3

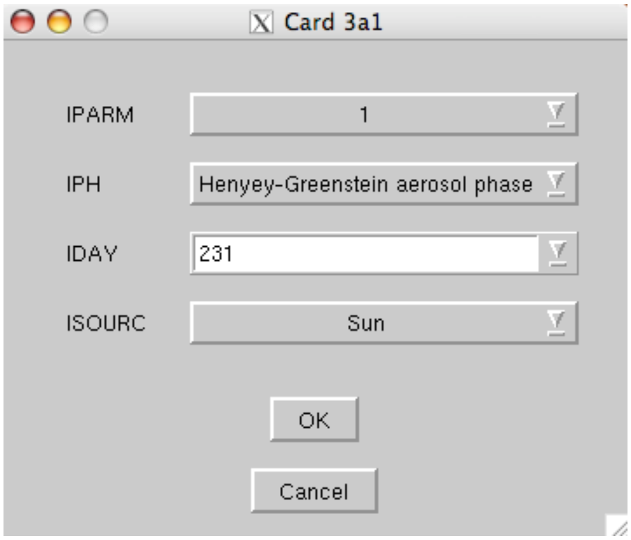

Figure 20: Stratus Cloud Scene, Card 3a1

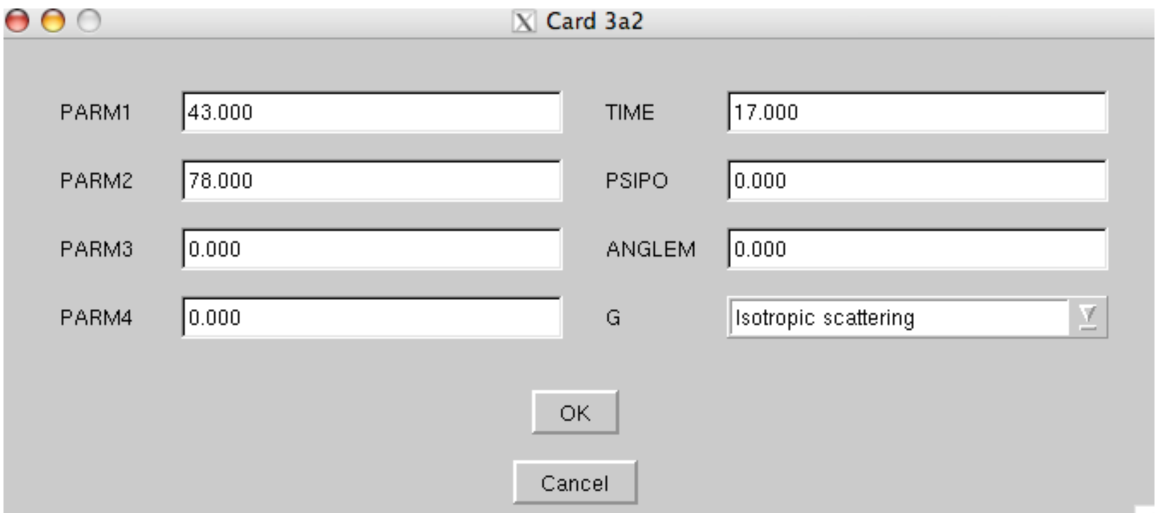

Figure 21: Stratus Cloud Scene, Card 3a2

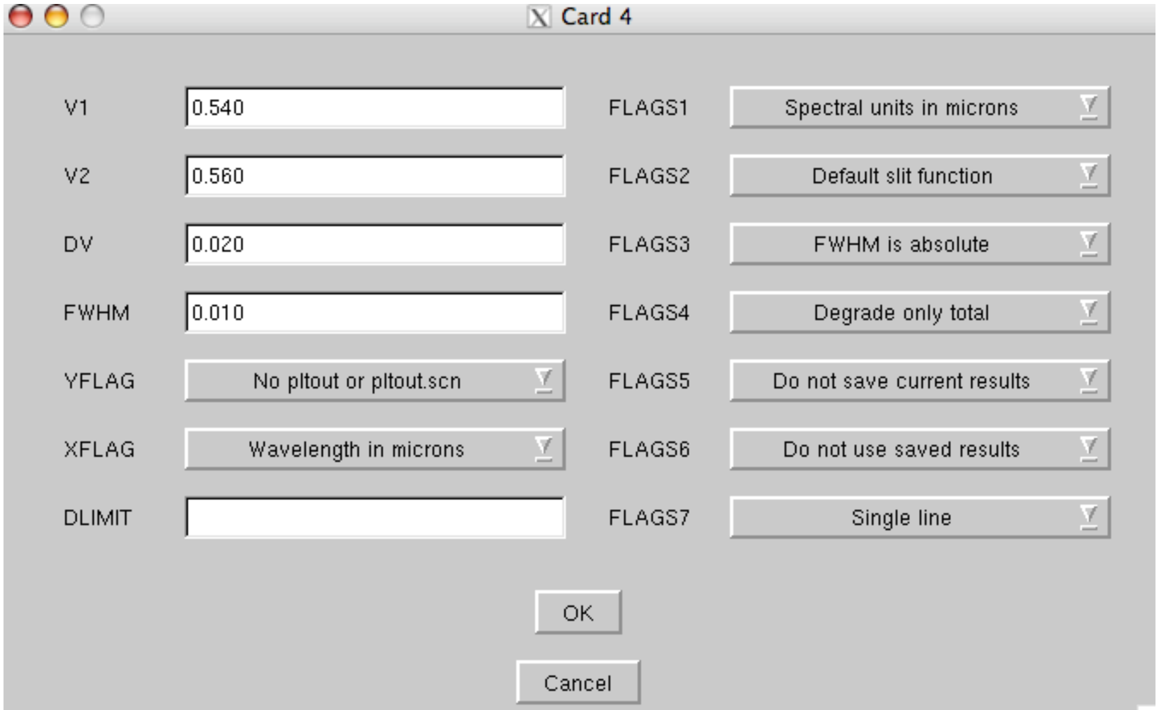

Figure 22: Stratus Cloud Scene, Card 4

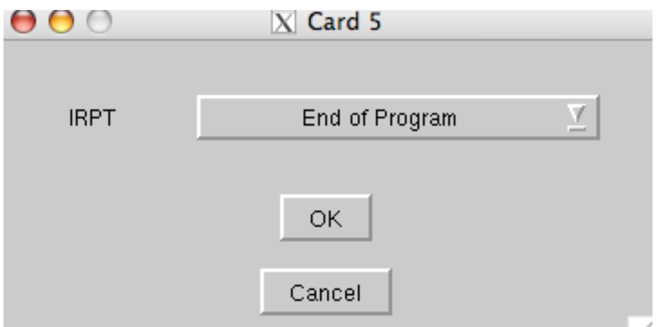

Figure 23: Stratus Cloud Scene, Card 5

As can be seen from the above MODTRAN cards, this run is set up to have the default stratus cloud included. With this run a new .ADB is created. This log noting creation of this .ADB can be seen below. The actual resulting .ADB file can be found in Appendix D: Calculation of Sensor Reaching Radiance, Stratus Scene.

```
*******************************************************
llama [50]% /dirs/pkg/dirsig3/bin/make_adb-4.2.0 cloud_stratus_run1_withcloud.cfg
DIRSIG 4.2.0
Build Date: Jul 17 2008 08:56:47

DIRSIG3 File Reader: Warning!
  DOWNWELLED_RADIANCE_MAPS are not available in DIRSIG4!

DIRSIG3 File Reader: Warning!
```

SOLAR_RADIANCE_MAPS are not available in DIRSIG4!

Initializing classic platform model:
Using static position method #1:
  Platform Location = [0, 0, 9000] (supplied)
  Target Location = [0, 0, 0] (supplied)
  Declination Angle = 0 (computed)
  Azimuth Angle = -0 degrees, clockwise from +Y (supplied)
  Range to Target = 9000 (computed)

Initializing imaging platform:
