Created in COMSOL Multiphysics 6.2

Orbit Thermal Loads

Introduction

This model demonstrates how to define Earth properties that are spatially varying on the planet. A satellite in orbit experiences solar, albedo, and planetary infrared (IR) loads, where albedo and planetary IR can vary with latitude and longitude. In this example, these inputs are read from spreadsheet and image data. The total irradiation and flux onto the satellite are evaluated over several orbits and the albedo flux is plotted over the surface of Earth.

Model Definition

To evaluate the total environmental heat loads on a satellite, it is sufficient to use a geometry that describes the outside envelope of the satellite structure. In this example, a 1U CubeSat is modeled as a 10 cm cube. A mapped mesh, with one element on each side, is sufficient to compute the incident loads since there is no shadowing.

When computing orbital heat loads, it is typical to use a two-band solar and ambient radiation model. Environmental radiation in the short-wavelength, solar band, is almost solely from the direct solar and albedo. Radiation in the long-wavelength, ambient band, is from Earth, direct solar, and albedo. The division between these bands is user-selectable and is based upon the emissive properties of the exposed materials. It is typically in the range 2–5 µm. In this example, the division is set to 2.5 µm.

The planet properties of albedo and planet flux are both functions of latitude and longitude, and since the two-band solar and ambient radiation model is used, a total of four different functions are needed.

- The albedo is a function of latitude and longitude in the solar spectral band. This is based upon the image data shown in Figure 1. The data in this figure is created for this example.

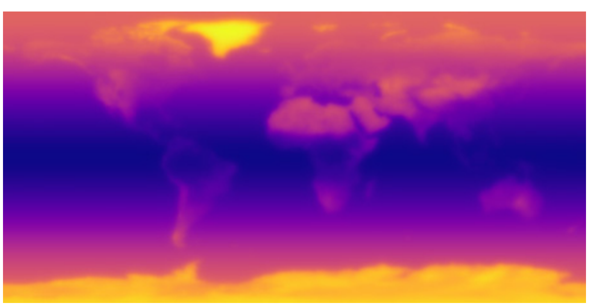

Figure 1: Image data of the albedo in the solar band.

- The albedo in the ambient spectral band is a constant value of 0.3 everywhere.
- The planet IR in the solar spectral band is zero.
- The planet IR in the ambient spectral band is tabular data and varies with latitude only.

Results and Discussion

Figure 2 displays the albedo flux from Earth by plotting the function on the planet surface dataset, and using the solar vector. This shows how the albedo flux can vary depending upon both latitude and longitude.

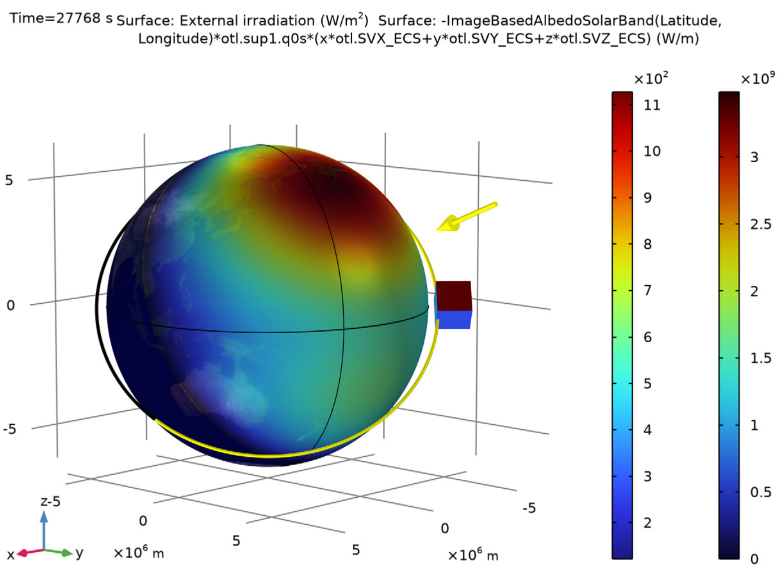

Figure 2: Diffusely reflected solar band flux, the albedo.

Figure 3 shows total and per band irradiation over time.

