CERES TOA Radiative Flux Reference Level
SW & LW Radiances vs $\theta$
(Spherical Earth Geometry; MODTRAN; Rayleigh Atmosphere)
Clear Ocean LW Radiance vs Viewing Zenith Angle (As Function of Reference Level \( h \))

![Graph showing the relationship between radiance and viewing zenith angle at different reference levels.](image)
LW Flux vs Reference Level
(Clear Ocean; MODTRAN)

LW Flux (W m\(^{-2}\)) vs Reference Level (km)

- **Direct Integration**
- **Inverse Square Law**

Reference Level (km): 0 1 2 3 4 5 6 7 8 9 10

LW Flux (W m\(^{-2}\)): 280 282 284 286 288

Source: [NASA Earth Observing System Science Team](http://eosweb.larc.nasa.gov)
LW Flux vs Reference Level
(Thick Ci; $\tau=1000; Z_t=11$ km; MODTRAN)
SW Flux vs Reference Level
(Rayleigh Atm; $\theta_o=45$; MODTRAN)
SW Flux vs Reference Level
(Thick Ci; $\tau=1000$; $Z_t=11$ km; $\theta_o=45$; MODTRAN)
Albedo & SW Flux Contribution From Off-Earth Views (MODTRAN; Surface Reference Level)

Albedo Difference

SW Flux Difference

Rayleigh Atmosphere
- Deep Convective Cloud

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Edition2B ADMs

- Evaluate ADM TOA flux by direct integration at 100-km reference level. Use MODTRAN radiances to fill-in radiances at off-earth views.

- Define ADMs at the surface reference level via inverse square law:

\[
R_{j}^{SW}(\theta_{oi}, \theta_{k}, \phi_{i}; h_{sfc}) = \frac{\pi I_{j}^{SW}(\theta_{oi}, \theta_{k}, \phi_{i}; h_{sfc})}{F_{j}^{SW}(\theta_{oi}; h_{100})} \left( \frac{r_{e}}{r_{e} + h_{100}} \right)^2
\]

\[
R_{j}^{LW}(\theta_{k}; h_{sfc}) = \frac{\pi I_{j}^{LW}(\theta_{k}; h_{sfc})}{F_{j}^{LW}(h_{100})} \left( \frac{r_{e}}{r_{e} + h_{100}} \right)^2
\]
TOA SW Flux Error by Using MODTRAN to Fill-In Off-Earth Views (Compared with ES8)

- Clear
- Thin Cirrus
- Thick Cloud

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Is there a reference level that is most appropriate for radiation budget studies?

\[ \frac{S_o}{4} (1 - \alpha) = F^a \]

\[ \frac{S_o}{4} (1 - \alpha_h - t_h) = F_h^a \]
Effective Transmission $t_h$

\[ t(r) = \frac{\int_0^\infty t_\lambda(r) S_{o\lambda} d\lambda}{\int_0^\infty S_{o\lambda} d\lambda} \]

\[ t_h = \frac{\int_0^{r_e + h} 2\pi r t(r) dr}{\pi (r_e + h)^2} \]
### $t_h$ for Sample MODTRAN Cases (h=100 km)

<table>
<thead>
<tr>
<th>Case</th>
<th>Profiles</th>
<th>Aerosol</th>
<th>Cloud</th>
<th>$t_h$ $(x10^{-2})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tropical</td>
<td>No</td>
<td>No</td>
<td>2.503</td>
</tr>
<tr>
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<td>No</td>
<td>2.446</td>
</tr>
<tr>
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<td>Thick Ice; $z_t=9$ km</td>
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<tr>
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<td>5</td>
<td>Subarctic Winter</td>
<td>No</td>
<td>No</td>
<td>2.546</td>
</tr>
<tr>
<td>6</td>
<td>No Atmosphere</td>
<td></td>
<td></td>
<td>3.067</td>
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</tbody>
</table>
At an arbitrary reference level $x$:

$$\frac{S_o}{4} - \left( \frac{r_e + h}{r_e + x} \right)^2 (F^r_h + F^a_h) - t_x S_o = 0$$

$$t_x = 1 - \left( \frac{r_e + h}{r_e + x} \right)^2 (1 - t_h)$$

At $x=d$, $t_x=0$:

$$d = (r_e + h)\sqrt{1 - t_h} - r_e$$
\( t_h \) and \( d \) for Sample MODTRAN Cases (h=100 km)

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<tr>
<th>Case</th>
<th>Profiles</th>
<th>Aerosol</th>
<th>Cloud</th>
<th>( t_h ) (x10^{-2})</th>
<th>( d ) (km)</th>
</tr>
</thead>
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<td>No Atmosphere</td>
<td></td>
<td></td>
<td>3.067</td>
<td>0</td>
</tr>
</tbody>
</table>
Net Flux vs Reference Level

\[ x = d \]

\[ \frac{S_0}{4} (1 - \alpha_x) - F_x^{LW} \]

\[ \frac{S_0}{4} (1 - \alpha_x - t_x) - F_x^{LW} \]
Instantaneous TOA Flux Estimate

Instantaneous flux at 20-km reference level:

\[ \hat{F}(Ω; h_{20}) = \hat{F}(Ω; h_{sfc}) \left( \frac{r_e}{r_e + h_{20}} \right)^2 \]

where,

\[ \hat{F}(Ω; h_{sfc}) = \frac{\pi I(Ω; h_{sfc})}{R_j(Ω; h_{sfc})} \]
Tropical Average Albedo & SW Flux Difference (SSF Ed2A - SSF Ed2B)

Albedo Difference

SW Flux Difference

- Albedo Difference vs. Solar Zenith Angle
- SW Flux Difference vs. Solar Zenith Angle

- Surface Reference Level
- 20-km Reference Level

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Comparison with ERBE Methodology

• ERBE ADMs constructed from Nimbus-7 using a surface reference level.

• On NOAA-9, 10 and ERBS, the ERBE ADMs were applied using viewing geometry defined at a 30-km reference level.

⇒ Viewing zenith used to estimate TOA flux is too small (inconsistent with how models were constructed).
Flux Error Due to Inconsistent Viewing Geometry

Flux Error (W m^-2)

\[ \theta_{30} - \theta_{sfc} \]

\[ \theta_{sfc} (°) \]

\[ \theta_{30} (°) \]

\[ \text{SW} \]

\[ \text{LW} \]