  Master clock rate = 1 [Hz]
Initializing static instrument mount ... done.
Initializing Band #1:
  Using raw capture method

Initializing truth collectors:
Material truth
Intersection truth
Path transmission truth
Path radiance truth

Creating unique focal plane groups ... done (identified 1 groups).
Focal Plane Group #1:
  Band #1

Adjusting model atmosphere to match weather data ... done
  Set boundary layer temperature to 300.70 C

Summary of instrument focal planes:
  Band #1:
    Spectral Bandpass: 0.550 - 0.570 [microns]

General simulation geometry:
  Average ground altitude = 0.0000 km.
  Average sensor altitude = 9.0000 km.

Computing total field-of-view ... done.
Sensor View Summary:
  Zenith = 0.0000 (from vertical)
  Azimuth = 0.0000 (East of North)
  Field-of-view = [0.0000, 18.0000]

Exoatmospheric source summary:
  Sun position = 30.37 declination, 262.42 azimuth
  Sub-Solar location = 32.66 +N Latitude, -114.53 +E Longitude

Moon position = 134.81 declination, 416.01 azimuth
Sub-Lunar location = -10.98 +N Latitude, -138.82 +E Longitude
Phase fraction = 87.66, Phase angle = 22.16

External Model Usage:
MODTRAN is needed by at least one band in the simulation
FASCODE is not needed for any bands in the simulation

Computing solar and lunar paths ... done.
Computing sensor paths .... done.
Computing downwelled paths .... done.

****

Figure 24: Log File from Creation of Stratus Cloud Scene .ADB

Once this .ADB is created, as done above, the parameters can be obtained to determine what the spatially uniform sensor reaching radiance would be. These calculations can be seen below:

sigma	30.366666
Hit Angle	0

	FROM .ADB SOURCES SECTION		FROM .ADB DOWNWELLED PATHS SECTION		IN DIRSIG .ODB & .MAT	FROM .ADB SENSOR PATHS SECTION		
	E_Sun	T_Sun	Total Downwelled Radiance	Calculated Incident Radiance (Direct + Downwelled) From ADB	Surface Reflectance	Path Trans	Path Radiance	Calculated Total Sensor Reaching Radiance
λ	$E'_{s\lambda}$	$\tau_1(\lambda)$	$L_{ds\lambda} + L_{d\varepsilon\lambda}$	$[E'_{s\lambda *}\cos(\sigma)*\tau_1(\lambda)*]/\pi + L_{ds\lambda} + L_{d\varepsilon\lambda}]$	$r(\lambda)$	$\tau_2(\lambda)$	$L_{us\lambda} + L_{u\varepsilon\lambda}$	$[E'_{s\lambda *}\cos(\sigma)*\tau_1(\lambda)*]/\pi + L_{ds\lambda} + L_{d\varepsilon\lambda}]*r(\lambda)*\tau_2(\lambda)+L_{us\lambda} + L_{u\varepsilon\lambda}$
0.54	1.85E-01	0	1.15E-02	1.15E-02	1.80E-01	0	2.89E-02	0.028911
0.56	1.82E-01	0	1.12E-02	1.12E-02	1.80E-01	0	2.80E-02	0.028014

Average Sensor Reaching Radiance:	**0.028463**	**W/(cm^2 sr um)**

Figure 25: Sensor Reaching Radiance Calculation for Stratus Cloud Scene

The calculation details for this can be found in Appendix D: Calculation of Sensor Reaching Radiance, Stratus Scene.

At the point analogous calculations have been performed, one calculates the total (spatially uniform) sensor reaching radiance in the absence of the sample stratus cloud to be 0.008914 W/(cm^2 sr um) and another with the presence of the sample stratus cloud to be 0.028463 W/(cm^2 sr um). This logically makes sense as we would expect to obtain significantly more radiance in the presence of the cloud which will scatter radiance back to the sensor than in the case without the cloud where there would simply be an 18% reflector.

The truth value is therefore set at 0.028463 W/(cm^2 sr um). This will be the value from which all the parametric cases are compared to and upon which the error is calculated.

Results:

Each of the parametric studies highlighted in Table 3 was run, and the resulting spectral images were obtained. For some of the runs, the DIRSIG version could not complete the run, and crashed. These runs have been notated as "FAILED". A sample log of one of these runs can be seen below.

```
******************************************************************
llama [51]% /dirs/pkg/dirsig3/bin/dirsig-4.2.0 cloud_stratus_run16.cfgDIRSIG 4.2.0
Build Date: Jul 17 2008 08:51:54

DIRSIG3 File Reader: Warning!
  DOWNWELLED_RADIANCE_MAPS are not available in DIRSIG4!

DIRSIG3 File Reader: Warning!
  SOLAR_RADIANCE_MAPS are not available in DIRSIG4!

Initializing classic platform model:
Using static position method #1:
   Platform Location = [0, 0, 9000] (supplied)
   Target Location = [0, 0, 0] (supplied)
   Declination Angle = 0 (computed)
   Azimuth Angle = -0 degrees, clockwise from +Y  (supplied)
   Range to Target = 9000 (computed)

Initializing imaging platform:
   Master clock rate = 1 [Hz]
Initializing static instrument mount ... done.
Initializing Band #1:
   Using raw capture method

Initializing truth collectors:
Material truth
Intersection truth
Path transmission truth
Path radiance truth
```

Creating unique focal plane groups ... done (identified 1 groups).
Focal Plane Group #1:
    Band #1

Reading in object database file: ./cloud_stratus.odb

Geometry: Added sphere (acts as a surface)
    Radius: 330
    Origin: 0,0,0
    MatId: 1
    Weight:
    Temp: -1

Geometry: Added a ground plane
    Anchor point: 0, 0, 0
    X slope: 0
    Y Slope: 0
    MatId: 48
Geometry: Added a box (acts as a surface)
    Lower extent: -1300,-1300,330
    Upper extent: 65,1300,1000
    MatIds: 101
    Weights:
    Temp: -1

Geometry summary:
    Total number of base objects = 3
    Total number of object instances = 0

Creating list of scene materials ... done.

Scene material IDs: 1, 48, 101

diffuse (ID = 1)
Surface Optical Properties:
    CDWardBRDF Reflectance Property
Generic Radiometry Solver
    Initial sample count = 10
    Maximum bounce count = 2
    Sample decay rate = 1
RIT-THERM Temperature Solver
    Specific heat = 0
    Mass density = 0
    Thermal conductivity = 0
    Solar absorption = computed
    Thermal emissivity = computed

Exposed area = 0

kodak_grey_card (ID = 48)
Surface Optical Properties:
Classic Emissivity:
Emissivity file = ./kodak_grey_card.ems
Specular fraction = 0
Classic Radiometry Solver
RIT-THERM Temperature Solver
Specific heat = 1
Mass density = 1
Thermal conductivity = 0
Solar absorption = computed
Thermal emissivity = computed
Exposed area = 0.17

cloud (ID = 101)
Surface Optical Properties:
PMFresnelBRDF Reflectance Property
PMFresnelBTDF Transmittance Property
Medium Boundary Radiometry Solver

The photon map repository registered mat ID: 1010 with map "cloud_map_run16"
cloudvolume (ID = 1010)
Bulk Optical Properties:
Scattering coefficient models:
ID: constant
Constant Scattering Model
Phase Function Models:
ID: uniform
Uniform Phase Function Model
Absorption coefficient models:
ID: constant
Constant Absorption Model
Medium Radiometry Solver
Photon map enabled
Spectral search radius: 100
Core search radius: 100

Applying material properties ... done.

Searching for secondary sources ... done.

Initializing the classic atmosphere model
Loading atmospheric database filename = ./cloud_stratus_wo_cloud.adb ... done.

```
Initializing the atmospheric optical properties:
Atmospheric Path Extinction
Atmospheric Path Scattering

Starting execution of all 1 acquisition task(s)
Atmosphere source sampler is being initialized...
  Sky contributions:
    Spectrally averaged total downwelled irradiance, Ed: 0.00748144
    Spectrally averaged total downwelled scalar irradiance, Eod: 0.0206226
  Sun contributions:
    Spectrally averaged downwelled irradiance, Ed: 0.15716
    Spectrally averaged downwelled scalar irradiance, Eod: 0.182149
    Spectrally averaged radiance, L: 2647.15
  Spectrally averaged total flux: 1.13315e+06
Atmosphere source sampler initialization complete

Shooting photons and building photon maps...

Saving map to "./cloud_stratus_run16.sav" ... done

Done building persistent map(s)
178955 total photons shot into the scene



Starting acquisition task #0
    1 capture(s) in this task
    Sun position at the start of this task (scene relative):
        30.3666 [degrees, declination from +Z]
        262.4157 [degrees, clockwise from +Y]
    Moon position at the start of this task (scene relative):
        Moon is below horizon.
    Platform (static) position for this task:
        [0.0000, 0.0000, 9000.0000]
    Platform pointing direction for this task:
        180.0000 [degrees, declination from +Z]


Executing capture #1 of 1
Current time = 2008-08-18T12:00:00.0000-05:00
Current platform location = [0.0000, 0.0000, 9000.0000]
14.2% completedirsig-4.2.0: base_geom/CDVector.cpp:111: void
CDVector::setUnitLength(): Assertion `length > 1e-10' failed.
Abort
************************************************************
```

Figure 26: Sample Failed DIRSIG Run

The table showing the final results of each of the parametric runs can be found below.

Run	Min	Max	Mean	St.Dev	% Error
1	0.001774	0.005356	0.002944	0.000284	89.66%
2	0.001774	0.005356	0.002944	0.000284	89.66%
3	0.001774	0.005356	0.002944	0.000284	89.66%
4	0.001774	0.005356	0.002944	0.000284	89.66%
5	0.001774	0.005356	0.002944	0.000284	89.66%
6	0.001572	0.002561	0.001728	0.000091	93.93%
7	0.002074	0.005424	0.002814	0.000292	90.11%
8	0.002233	0.005569	0.002943	0.000331	89.66%
9	0.002062	0.005352	0.002917	0.000292	89.75%
10	0.002043	0.004609	0.002944	0.000392	89.66%
11	0.002297	0.003482	0.002840	0.000224	90.02%
12	0.002469	0.003218	0.002844	0.000128	90.01%
13	0.002479	0.003192	0.002832	0.000120	90.05%
14	0.001183	0.001264	0.001227	0.000015	95.69%
15	0.001534	0.001789	0.001617	0.000046	94.32%
16	FAILED				100.00%
17	FAILED				100.00%
18	FAILED				100.00%
19	0.001011	0.001189	0.001071	0.000067	96.24%
20	0.003168	0.004718	0.003922	0.000293	86.22%
21	0.003346	0.005488	0.004369	0.000411	84.65%
22	0.002446	0.003376	0.002852	0.000152	89.98%
23	0.001637	0.002055	0.001850	0.000073	93.50%
24	0.001947	0.002529	0.002246	0.000106	92.11%
25	FAILED				100.00%
26	FAILED				100.00%
27	0.001863	0.004343	0.002961	0.000450	89.60%
28	0.002042	0.003751	0.002916	0.000285	89.76%
29	0.002486	0.003076	0.002785	0.000107	90.22%
30	0.002445	0.003033	0.002729	0.000096	90.41%
31	0.000983	0.134461	0.002995	0.003735	89.48%
32	0.002091	0.004057	0.002961	0.000339	89.60%
33	0.002306	0.003617	0.002915	0.000227	89.76%
34	0.002375	0.003342	0.002883	0.000179	89.87%
Cloudless	0.008782	0.008793	0.008782	0.000005	1.48%

Table 4: Parametric Study Run Results

Conclusions:

As can be seen from the table above 5 of the 34 runs failed, and the remaining runs all had a significant amount of error. None of the runs results in a sensor reaching radiance that was anywhere approaching the truth value predicted by MODTRAN. It is also worth noting that all of the runs resulted in sensor reaching radiance that was well below the predicted value (vs. above the predicted value). This could be seen in the resulting images in which the clouds all appeared darker that the surrounding scene.

The “Cloudless” run indicated an error of 1.48%. This could imply that the error is being introduced somewhere within the modeling of the cloud volume.

All of the resulting imagery can be found in Appendix E: DIRSIG Parametric Cloud Study Sensor Reaching Radiance Images and Appendix F: DIRSIG Parametric Cloud Study Truth Images. These results however should not be expected as the parametric nature of the study ensure that the DIRSIG runs were not only completed at that expected values of the stratus cloud, but also at values the were varying extremely. For example in Run 20 had no absorption modeled (all scattering), however, the sensor reaching radiance was still significantly lower than expected. The final results indicate the DIRSIG version 4-2.0 is not performing the modeling of the cloud media correctly. More investigation would be needed to determine the exact nature of the failure.

Appendices:

Appendix A: DIRSIG Parametric Cloud Study Configuration Files

See files attached to paper.

Appendix B: DIRSIG Parametric Cloud Study Material Files

See files attached to paper.

Appendix C: Calculation of Sensor Reaching Radiance, Cloudless Scene

See files attached to paper.

Appendix D: Calculation of Sensor Reaching Radiance, Stratus Scene

See files attached to paper.

Appendix E: DIRSIG Parametric Cloud Study Sensor Reaching Radiance Images

See files attached to paper.

Appendix F: DIRSIG Parametric Cloud Study Truth Images

See files attached to paper.

References:

[1] Schott 1997, Remote Sensing: The Image Chain Approach , John R. Schott, Oxford University Press, New York, 1997.

[2] Schott 1993, DIRSIG-Digital Imaging and Remote Sensing Image Generation Model: Description, Enhancements, and Validation , J. R. Schott, J. E. Mason, C. N. Salvaggio, J. D. Sirianni, R. A. Rose, E. O. Kulp, and D. K. Ranking, Digital Imaging and Remote Sensing Laboratory , Rochester Institute and Technology, July 1993.
[3] Berk, A., Bernstein, L., Anderson, G., Acharya, P., Robertson, D., Chetwynd, J. and Adler-Golden, S., modtran cloud and multiple scattering upgrades with applications to AVIRIS. Remote Sensing of Environment. v65 i3. 367-375.

[4] Alexander Berk et al, MODTRAN: A Moderate Resolution Model for LOWTRAN 7, Air Force Geophysics Lab, GL-TR-89-C122, April 1989

[5] Adam Goodenough, CDGenericRadSolver Technical Brief, DIRS 05/06-1978-170, May 2006.