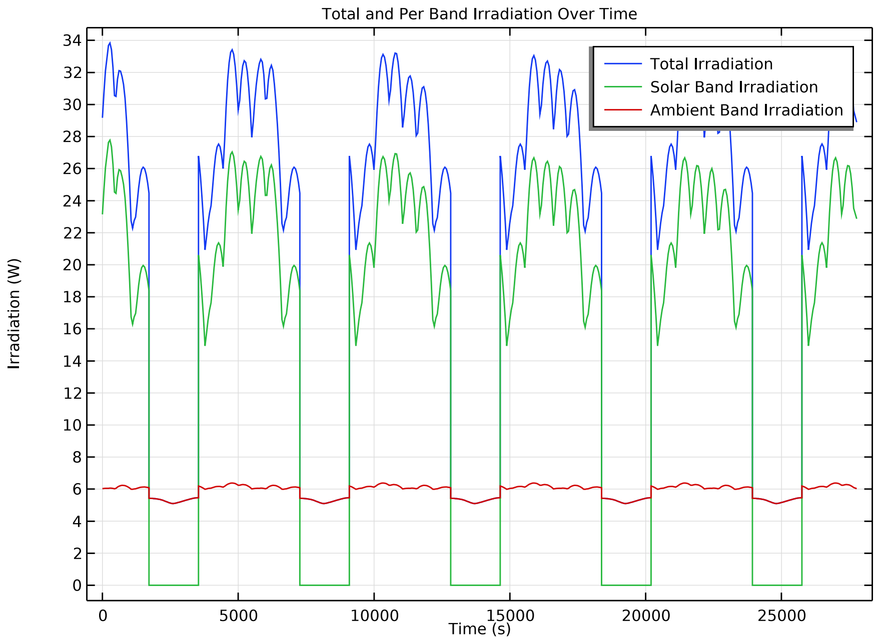

Figure 3: Variation of the total irradiation over several orbit periods.

Figure 4 compares the total irradiation between orbits. The irradiation varies between the orbits because the planet properties depend on latitude and longitude.

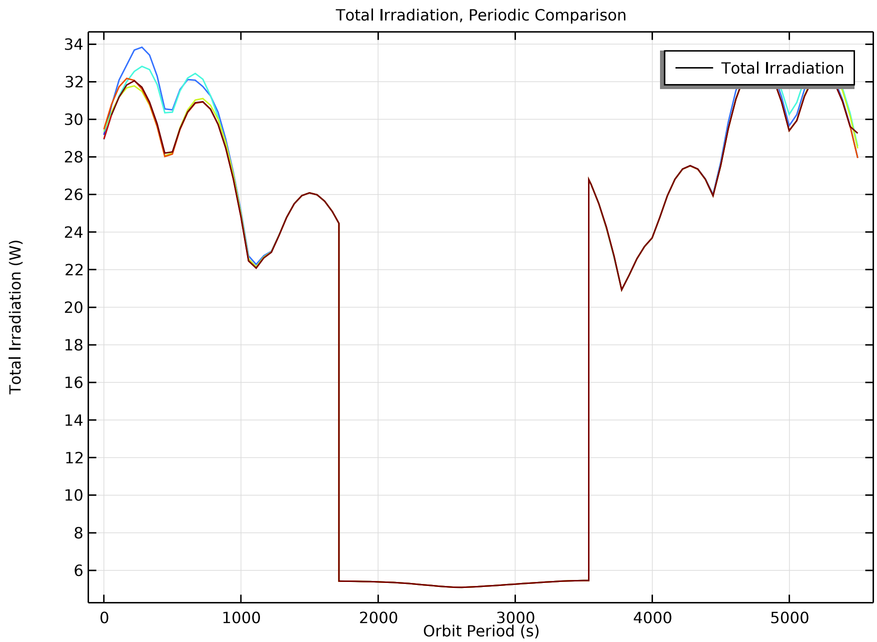

Figure 4: Comparison of the total irradiation over several orbit periods.

Application Library path: `Heat_Transfer_Module/Orbital_Thermal_Loads/orbit_thermal_loads`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **Heat Transfer>Radiation>Orbital Thermal Loads (otl)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces> Orbit Thermal Loads**.

6 Click **Done**.

GEOMETRY 1

Block 1 (blk1)

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Geometry 1** node.

2 Right-click **Geometry 1** and choose **Block**.

3 In the **Settings** window for **Block**, locate the **Size and Shape** section.

4 In the **Width** text field, type `10[cm]`.

5 In the **Depth** text field, type `10[cm]`.

6 In the **Height** text field, type `10[cm]`.

7 Locate the **Position** section. From the **Base** list, choose **Center**.

DEFINITIONS

Now, define the two functions for the albedo in the solar and ambient bands.

The albedo in the solar band is defined as a function of latitude and longitude and based upon image data.

Image Data of Solar Band Albedo

1 In the **Home** toolbar, click f(X) **Functions** and choose **Local>Image**.

2 In the **Settings** window for **Image**, type `Image Data of Solar Band Albedo` in the **Label** text field.

3 Locate the **File** section. Click **Browse**.

4 Browse to the model's Application Libraries folder and double-click the file `solarBandAlbedoData.png`.

5 Click **Import**.

6 In the **Function name** text field, type `imageData`.

7 Locate the **Coordinates** section. In the **x minimum** text field, type `-pi`.

8 In the **x maximum** text field, type `pi`.

9 In the **y minimum** text field, type `-pi/2`.

10 In the **y maximum** text field, type `pi/2`.

11 Locate the **Units** section. In the **Arguments** text field, type `rad`.

12 In the **Function** text field, type `1`.

Image-Based Albedo, Solar Band

1 In the **Home** toolbar, click f(X) **Functions** and choose **Local>Analytic**.

2 In the **Settings** window for **Analytic**, type `Image-Based Albedo, Solar Band` in the **Label** text field.

3 In the **Function name** text field, type `ImageBasedAlbedoSolarBand`.

4 Locate the **Definition** section. In the **Expression** text field, type `imageData(Longitude, Latitude)`.

5 In the **Arguments** text field, type `Latitude, Longitude`.

6 Locate the **Units** section. In the table, enter the following settings:

Argument	Unit
Latitude	rad
Longitude	rad

7 Locate the **Plot Parameters** section. In the table, enter the following settings:

Plot	Argument	Lower limit	Upper limit	Fixed value	Unit
√	Latitude	-pi/2	pi/2	0	rad
√	Longitude	-pi	pi	0	rad

Constant Albedo, IR Band

1 In the **Home** toolbar, click f(X) **Functions** and choose **Local>Analytic**.

In the ambient band, the albedo is set to 0.3 everywhere on the planet.

2 In the **Settings** window for **Analytic**, type `Constant Albedo, IR Band` in the **Label** text field.

3 In the **Function name** text field, type `ConstantAlbedo_IR_Band`.

4 Locate the **Definition** section. In the **Expression** text field, type `0.3`.

5 In the **Arguments** text field, type `Latitude, Longitude`.

Now, define the planet IR flux in the ambient band. It is defined from tabular data and varies with latitude only. The planet IR flux function in the solar band is zero.

IR Flux w.r.t. Latitude

1 In the **Home** toolbar, click f(X) **Functions** and choose **Local>Interpolation**.

2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 In the table, enter the following settings:

t	f(t)
85	195
75	200
65	205
55	215
45	225
35	245
25	265
15	260
5	245
-5	255
-15	265
-25	265
-35	245
-45	225
-55	210
-65	195
-75	165
-85	155

4 In the **Label** text field, type `IR Flux w.r.t. Latitude`.

5 Locate the **Units** section. In the **Function** table, enter the following settings:

Function	Unit
intI	W/m^2

6 In the **Argument** table, enter the following settings:

Argument	Unit
t	1

Planetary Flux, IR Band

1 In the **Home** toolbar, click f(X) **Functions** and choose **Local>Analytic**.

2 In the **Settings** window for **Analytic**, type `Planetary Flux, IR Band` in the **Label** text field.

3 In the **Function name** text field, type `PlanetaryFlux_IR_Band`.

4 Locate the **Definition** section. In the **Expression** text field, type `int1(Latitude*90/pi)`.

5 In the **Arguments** text field, type `Latitude, Longitude`.

6 Locate the **Units** section. In the table, enter the following settings:

Argument	Unit
Latitude	1
Longitude	1

Integration 1 (intop1)

1 In the **Definitions** toolbar, click **Nonlocal Couplings** and choose **Integration**.

An integration operator is added to integrate the external irradiation over the spacecraft boundaries.

2 In the **Settings** window for **Integration**, type `intopAll` in the **Operator name** text field.

3 Locate the **Source Selection** section. From the **Geometric entity level** list, choose **Boundary**.

4 From the **Selection** list, choose **All boundaries**.

ORBITAL THERMAL LOADS (OTL)

Sun Properties 1

The Sun vector and solar flux are set to correspond to the summer solstice.

1 In the **Model Builder** window, under **Component 1 (comp1)>Orbital Thermal Loads (otl)** click **Sun Properties 1**.

2 In the **Settings** window for **Sun Properties**, locate the **Sun Properties** section.

3 From the **Sun direction** list, choose **Summer solstice**.

Planet Properties 1

1 In the **Model Builder** window, click **Planet Properties 1**.

2 In the **Settings** window for **Planet Properties**, locate the **Planet Properties** section.

3 Find the **Planet initial position** subsection. From the **Planet longitude at start time** list, choose **Longitude at subspacecraft point**.

Select the previously defined functions for the albedo and planet IR flux depending on latitude and longitude.

4 Locate the **Radiative Properties** section. From the **Geographic position dependence** list, choose **Latitude and longitude**.

5 From the $f_{\alpha 0}$(lat,long) list, choose **User-defined for each band**.

6 In the table, enter the following settings:

Spectral band	Albedo function
Solar: [0, 2.5[um][	Image-Based Albedo, Solar Band (ImageBasedAlbedoSolarBand)
Ambient: [2.5[um], +infinity[	Constant Albedo, IR Band (ConstantAlbedo_IR_Band)

7 From the f_{q0}(lat,long) list, choose **User-defined for each band**.

8 In the table, enter the following settings:

Spectral band	Planet radiative flux function
Ambient: [2.5[um], +infinity[	Planetary Flux, IR Band (PlanetaryFlux_IR_Band)

Orbital Parameters 1

A circular orbit is defined at 400 km altitude, inclination of 50°, and local time at ascending node set to 15 h.

1 In the **Model Builder** window, click **Orbital Parameters 1**.

2 In the **Settings** window for **Orbital Parameters**, locate the **Orbital Parameters** section.

3 From the **Orbit type** list, choose **Circular**.

4 In the R text field, type `otl.R_planet+400[km]`.

5 In the i text field, type `50[deg]`.

6 From the **Ascending node** list, choose **Local time at ascending node**.

7 In the t_{Ω} text field, type `15[h]`.

Spacecraft Orientation 1

The orientation of the satellite is such that the primary direction points toward Earth. The satellite is slowly rotating about its primary axis, so the secondary axis can be any vector that is not parallel to nadir. In this case the default setting, of the +X direction corresponding to the direction of travel, is used.

1 In the **Model Builder** window, click **Spacecraft Orientation 1**.

2 In the **Settings** window for **Spacecraft Orientation**, locate the **Spacecraft Orientation** section.

3 Find the **Rotations** subsection. From the **Rotation about primary axis** list, choose **Angular rate**.

4 In the ω text field, type `2*360[deg]/otl.T_orbit`.

Diffuse Surface 1

Now, define the radiative properties of the different boundaries.

1 In the **Model Builder** window, click **Diffuse Surface 1**.

2 In the **Settings** window for **Diffuse Surface**, locate the **Surface Emissivity** section.

3 From the ε list, choose **User-defined for each band**.

4 In the table, enter the following settings:

Spectral band	Emissivity (1)
Solar: [0, 2.5[um][	0.3
Ambient: [2.5[um], +infinity[	0.85

Diffuse Surface 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Diffuse Surface**.

2 In the **Settings** window for **Diffuse Surface**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `1 2 5 6` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Diffuse Surface**, locate the **Surface Emissivity** section.

7 From the ε list, choose **User defined**. In the associated text field, type `0.95`.

MESH 1

A mapped mesh, with one element on each side, is sufficient to compute the incident loads since there is no shadowing.

Swept 1

In the **Mesh** toolbar, click **Swept**.

Size

1 In the **Model Builder** window, click **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section. In the **Maximum element size** text field, type `0.1`.

5 Click **Build All**.

STUDY 1

Step 1: Orbit Thermal Loads

1 In the **Model Builder** window, under **Study 1** click **Step 1: Orbit Thermal Loads**.

2 In the **Settings** window for **Orbit Thermal Loads**, locate the **Study Settings** section.

3 In the **Output orbit times** text field, type `range(0,0.01,5)`.

4 Click to expand the **Values of Dependent Variables** section. In the **Home** toolbar, click **Compute**.

RESULTS

Orbit Visualization (otl)

Modify the default Orbit Visualization plot to display the albedo flux on the planet.

1 In the **Model Builder** window, expand the **Orbit Visualization (otl)** node.

Eclipse

1 In the **Model Builder** window, expand the **Results>Orbit Visualization (otl)>Eclipse** node, then click **Eclipse**.

2 In the **Settings** window for **Surface**, locate the **Coloring and Style** section.

3 From the **Color** list, choose **Custom**.

4 On Windows, click the colored bar underneath, or — if you are running the cross-platform desktop — the **Color** button.

5 Click **Define custom colors**.

6 Set the RGB values to 0, 0, and 64, respectively.

7 Click **Add to custom colors**.

8 Click **Show color palette only** or **OK** on the cross-platform desktop.

Transparency 1

1 In the **Model Builder** window, click **Transparency 1**.

2 In the **Settings** window for **Transparency**, locate the **Transparency** section.

3 In the **Transparency** text field, type `0.2`.

Albedo Flux

1 In the **Model Builder** window, right-click **Orbit Visualization (otl)** and choose **Surface**.

2 In the **Settings** window for **Surface**, type `Albedo Flux` in the **Label** text field.

3 Locate the **Expression** section. In the **Expression** text field, type `-ImageBasedAlbedoSolarBand(Latitude, Longitude)*otl.sup1.q0s*(x*otl.SVX_ECS+y*otl.SVY_ECS+z*otl.SVZ_ECS)`.

4 Locate the **Coloring and Style** section. Click **Change Color Table**.

5 In the **Color Table** dialog box, select **Rainbow>RainbowDark** in the tree.

6 Click **OK**.

Filter 1

1 Right-click **Albedo Flux** and choose **Filter**.

2 In the **Settings** window for **Filter**, locate the **Element Selection** section.

3 In the **Logical expression for inclusion** text field, type `x*otl.SVX_ECS+y*otl.SVY_ECS+z*otl.SVZ_ECS<0`.

Transparency 1

1 In the **Model Builder** window, right-click **Albedo Flux** and choose **Transparency**.

2 In the **Settings** window for **Transparency**, locate the **Transparency** section.

3 In the **Transparency** text field, type `0.2`.

Albedo Flux

1 In the **Model Builder** window, click **Albedo Flux**.

2 In the **Orbit Visualization (otl)** toolbar, click **Plot**.

Plot the evolution of total and per band irradiation over time.

Total and Per Band Irradiation Over Time

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Total and Per Band Irradiation Over Time` in the **Label** text field.

3 Locate the **Plot Settings** section.

4 Select the **y-axis label** check box. In the associated text field, type `Irradiation (W)`.

5 Click to expand the **Title** section. From the **Title type** list, choose **Label**.

Global 1

1 Right-click **Total and Per Band Irradiation Over Time** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
intopAll(otl.Gext1+otl.Gext2)	W	Total Irradiation
intopAll(otl.Gext1)	W	Solar Band Irradiation
intopAll(otl.Gext2)	W	Ambient Band Irradiation

4 In the **Total and Per Band Irradiation Over Time** toolbar, click **Plot**.

Plot the evolution of total irradiation on each orbit period.

Total Irradiation, Periodic Comparison

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Total Irradiation, Periodic Comparison` in the **Label** text field.

3 Locate the **Plot Settings** section.

4 Select the **x-axis label** check box. In the associated text field, type `Orbit Period (s)`.

5 Locate the **Title** section. From the **Title type** list, choose **Label**.

Global 1

1 Right-click **Total Irradiation, Periodic Comparison** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
intopAll(otl.Gext1+otl.Gext2)	W	Total Irradiation

4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

5 In the **Expression** text field, type `mod(t,otl.T_orbit)`.

Filter 1

1 Right-click **Global 1** and choose **Filter**.

2 In the **Settings** window for **Filter**, locate the **Line Segment Selection** section.

3 Clear the **Decreasing x** check box.

Color Expression 1

1 In the **Model Builder** window, right-click **Global 1** and choose **Color Expression**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `ceil(t/otl.T_orbit)`.

4 Select the **Description** check box. In the associated text field, type `Orbit Number`.

5 Locate the **Coloring and Style** section. Clear the **Color legend** check box.

6 In the **Total Irradiation, Periodic Comparison** toolbar, click **Plot**.

Total Irradiation, Periodic Comparison

1 In the **Model Builder** window, under **Results** click **Total Irradiation, Periodic Comparison**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 Clear the **Show legends** check box.

Finally, add an evaluation group to get the time-averaged total environmental irradiation.

Average of Total Irradiation Over Time

1 In the **Results** toolbar, click **Evaluation Group**.

2 In the **Settings** window for **Evaluation Group**, type `Average of Total Irradiation Over Time` in the **Label** text field.

3 Locate the **Data** section. From the **Time selection** list, choose **First**.

4 Locate the **Transformation** section. Select the **Transpose** check box.

5 Click to expand the **Format** section. From the **Include parameters** list, choose **Off**.

Global Evaluation 1

1 Right-click **Average of Total Irradiation Over Time** and choose **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, locate the **Expressions** section.

3 In the table, enter the following settings:

Expression	Unit	Description
`timeavg(0, at('last',t), intopAll(otl.Gext1+ otl.Gext2), 'nointerp')`	`W`	`Time-averaged total irradiation`

4 In the **Average of Total Irradiation Over Time** toolbar, click **Evaluate**.