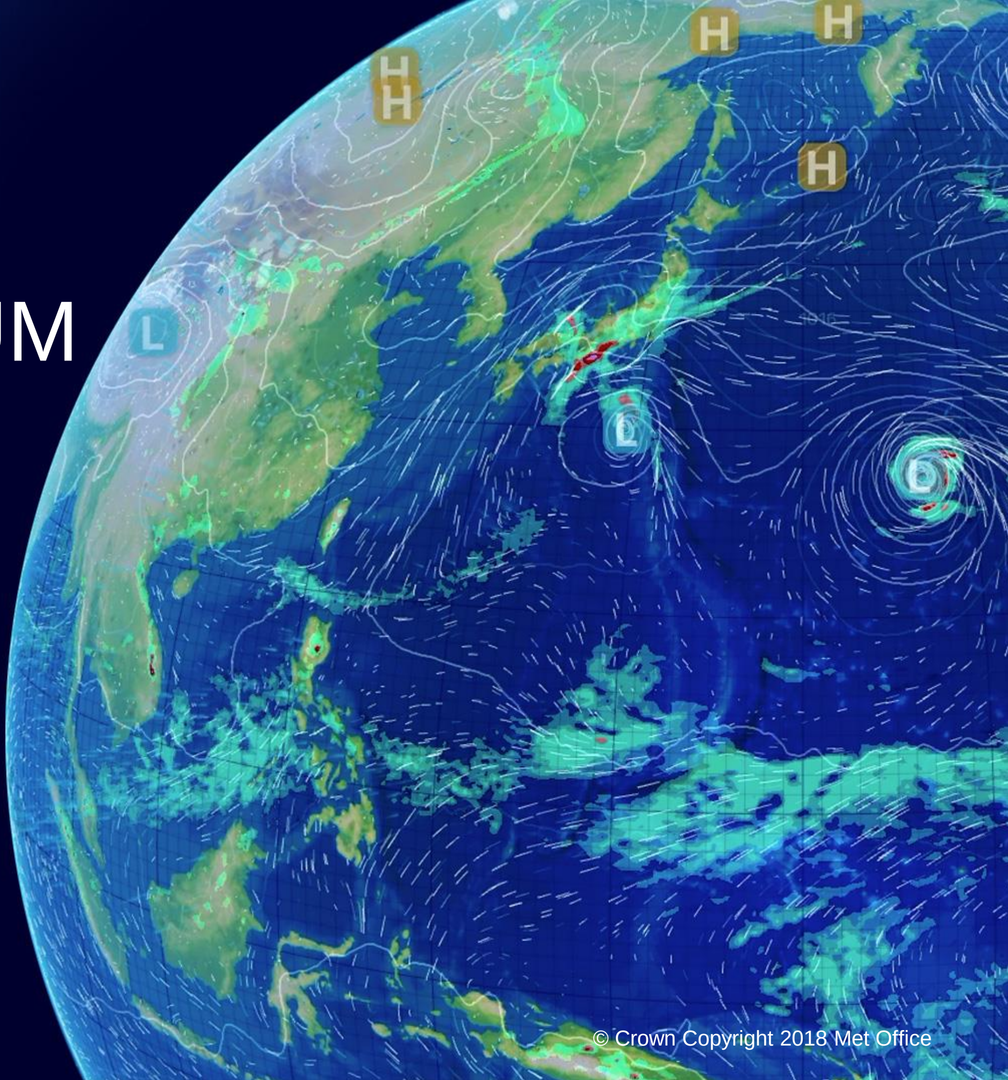
MLT radiation scheme developments in the UM

James Manners 14/06/18



- Socrates: A flexible radiative transfer configuration
- Treatment of spherical geometry for direct solar radiation
- Planned extension of Socrates for FUV/EUV photolysis
- Non-LTE: Initial use of Fomichev near-IR and 15μm schemes
- Future developments

Socrates: Suite Of Community RAdiative Transfer codes based on Edwards & Slingo 1996

Includes:

- Two-stream flux code (used to calculate atmospheric heating rates in the UM)
- Spherical harmonics radiance code
- Code to generate correlated-*k* coefficients
- Code to generate optical properties for Mie scatterers

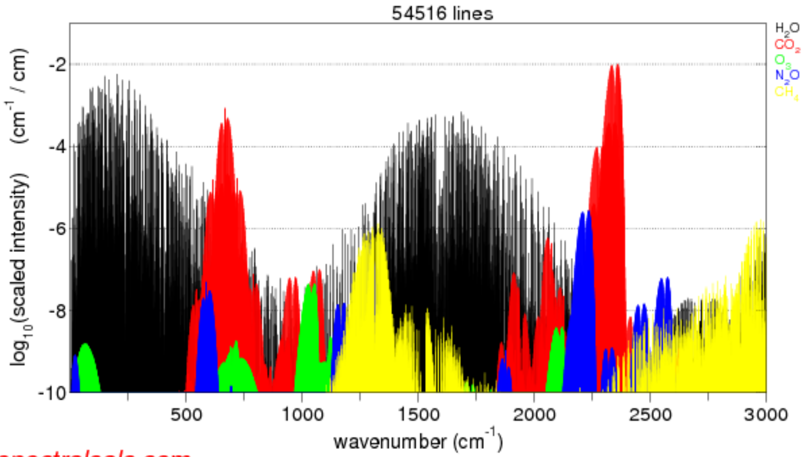
Flexible configuration: spectral files

Spectral bands: high / low resolution

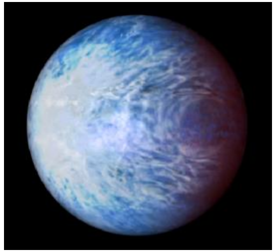
Gas *k*-terms

Aerosol / cloud optical properties

Solar spectrum (including time variation) etc.



spectralcalc.com



Hot Jupiters

Mars

Many configurations can be run

HadCM3

HadGEM1

HadGEM2

GA3

GA7

300 band LW / 260 band SW

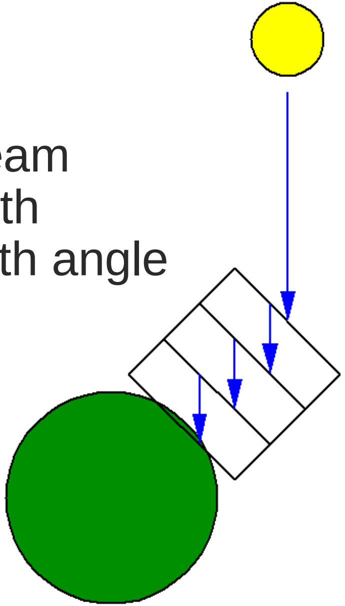
Aim to use the same two-stream solver throughout the atmosphere for:

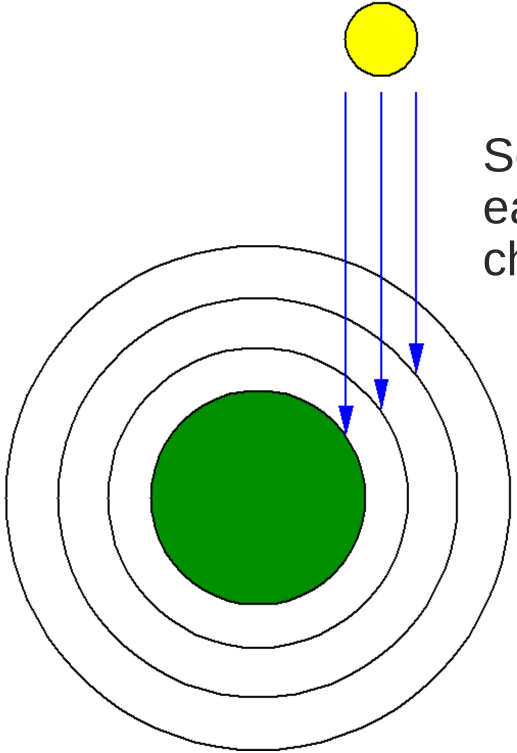
- Direct radiative heating
- Actinic flux for photolysis
- Non-LTE source functions

Spherical geometry

Plane-parallel vs. spherical geometry

One direct beam calculation with constant zenith angle

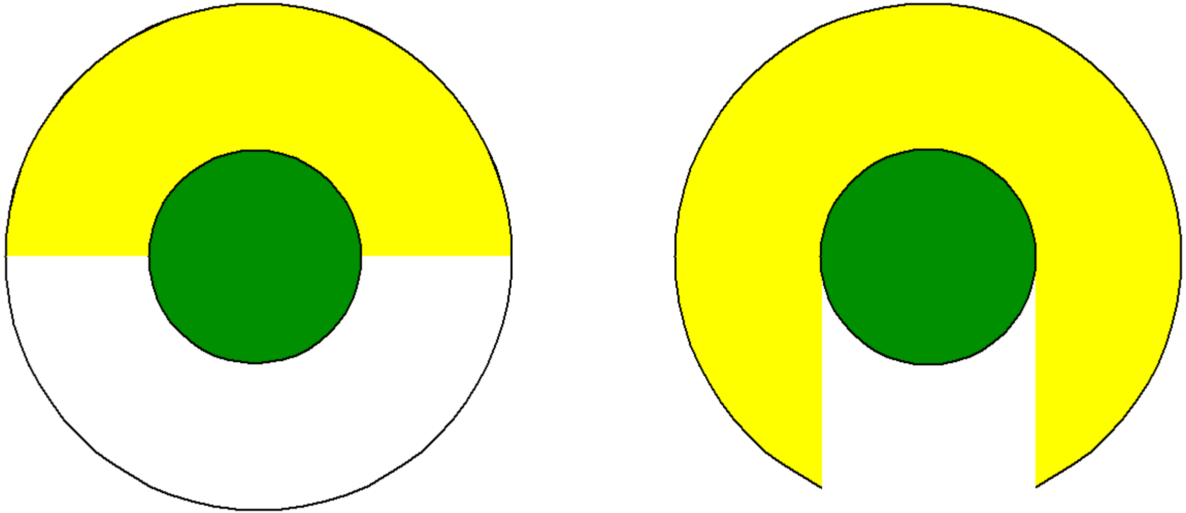




Separate calculation for each layer with changing zenith angle

Plane-parallel vs. spherical geometry

Stratopause (altitude ~ 50km) should be lit ~800km into the “nightside” (an extra hour’s daylight on the equator).



Spherical geometry
for the direct solar beam.

Plane-parallel geometry for the scattered (diffuse) fluxes.

(The pseudo-spherical approximation.)

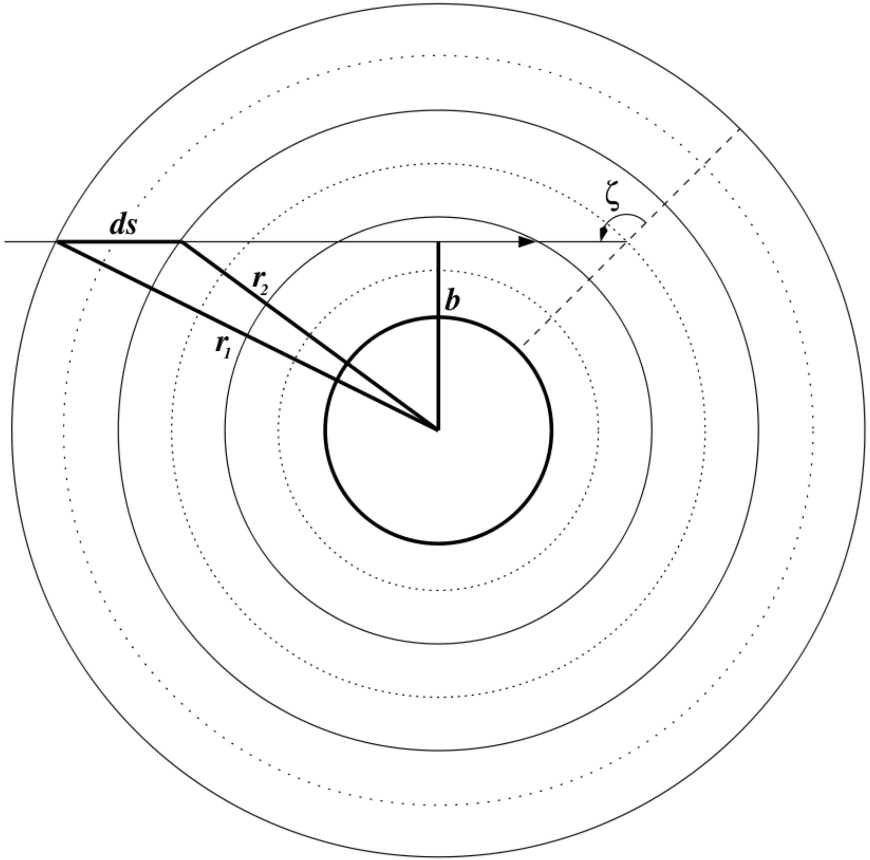
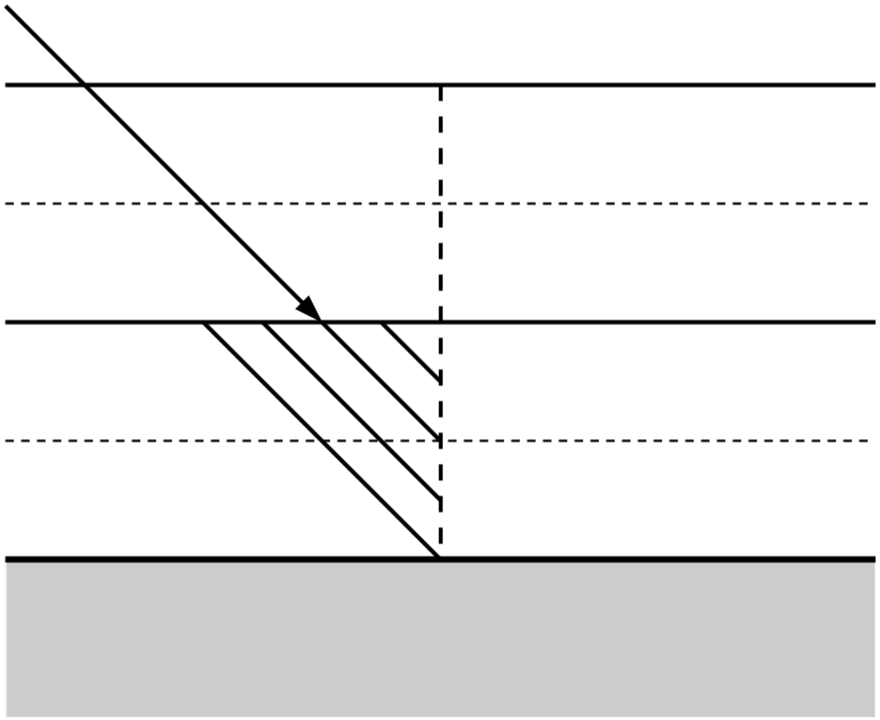
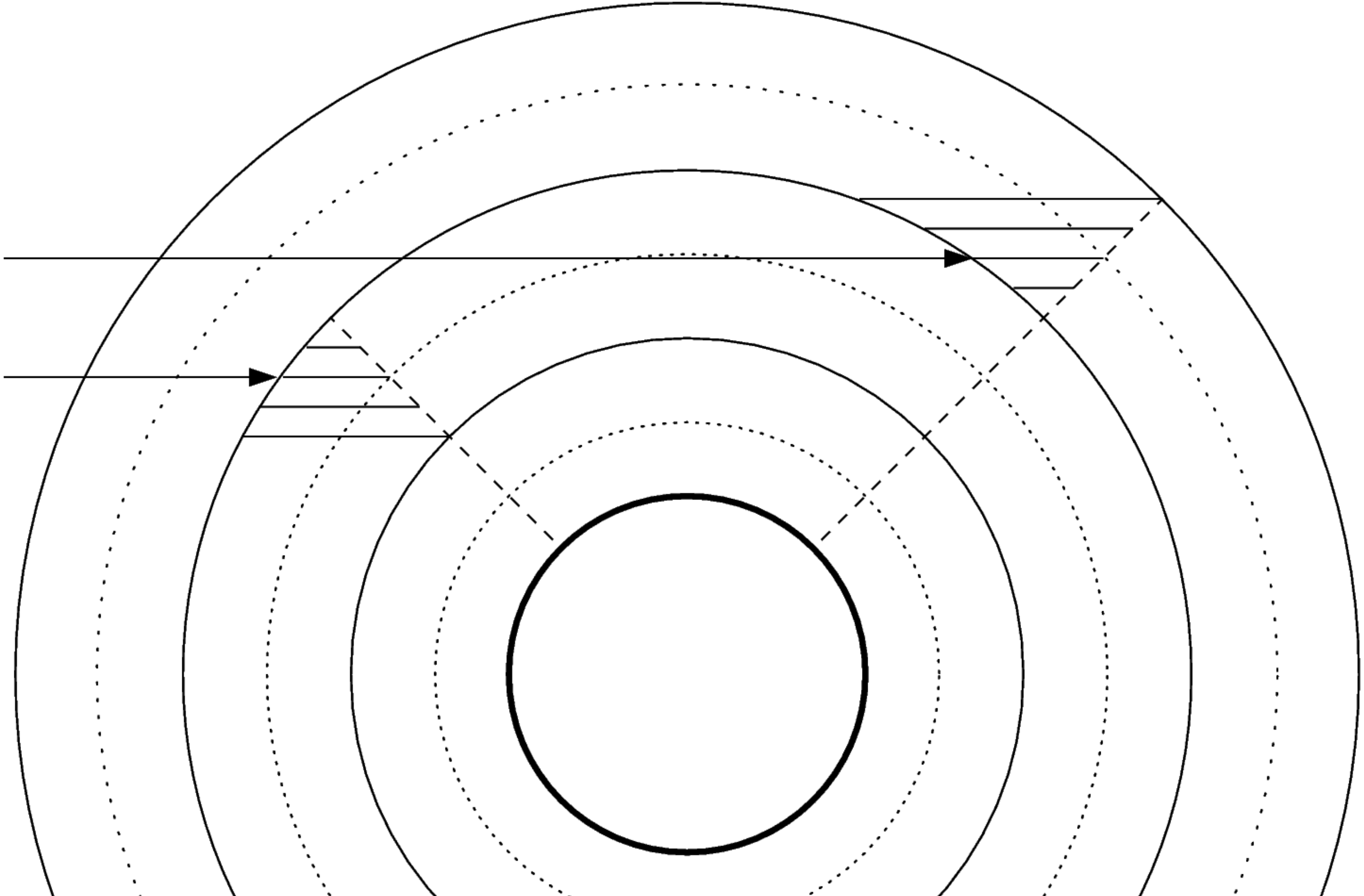
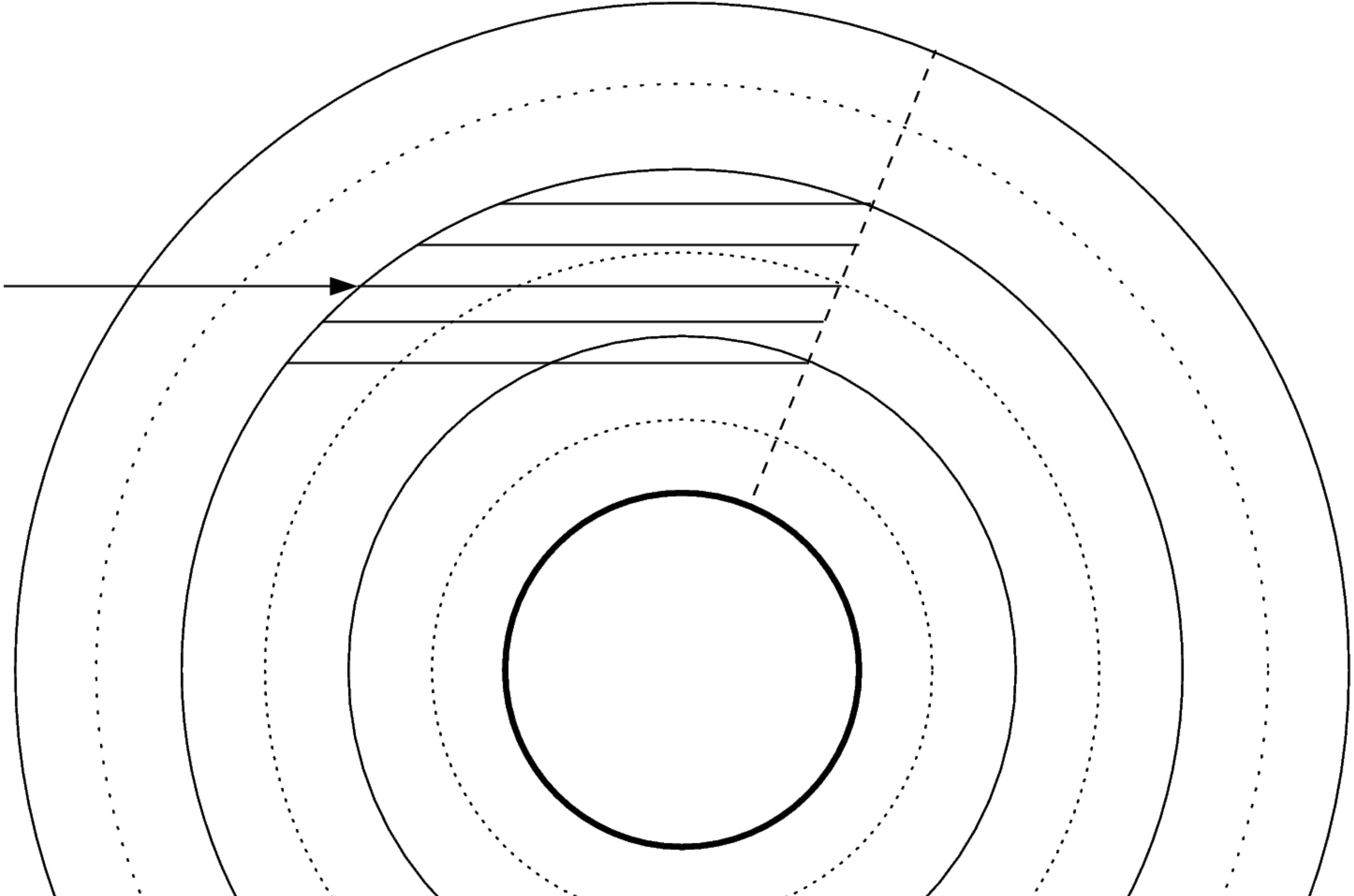
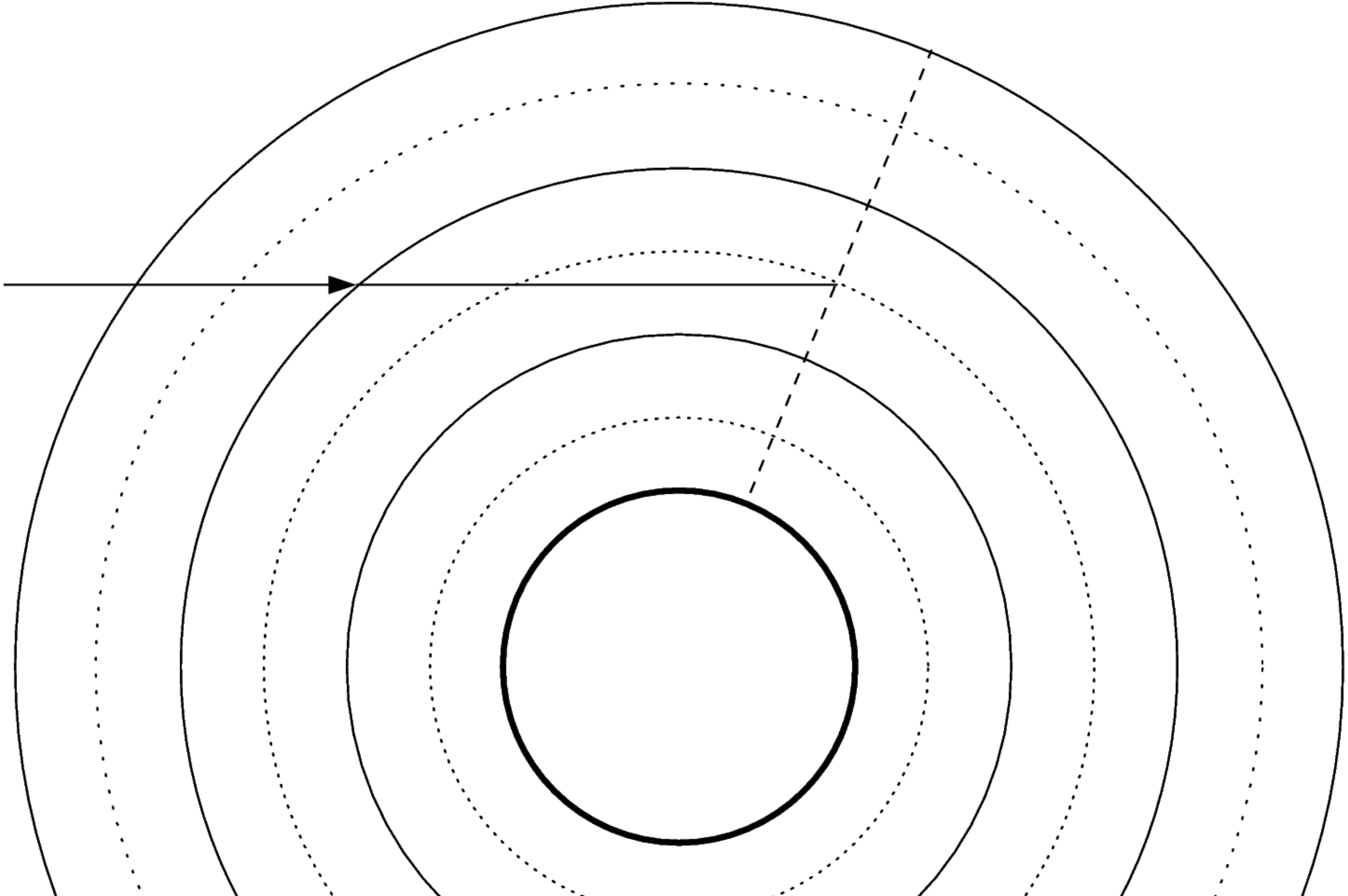


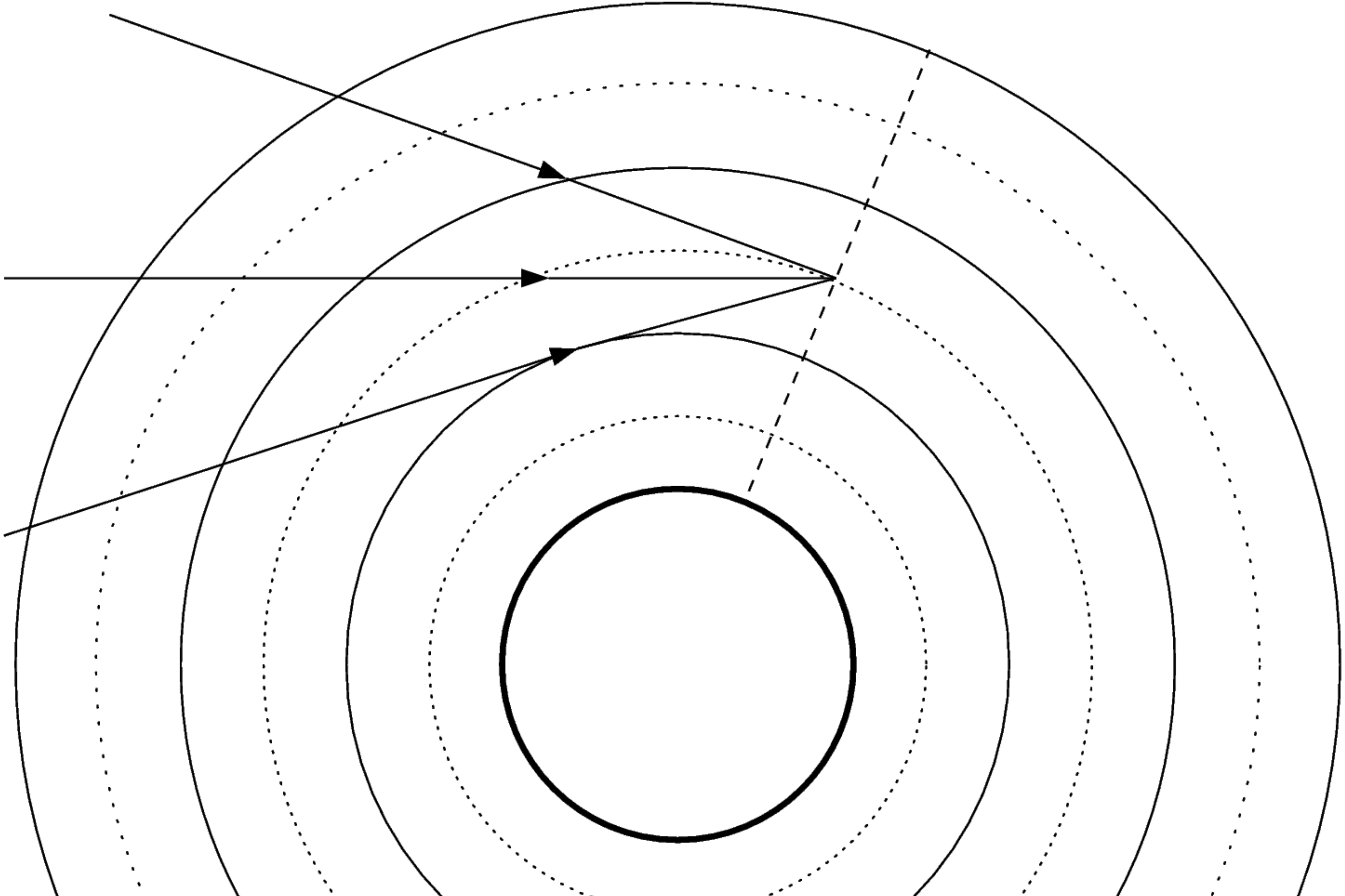
Figure 1.2: Spherical shell geometry. Layer centres are denoted by dotted lines and layer edges by solid lines. Parameters are shown for the slant path to a particular layer for a model column located in the position of the dashed line. ζ denotes the local solar zenith angle (which may be greater than 90 degrees), b the impact parameter, and ds the path length element for the layer bounded by radii r_1 and r_2.

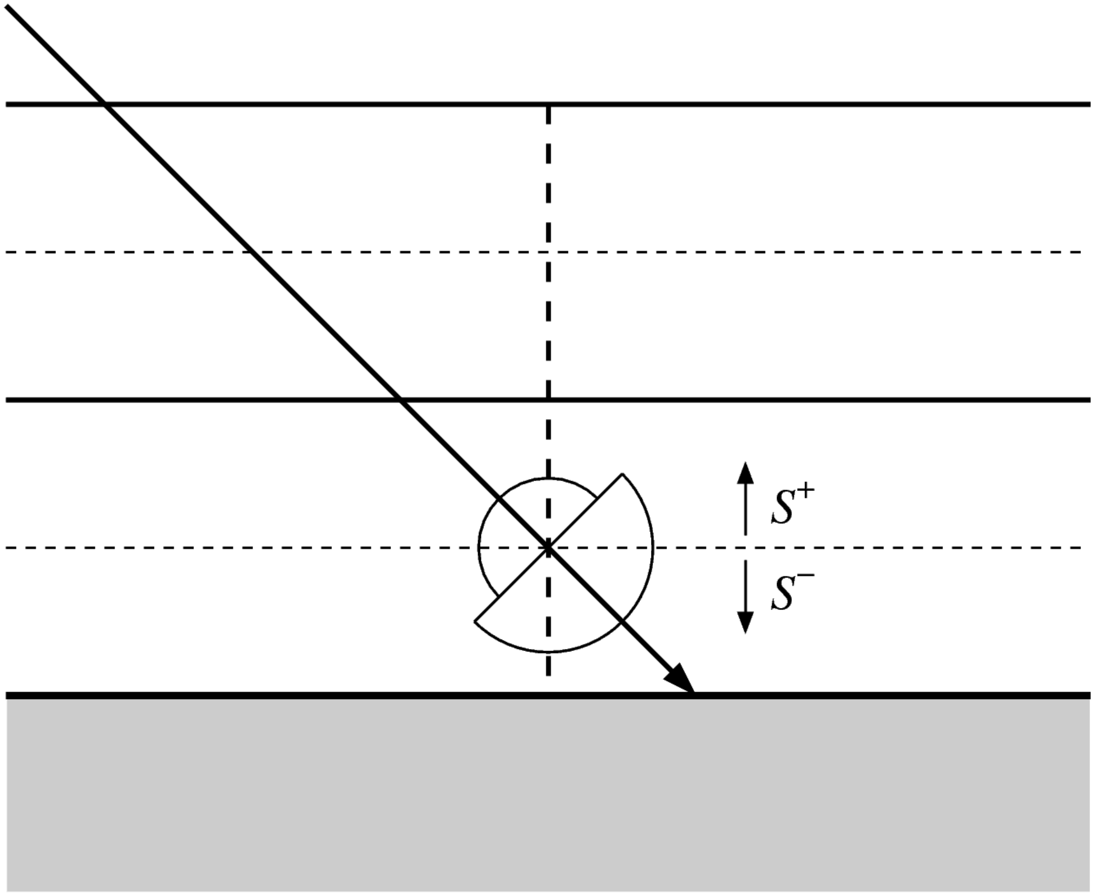








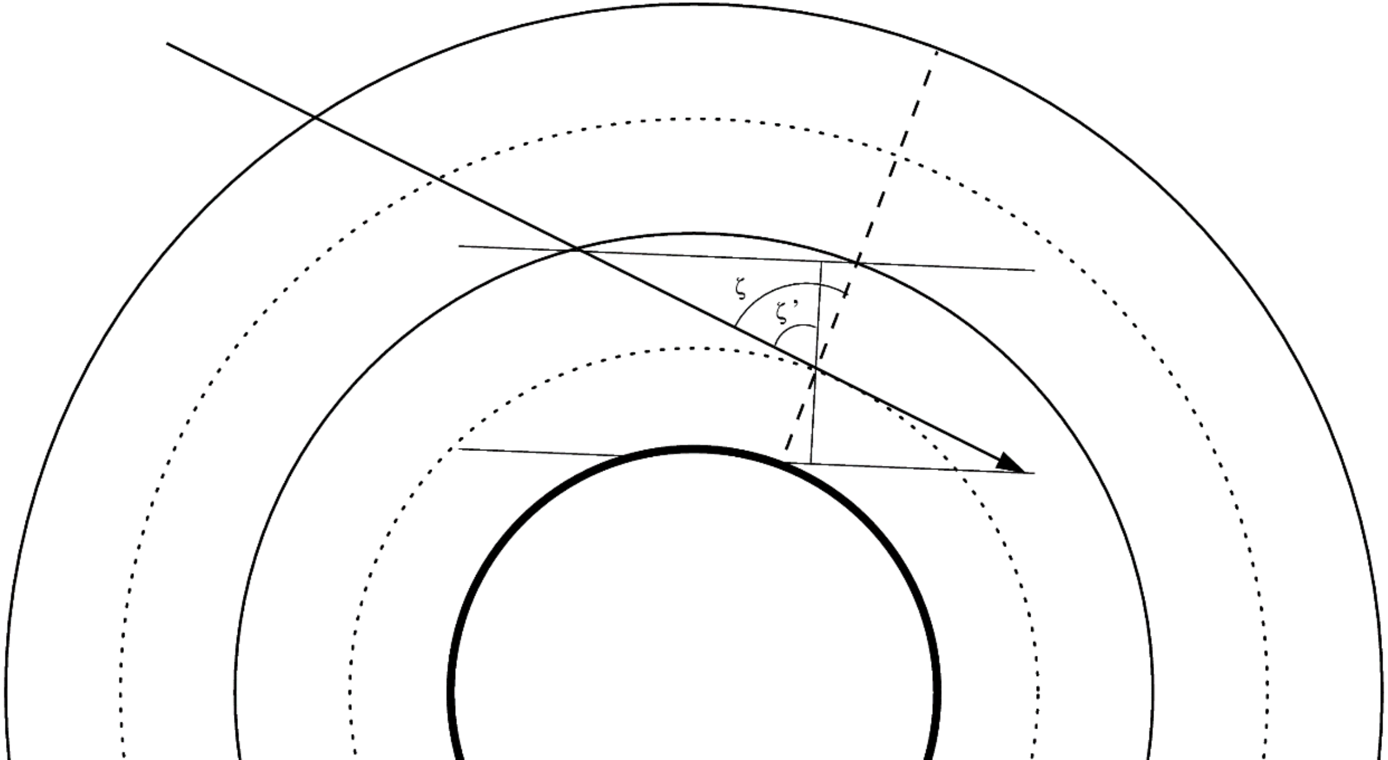


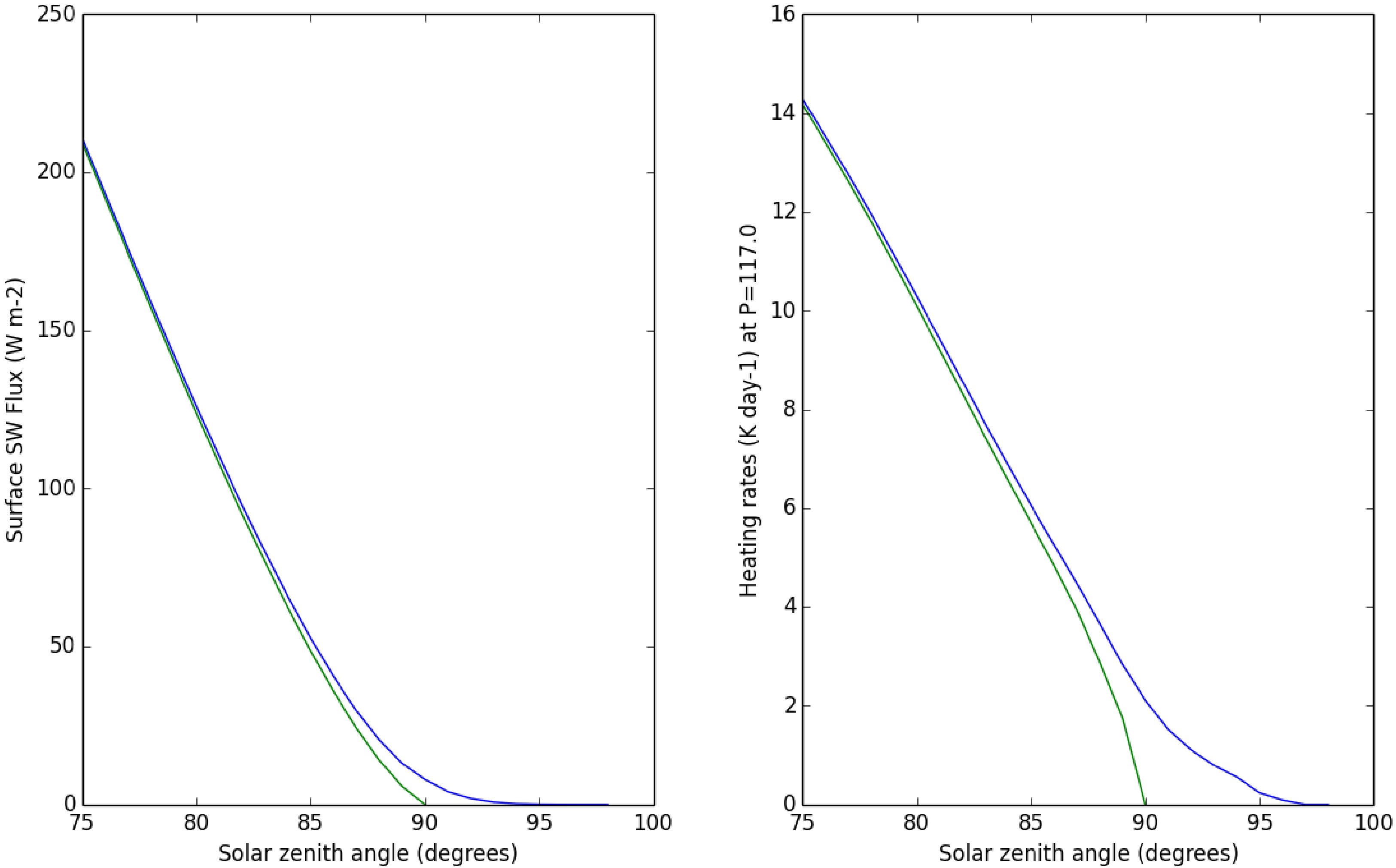


S^{+}
S^{-}

$$S_{up} = \frac{1}{2}[(1 + \cos\zeta \sec\zeta')S'^{+} + (1 - \cos\zeta \sec\zeta')S'^{-}]$$

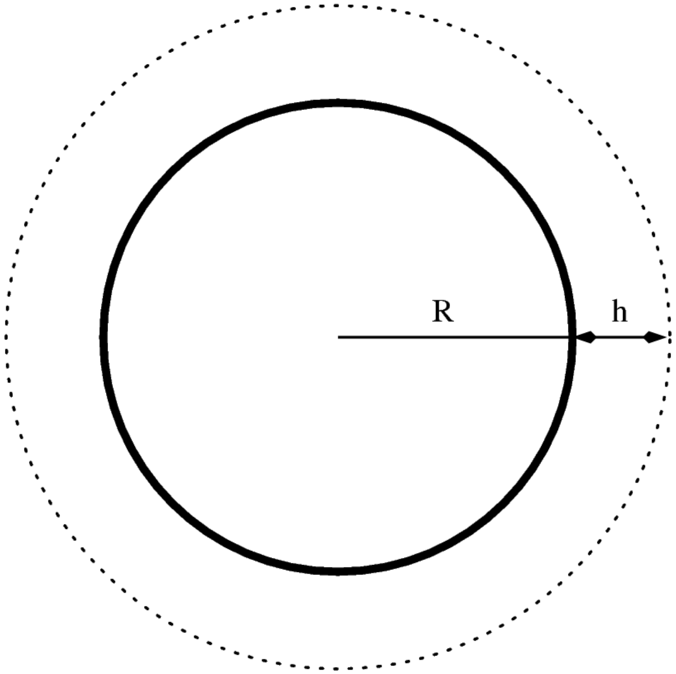
$$S_{down} = \frac{1}{2}[(1 + \cos\zeta \sec\zeta')S'^{-} + (1 - \cos\zeta \sec\zeta')S'^{+}]$$





Surface SW Flux (W m-2)
Solar zenith angle (degrees)
Heating rates (K day-1) at P=117.0
Solar zenith angle (degrees)

Energy balance



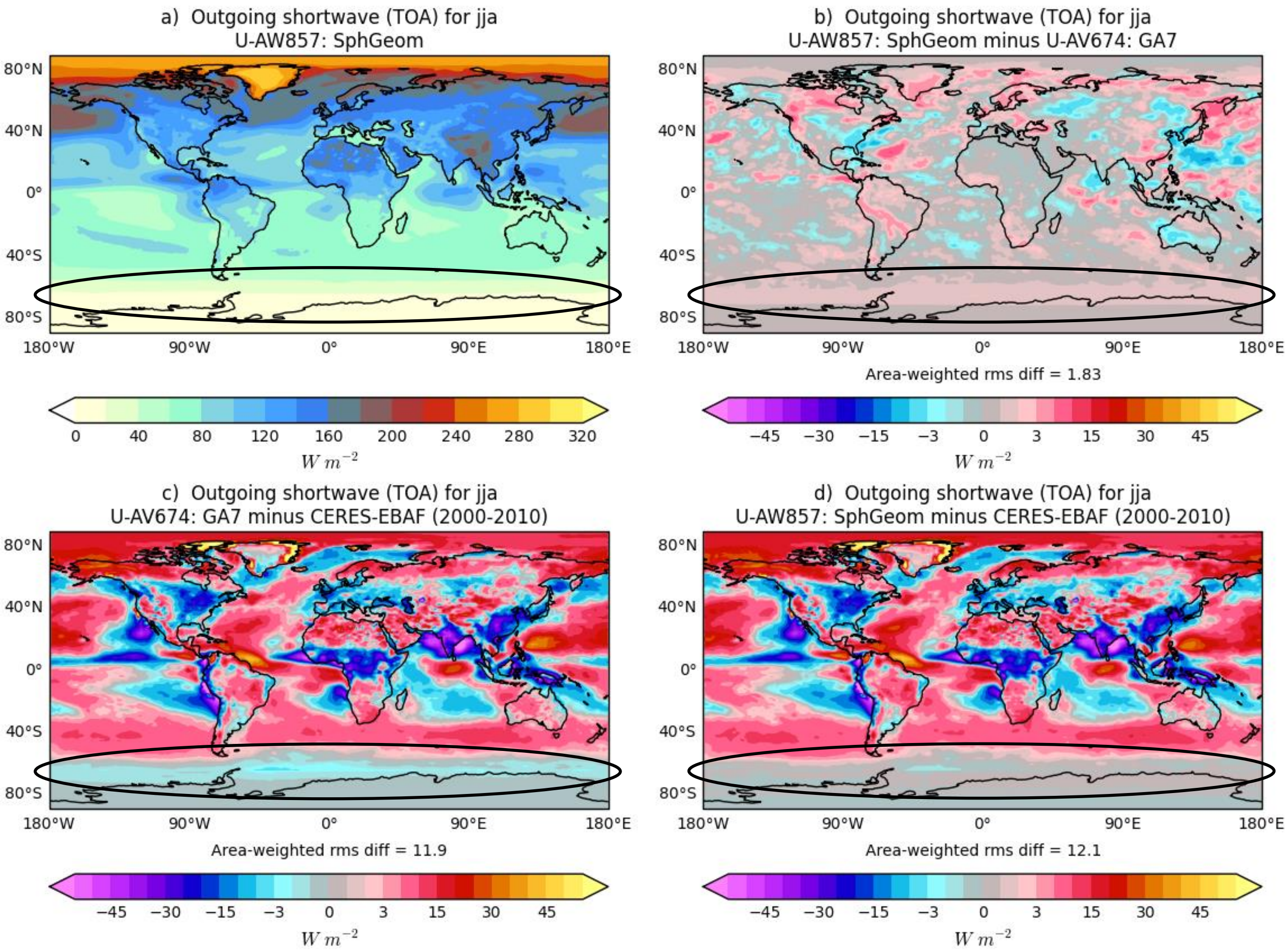
h ~ 1% of R

Area increase ~ 2%

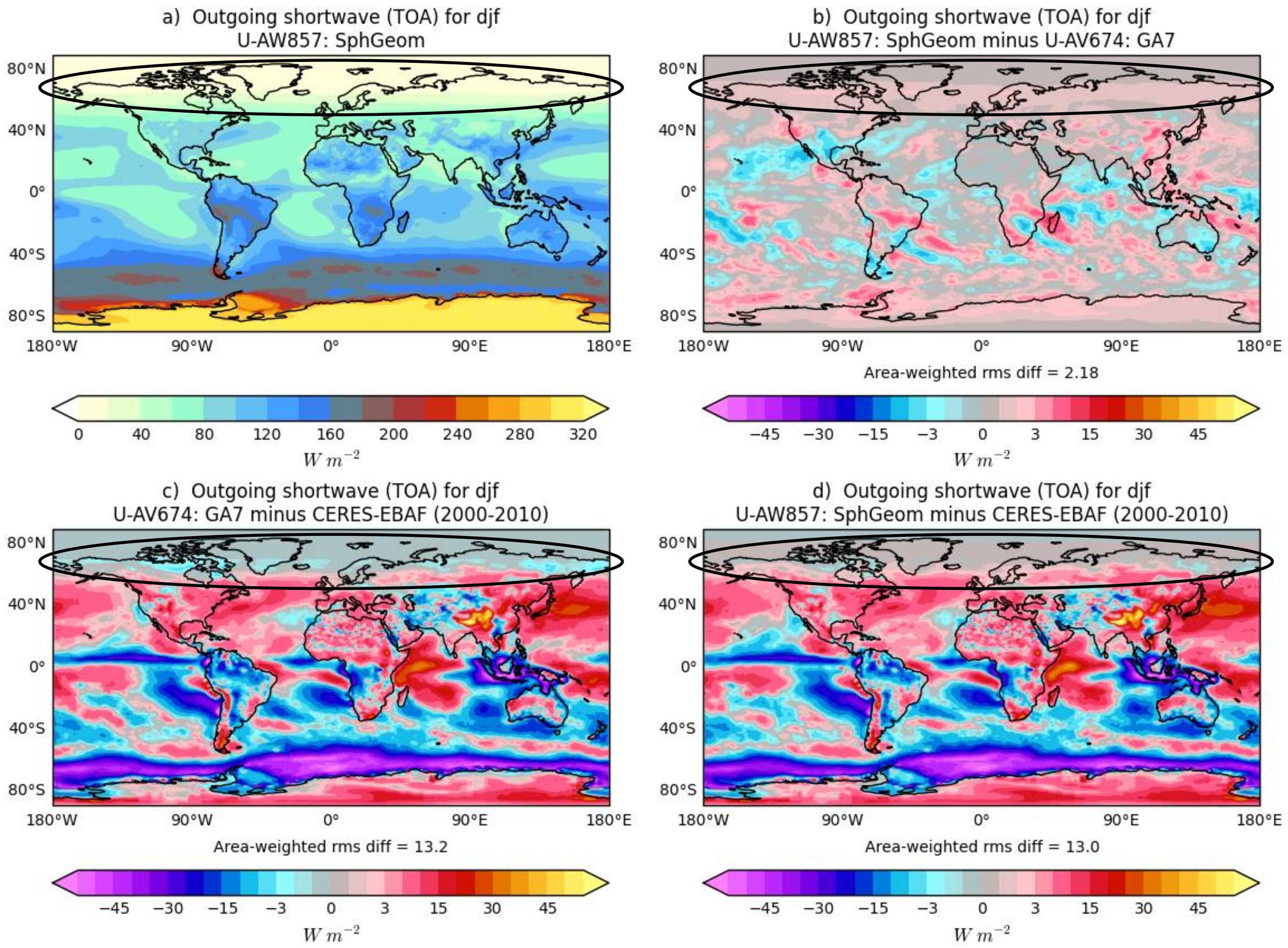
Surface area for emission should also increase (to be done)

20-year climate run

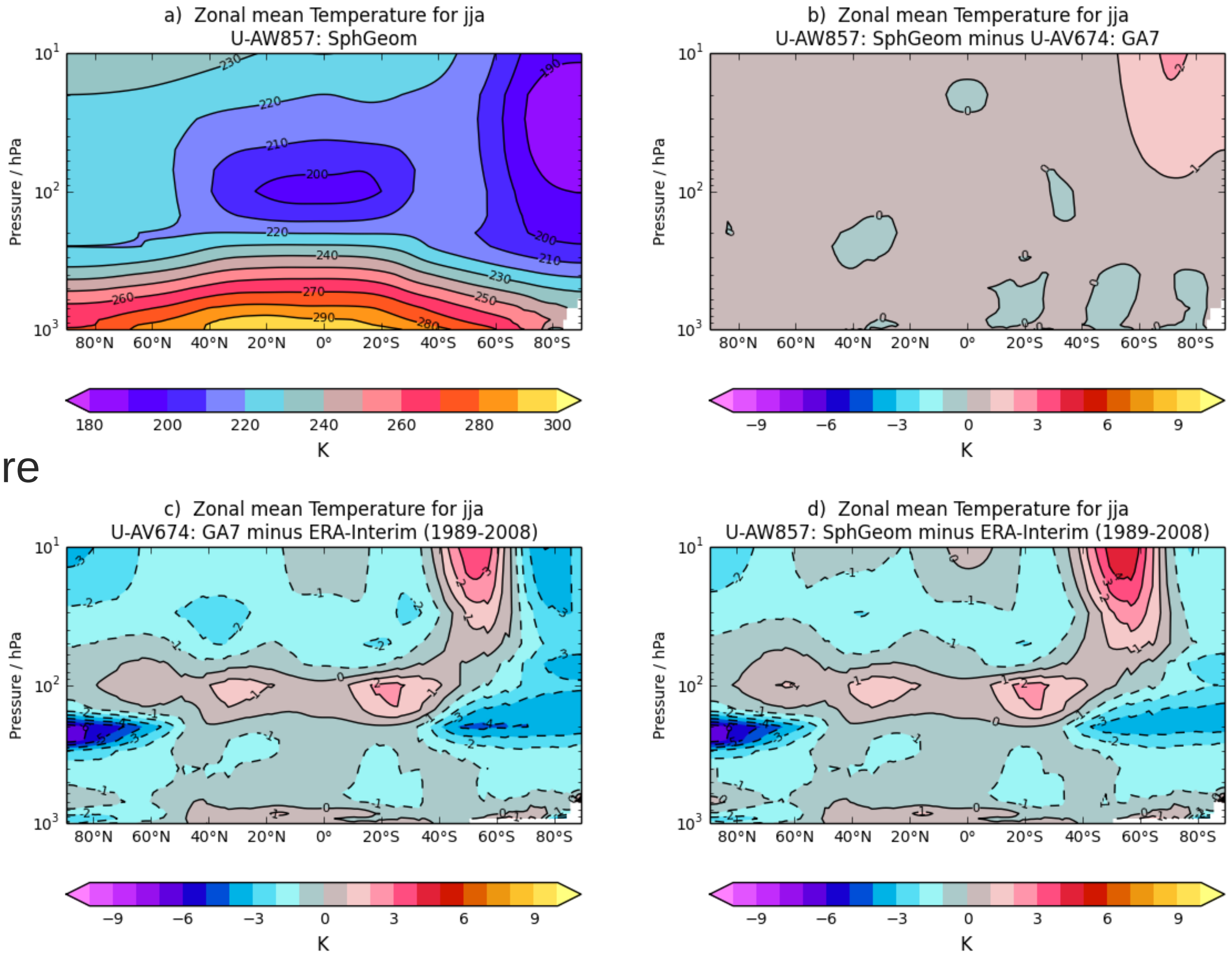
Outgoing SW at TOA
June-July-August



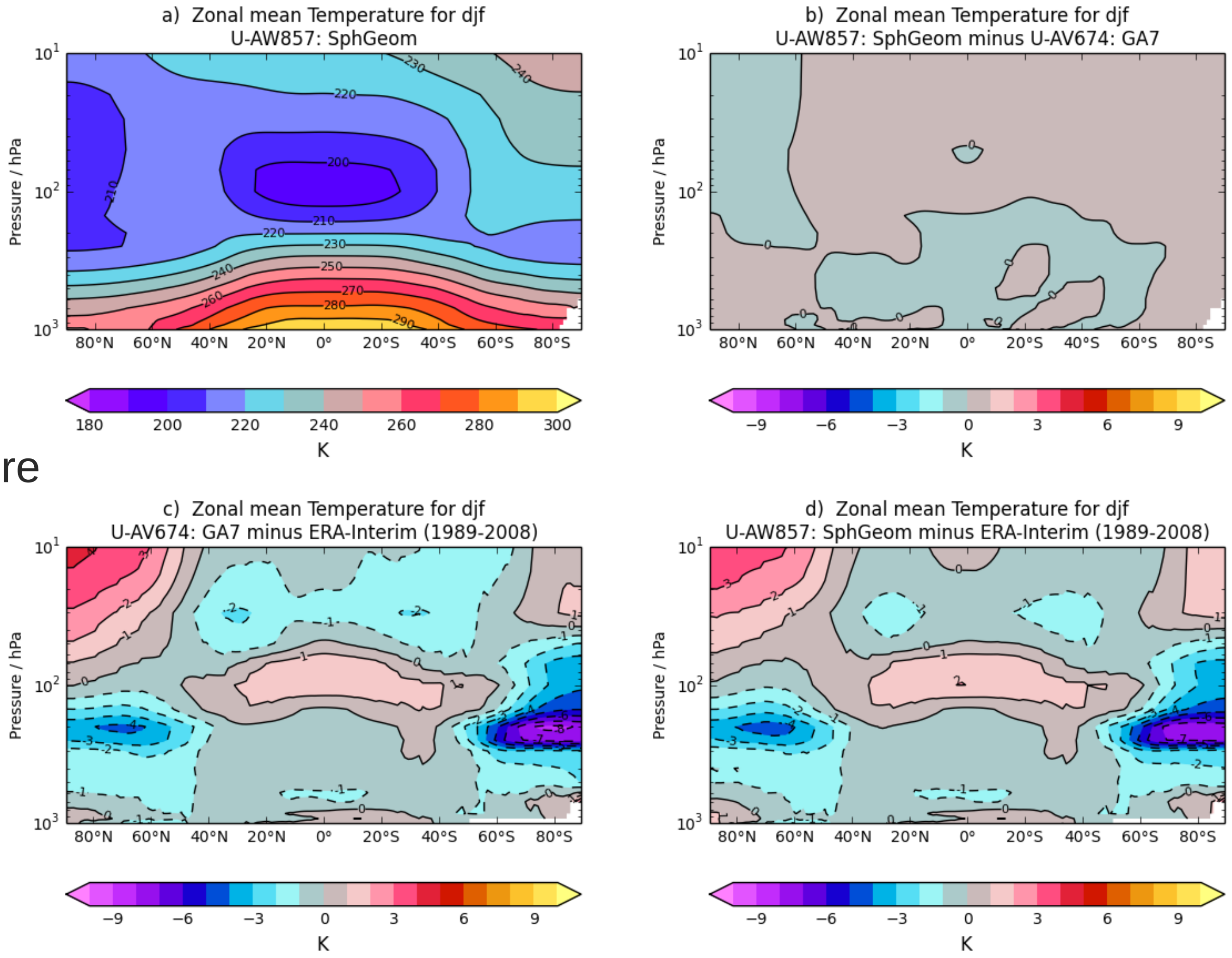
Outgoing SW at TOA
Dec-Jan-Feb



Zonal mean Temperature
June-July-August

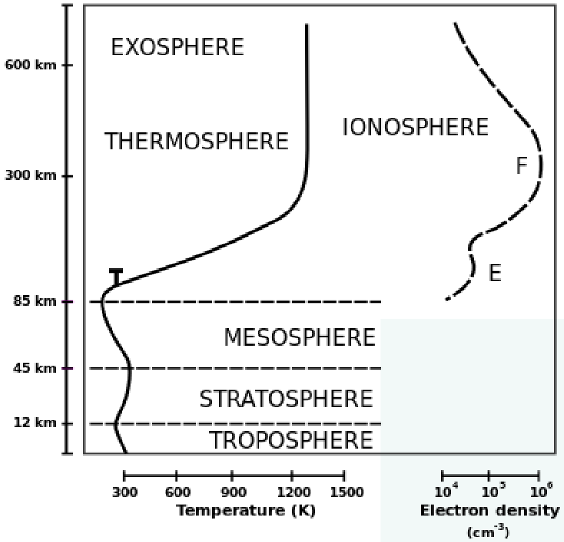


Zonal mean Temperature
Dec-Jan-Feb



Far & Extreme Ultra-Violet

Photolysis and heating in the upper atmosphere



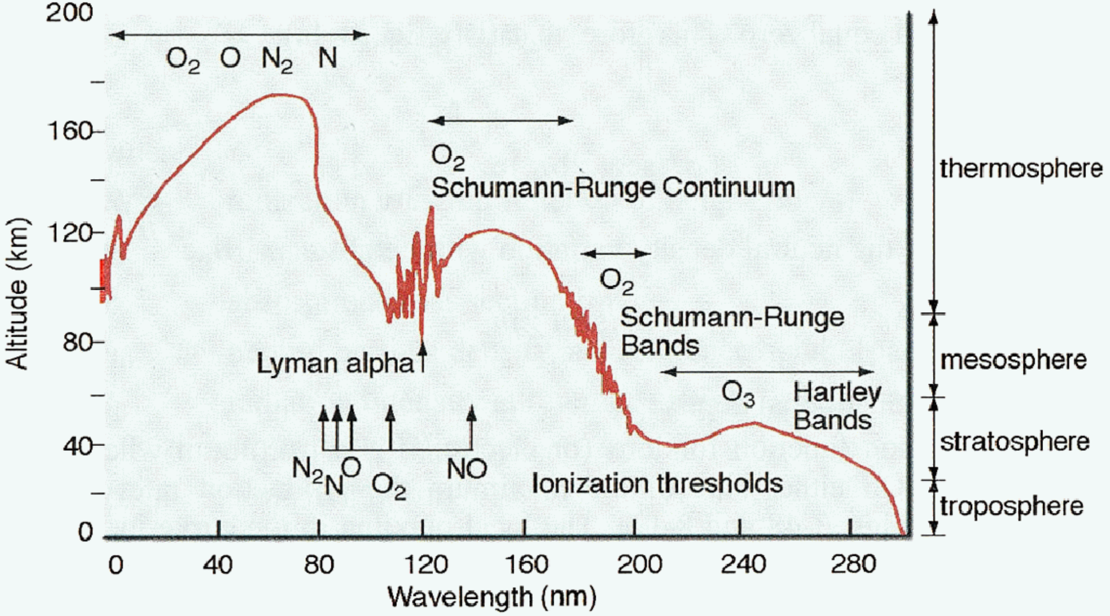
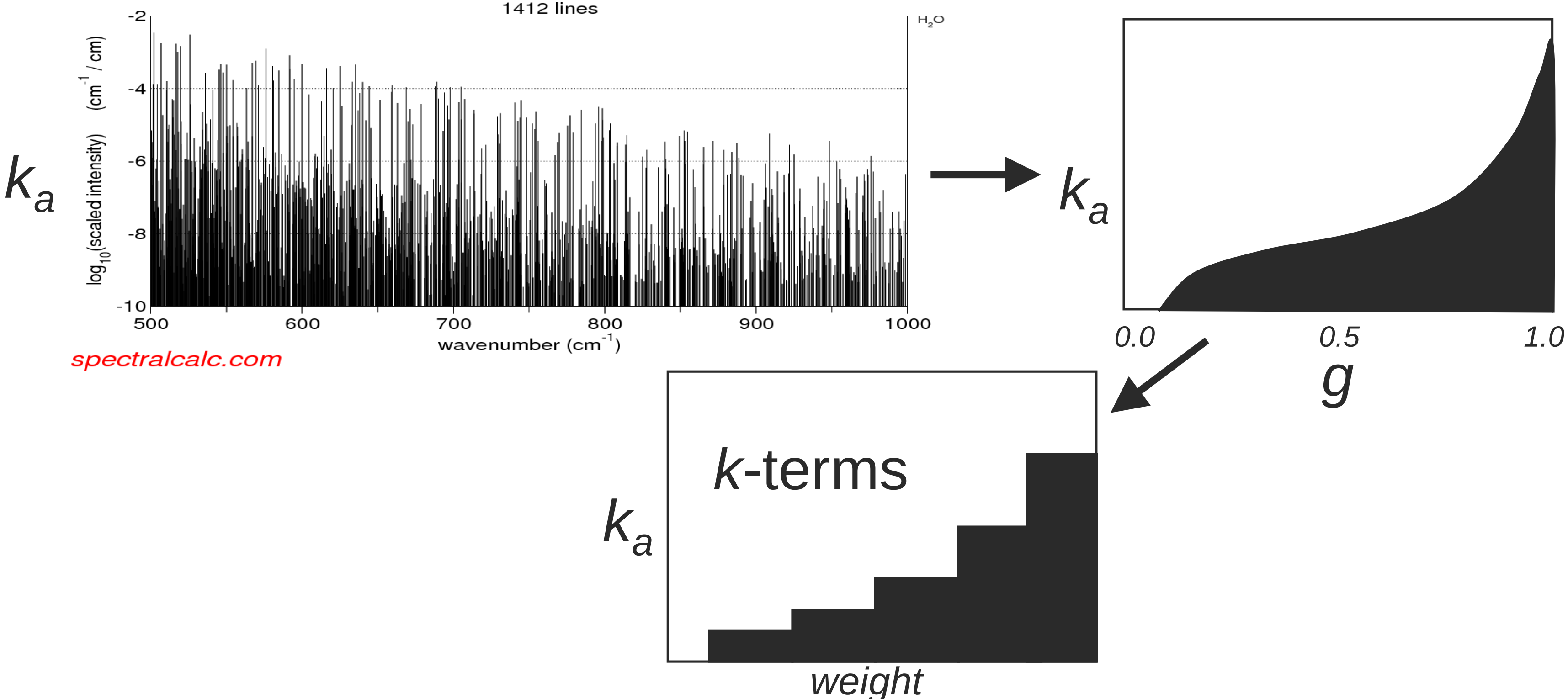


Fig. 5 Solar irradiance atmospheric penetration depth, unitary optical depth, for photons from hard X-rays to 300 nm (from Chamberlain 1978)

Plan to derive Socrates spectral files for the FUV/EUV (0.05 – 200nm):

- Cross-section data from JPL
- Construct reference file with resolution of 0.1 - 1nm
- Construct broadband file using correlated-*k* technique

k-distribution method to bin similar absorption coefficients within each broad band

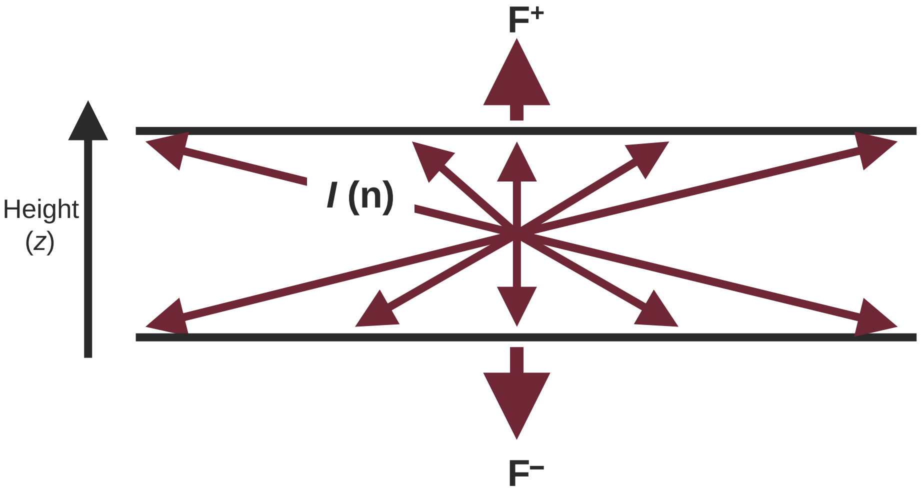


Broadband options:

- Moderate resolution (safe, slow):
    - Sufficient resolution to capture solar spectral variability
    - Sufficient resolution to provide wavelength dependent photolysis rates
    - Use same bands as Solomon and Qian (2005) in EUV to allow use of their photoelectron process rates

- Low/High resolution (speculative, fast):
    - Small number of bands defined so there is a single major gas in each band
    - Correlated-*k*: Map wavelengths into absorption coefficient bins
    - Un-map calculated fluxes back to high wavelength resolution and scale by the high resolution solar spectrum
    - Photolysis and heating rates calculated at high wavelength resolution

Calculate Actinic flux using Two-stream approximation



Integrate over up and down directions:

$$F^{\pm} = \int_{\Omega_\pm} \cos\theta \; I d\omega_n$$
$$= \frac{1}{D}\int_{\Omega_\pm} I d\omega_n$$

Diffusivity factor:

$$D_\pm = \frac{\int_{\Omega_\pm} I d\omega_n}{\int_{\Omega_\pm} \cos\theta \; I d\omega_n} = 2 \text{ if isotropic}$$

Actinic flux:

$$A = \int_{\Omega} I d\omega_n$$
$$= D(F^+ + F^-) + Z$$

Direct beam (using spherical geometry)

Non – