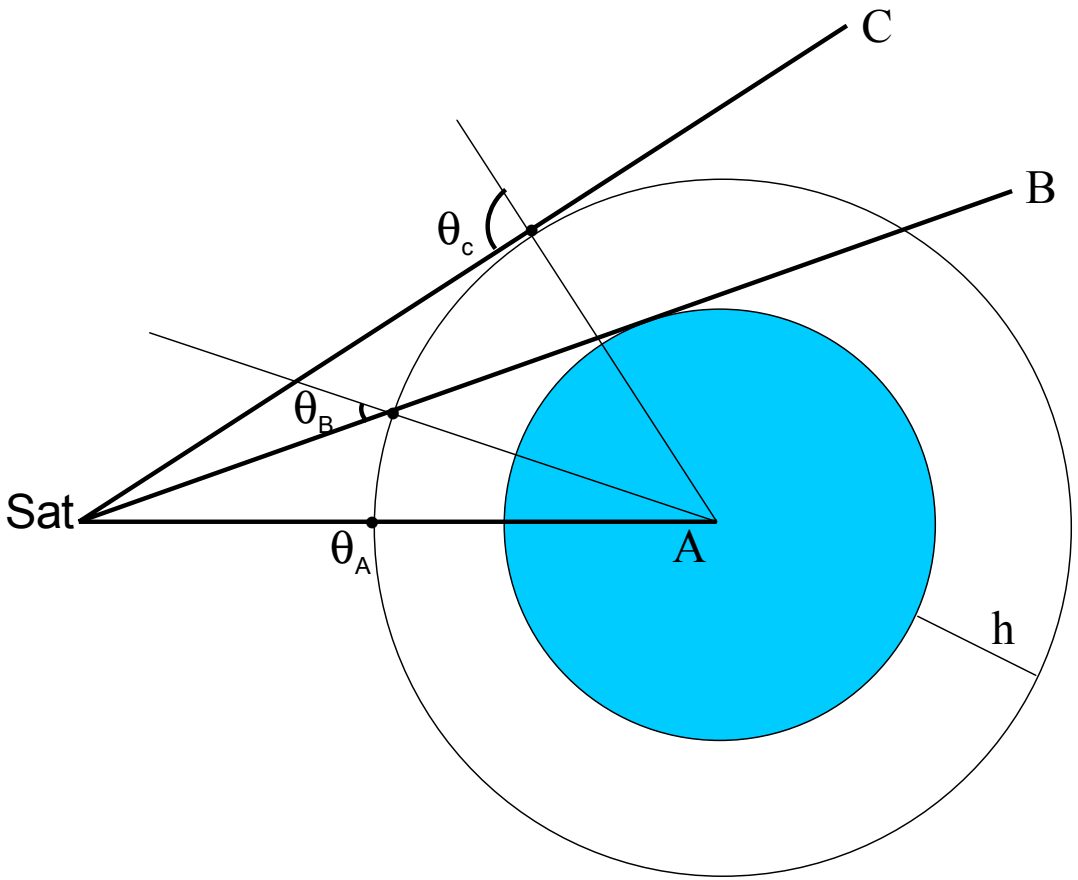
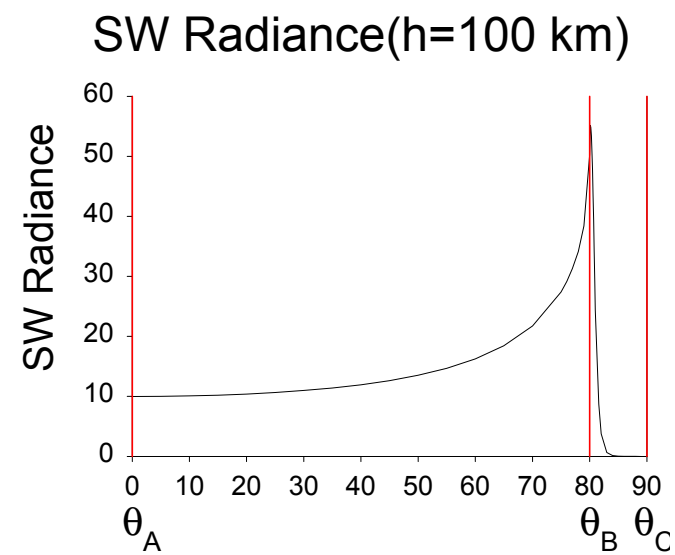
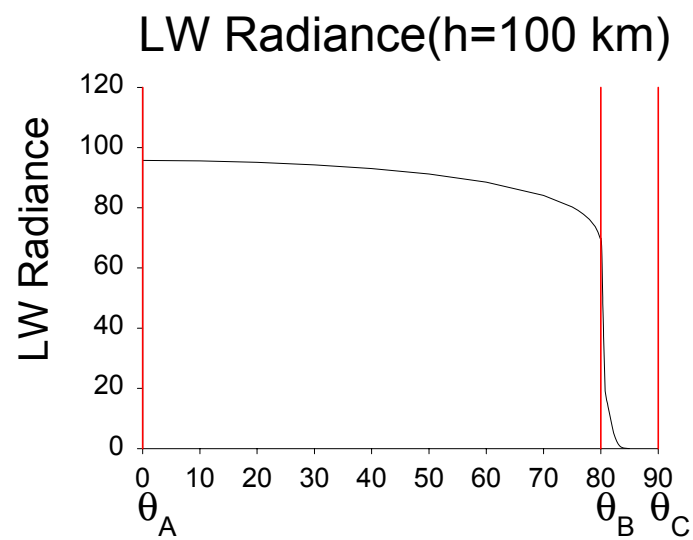
CERES TOA Radiative Flux Reference Level

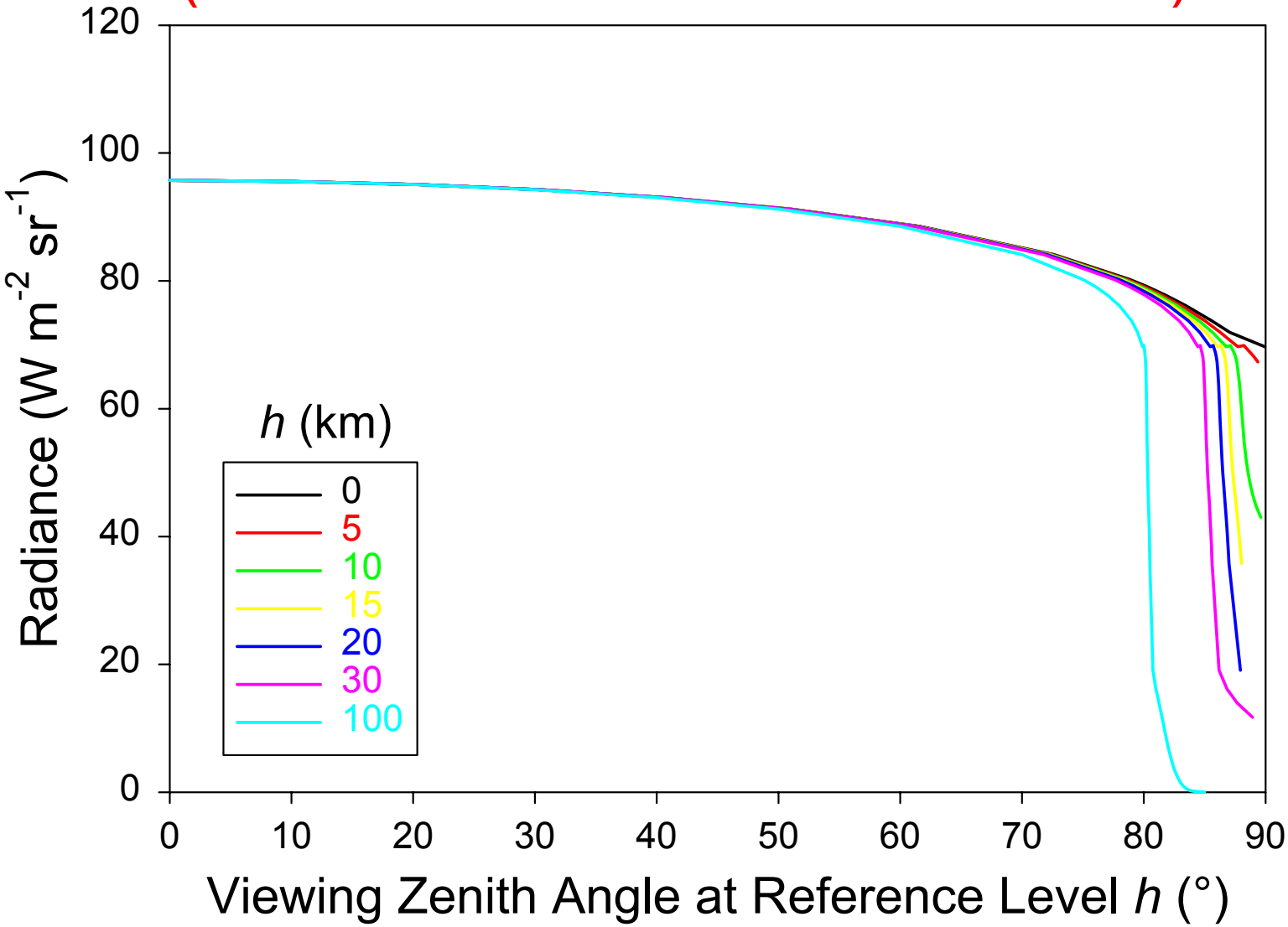
SW & LW Radiances vs θ
(Spherical Earth Geometry; MODTRAN; Rayleigh Atmosphere)



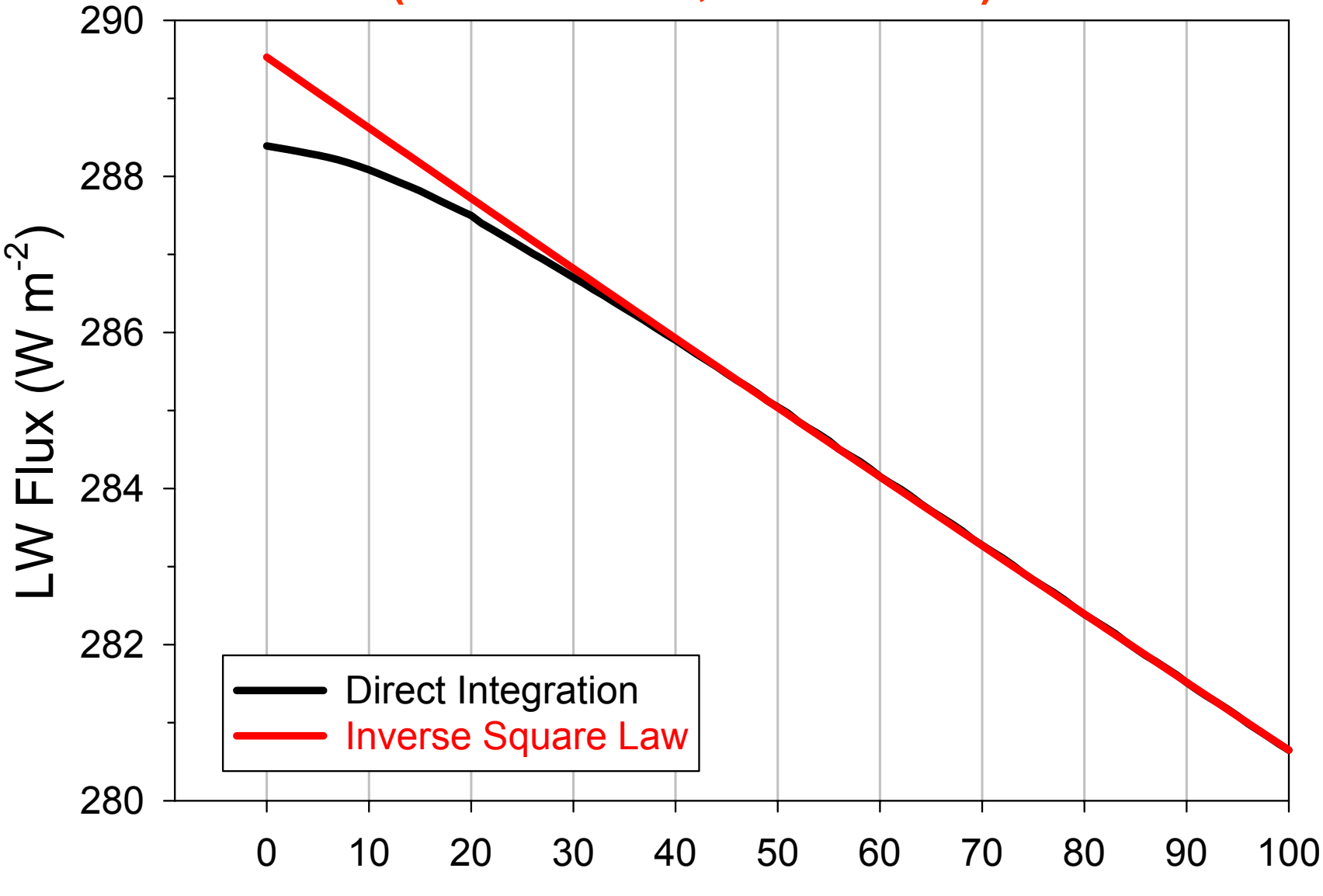




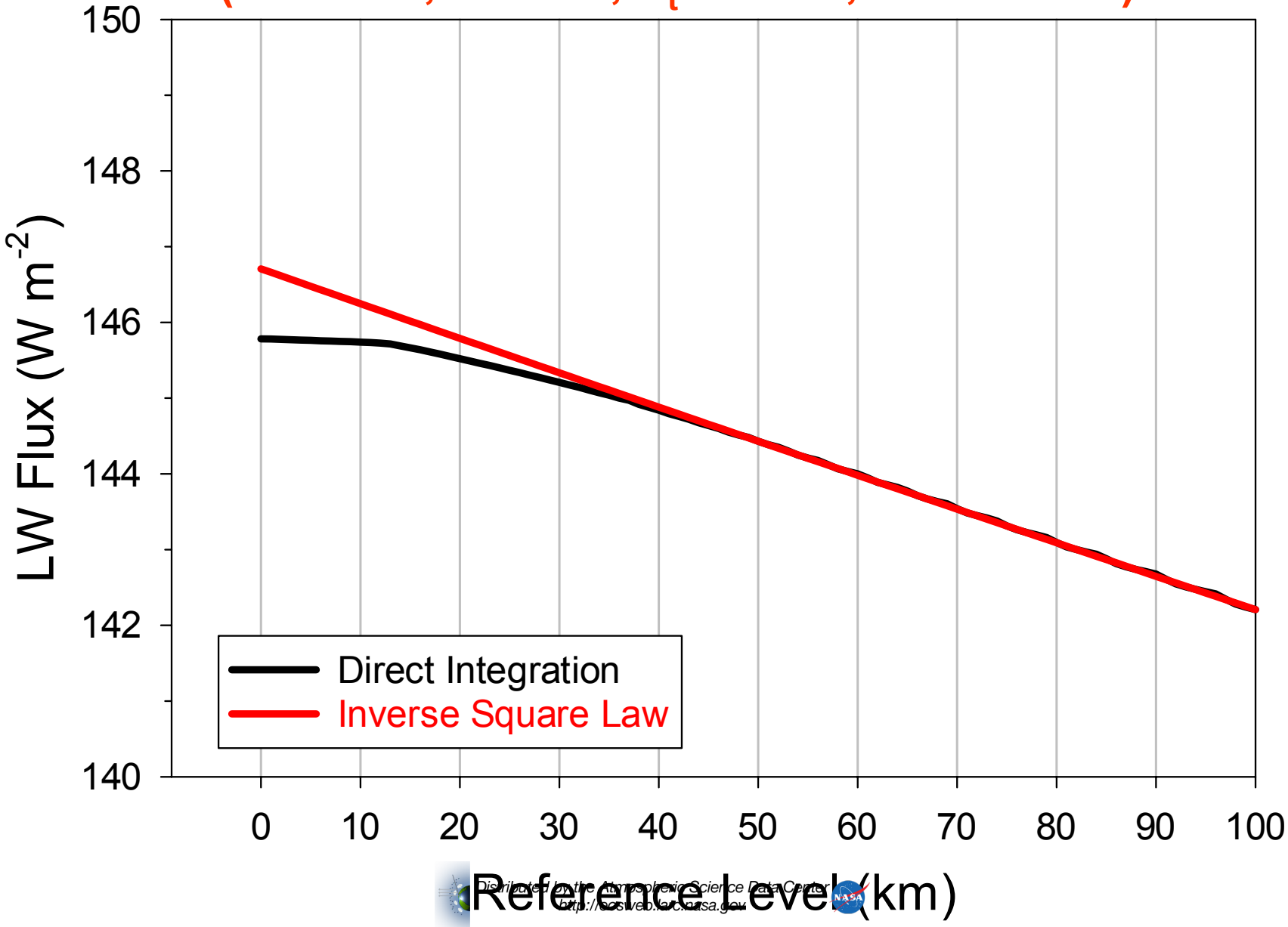
Clear Ocean LW Radiance vs Viewing Zenith Angle (As Function of Reference Level *h*)



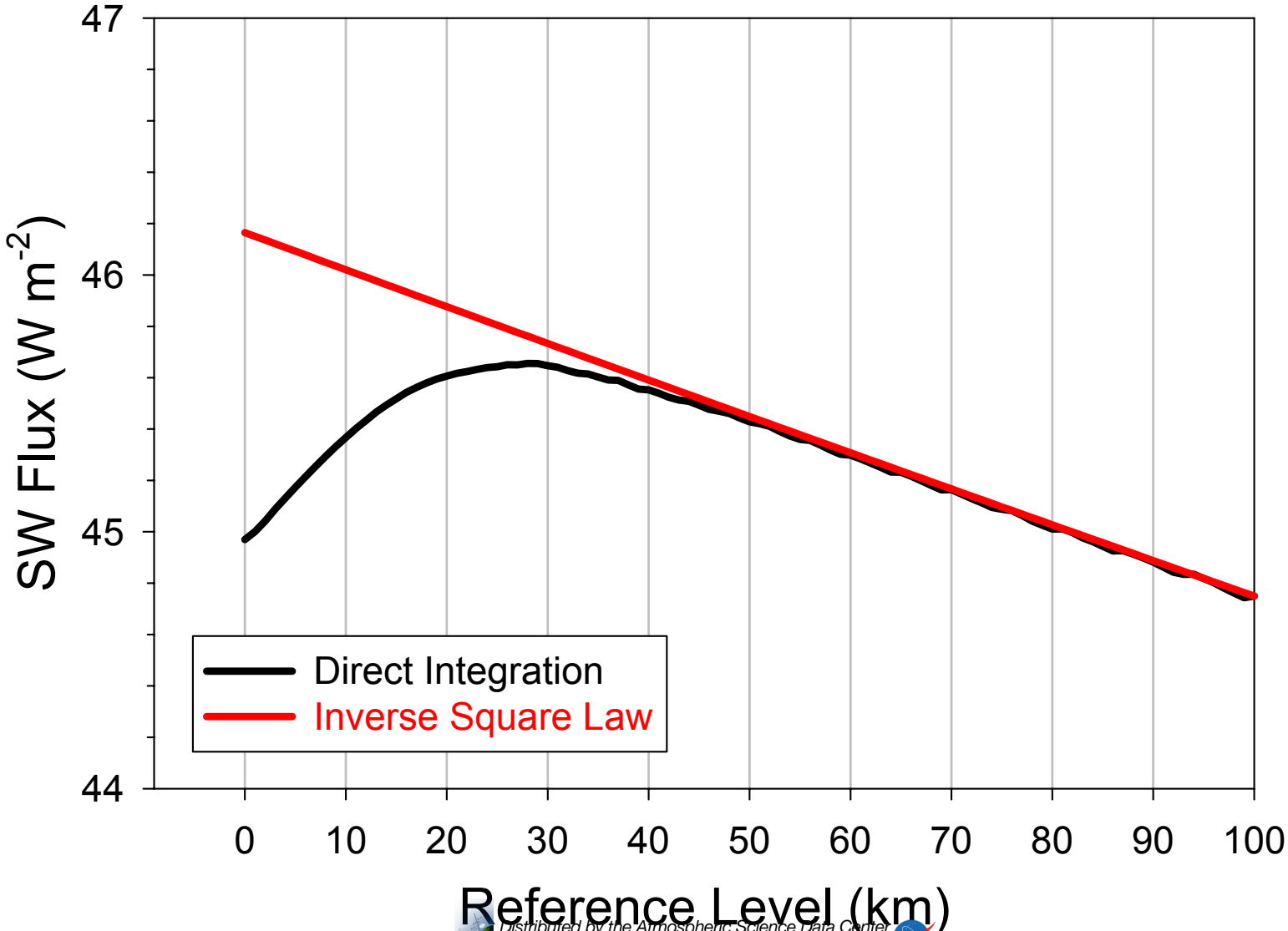
LW Flux vs Reference Level (Clear Ocean; MODTRAN)



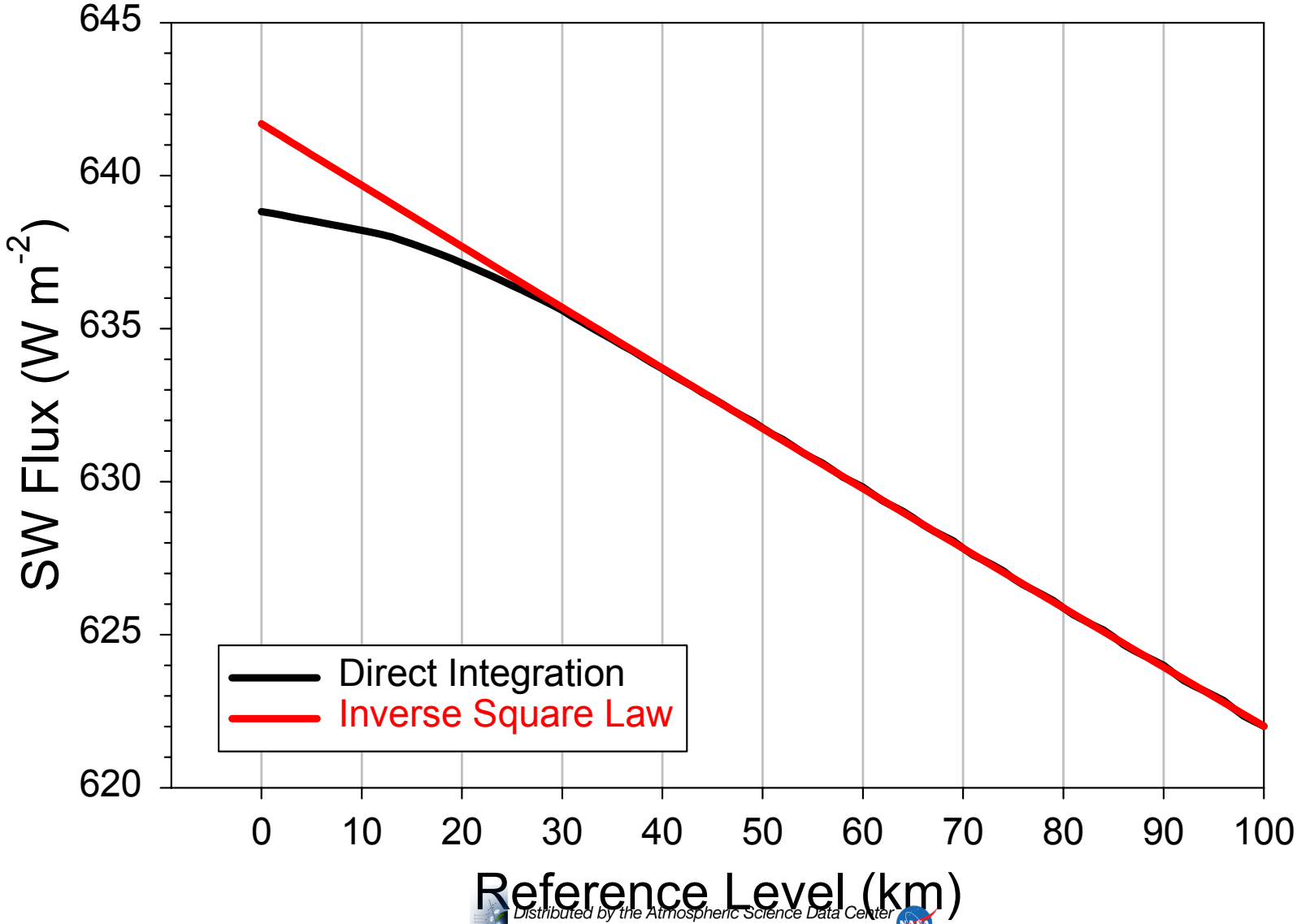
LW Flux vs Reference Level
(Thick Ci; τ=1000; Z_t=11 km; MODTRAN)



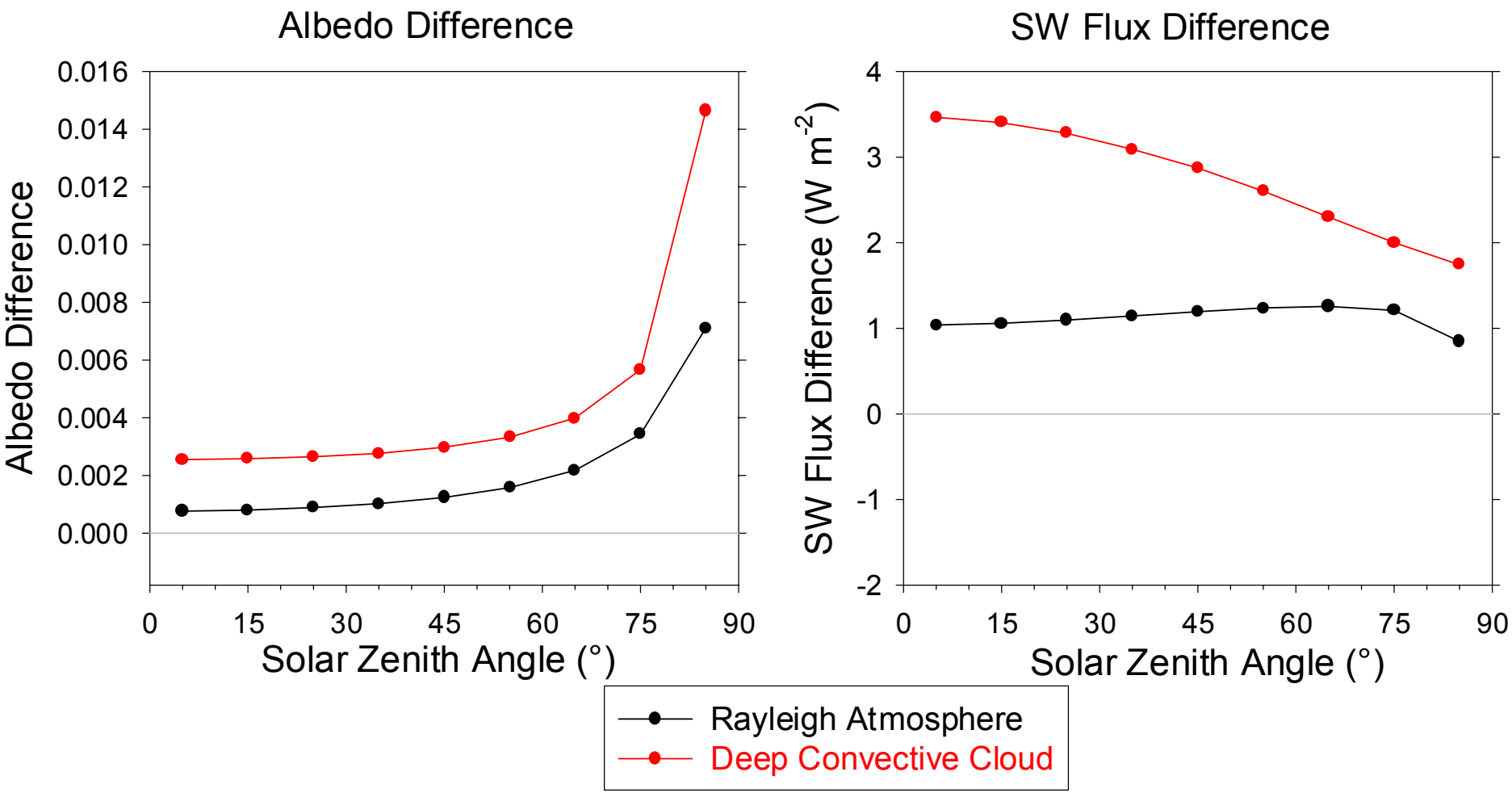
SW Flux vs Reference Level (Rayleigh Atm; θ_o=45; MODTRAN)



SW Flux vs Reference Level
(Thick Ci; τ=1000; Z_t=11 km; θ_o=45; MODTRAN)



Albedo & SW Flux Contribution From Off-Earth Views (MODTRAN; Surface Reference Level)



Edition2B ADMs

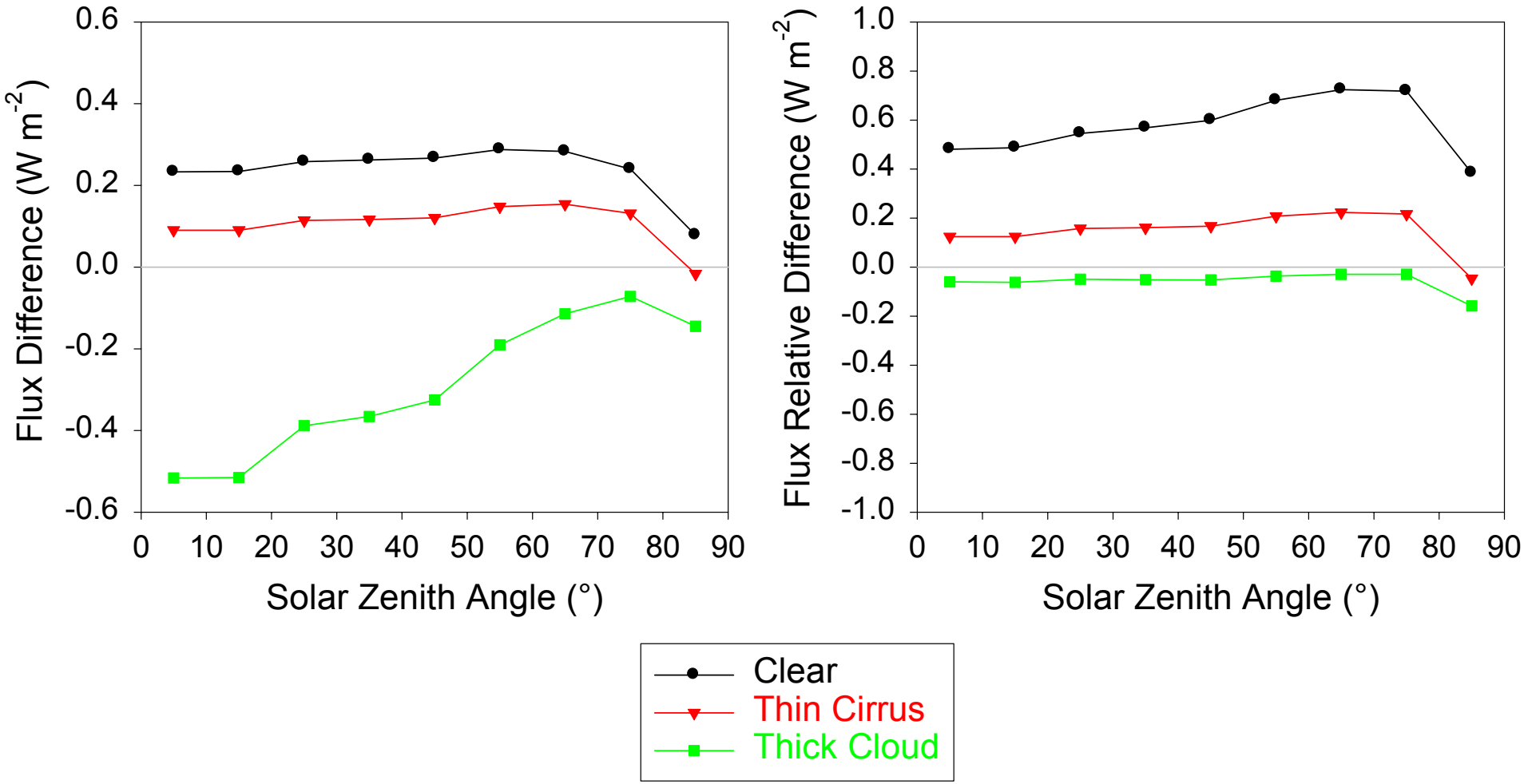
- Evaluate ADM TOA flux by direct integration at 100-km reference level. Use MODTRAN radiances to fill-in radiances at off-earth views.

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

$$R_j^{SW}(\theta_{oi},\theta_k,\phi_l;\ \mathrm{h_{sfc}}) = \frac{\pi \bar{I}_j^{SW}(\theta_{oi},\theta_k,\phi_l;\ \mathrm{h_{sfc}})}{F_j^{SW}(\theta_{oi};\mathrm{h_{100}})}\left(\frac{r_e}{r_e + h_{100}}\right)^2$$

$$R_j^{LW}(\theta_k;\ \mathrm{h_{sfc}}) = \frac{\pi \bar{I}_j^{LW}(\theta_k;\ \mathrm{h_{sfc}})}{F_j^{LW}(h_{100})}\left(\frac{r_e}{r_e + h_{100}}\right)^2$$

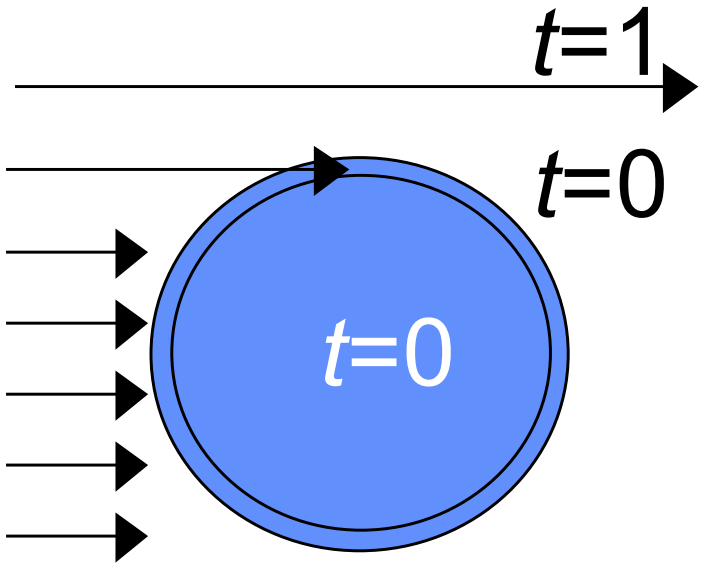
TOA SW Flux Error by Using MODTRAN to Fill-In Off-Earth Views (Compared with ES8)



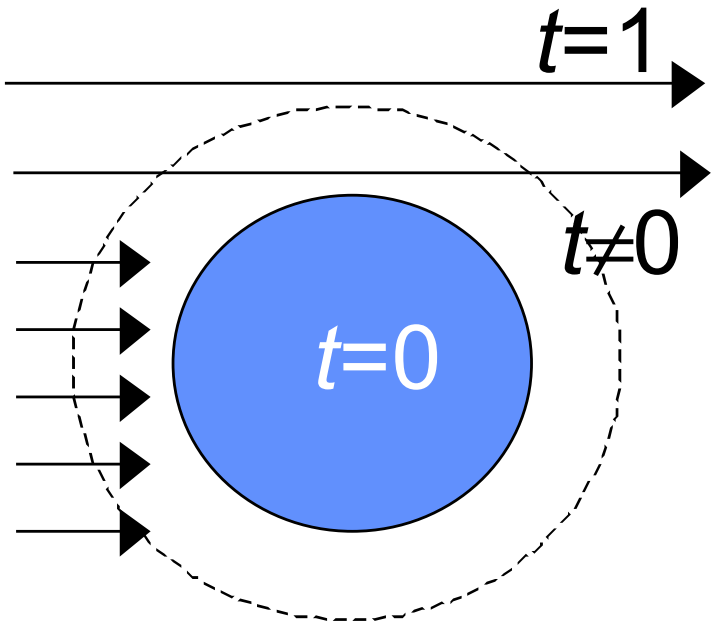
TOA Flux Reference Level

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

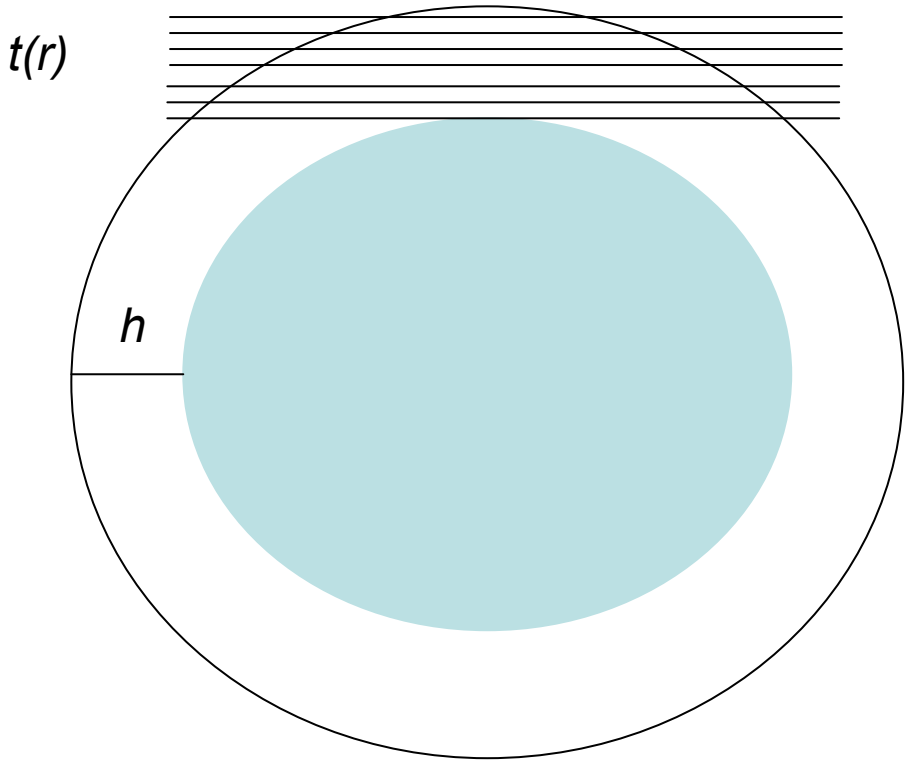
$$\frac{S_o}{4}(1-\alpha) = F^a$$



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



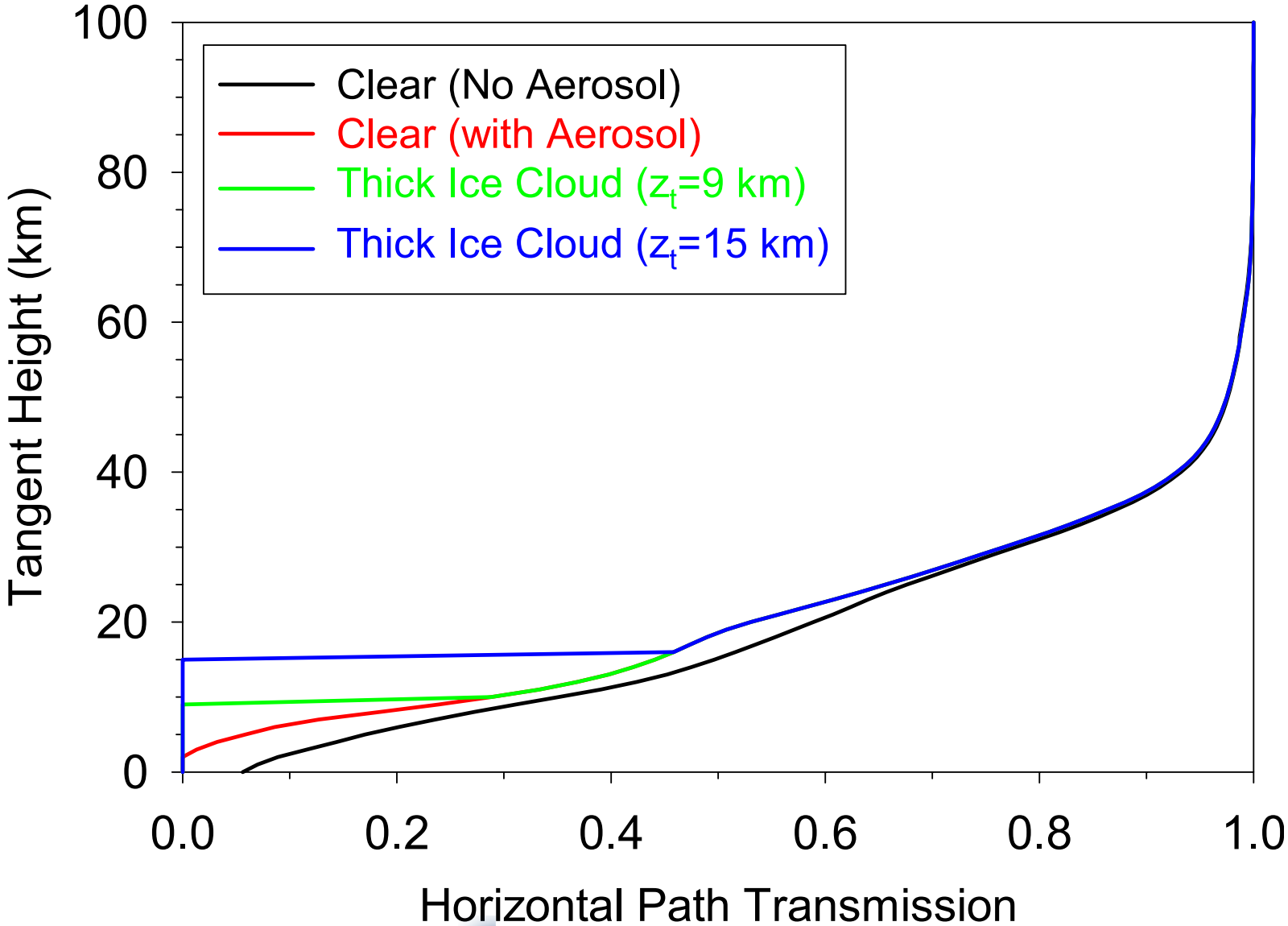
Effective Transmission t_h



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

$$t_h = \frac{\int_0^{r_e+h} 2\pi r t(r) dr}{\pi (r_e + h)^2}$$

MODTRAN Horizontal Path Transmission *t(r)*



t_h for Sample MODTRAN Cases (h=100 km)

Case	Profiles	Aerosol	Cloud	t_h ($\times 10^{-2}$)
1	Tropical	No	No	2.503
2	Tropical	Yes	No	2.446
3	Tropical	Yes	Thick Ice; z_t=9 km	2.423
4	Tropical	Yes	Thick Ice; z_t=15 km	2.354
5	Subarctic Winter	No	No	2.546
6	No Atmosphere			3.067

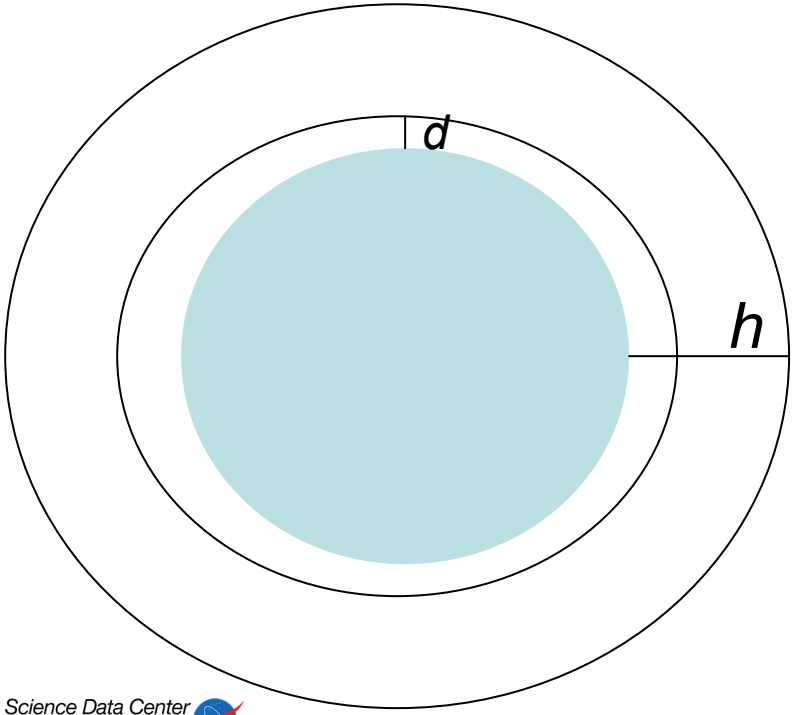
At an arbitrary reference level x:

$$\frac{S_o}{4} - \left(\frac{r_e + h}{r_e + x}\right)^2 (F_h^r + F_h^a) - t_x \frac{S_o}{4} = 0$$

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

At x=d, t_x=0 :

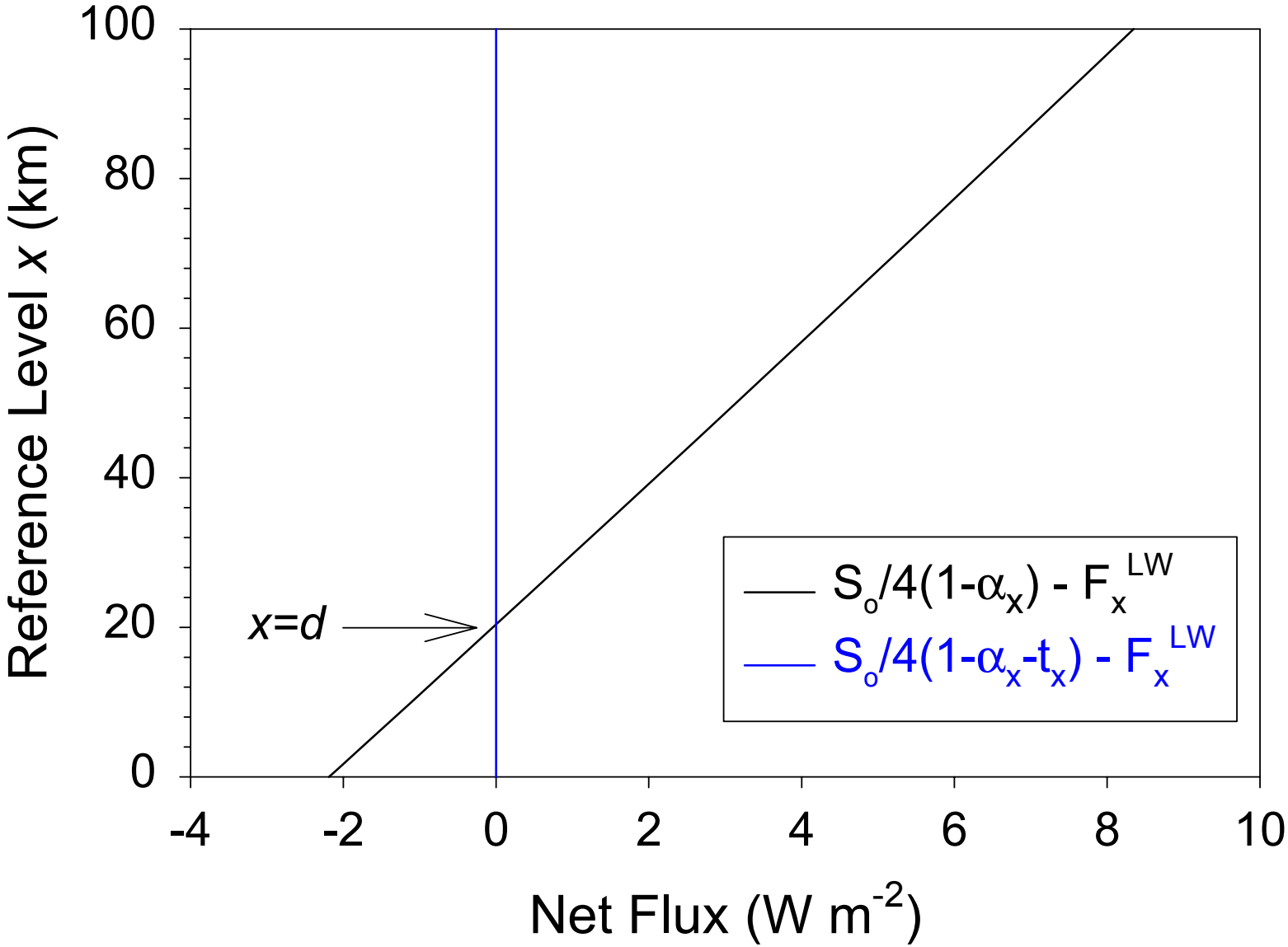
$$d = (r_e + h)\sqrt{1 - t_h} - r_e$$



t_h and d for Sample MODTRAN Cases (h=100 km)

Case	Profiles	Aerosol	Cloud	t_h ($\times 10^{-2}$)	d (km)
1	Tropical	No	No	2.503	18.5
2	Tropical	Yes	No	2.446	20.5
3	Tropical	Yes	Thick Ice; z_t=9 km	2.423	21.1
4	Tropical	Yes	Thick Ice; z_t=15 km	2.354	23.4
5	Subarctic Winter	No	No	2.546	17.1
6	No Atmosphere			3.067	0

Net Flux vs Reference Level



Instantaneous TOA Flux Estimate

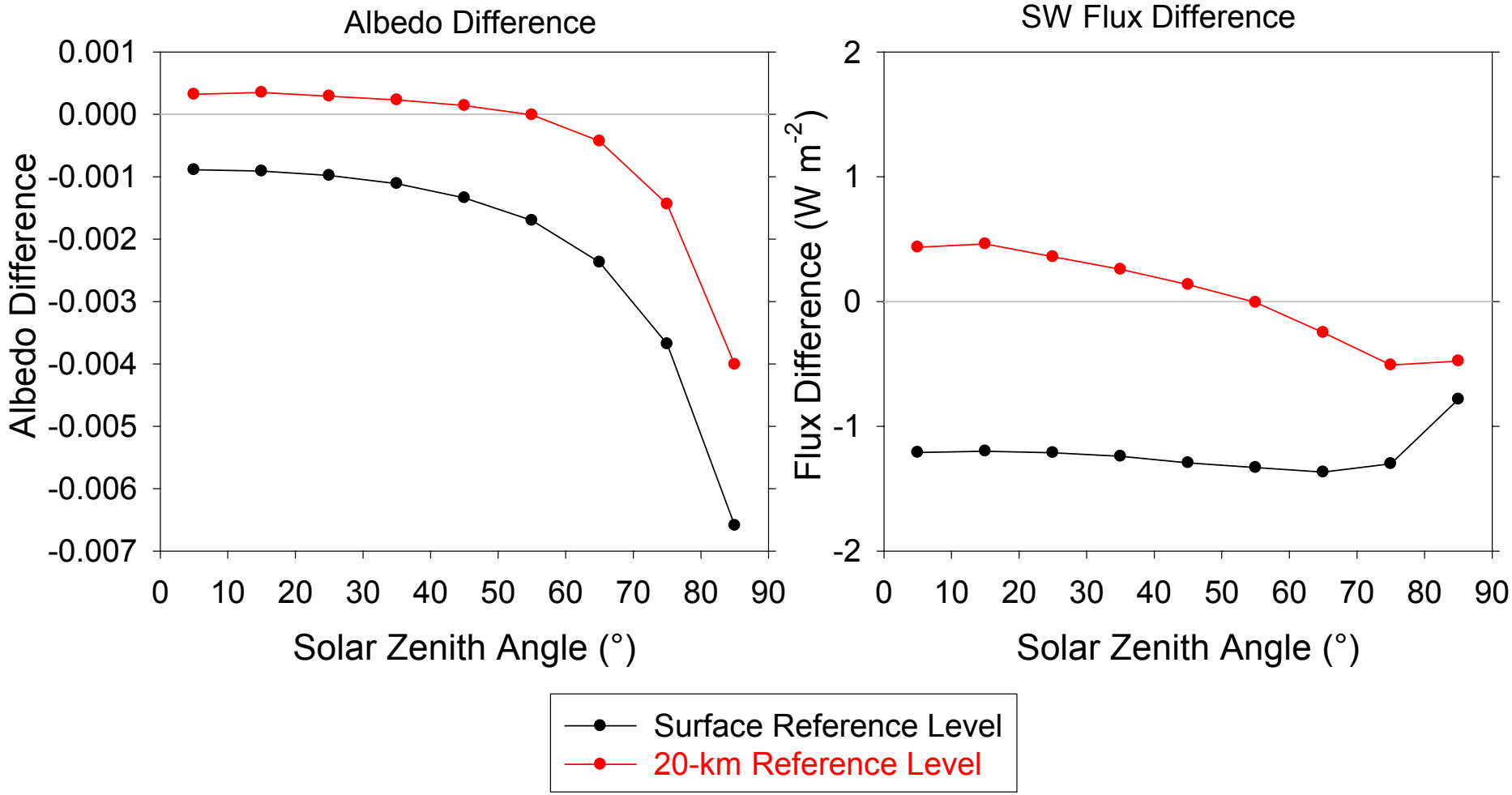
Instantaneous flux at 20-km reference level:

$$\hat{F}(\Omega; h_{20}) = \hat{F}(\Omega; h_{sfc})\left(\frac{r_e}{r_e + h_{20}}\right)^2$$

where,

$$\hat{F}(\Omega; \mathrm{h}_{\mathrm{sfc}}) = \frac{\pi I(\Omega;\ \mathrm{h}_{\mathrm{sfc}})}{R_j(\Omega;\ \mathrm{h}_{\mathrm{sfc}})}$$

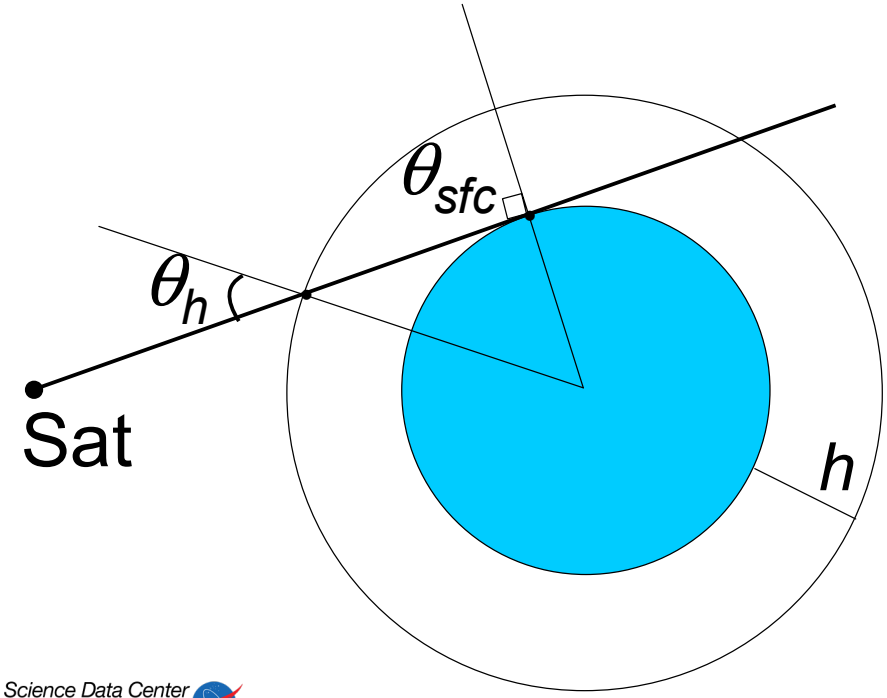
Tropical Average Albedo & SW Flux Difference (SSF Ed2A - SSF Ed2B)



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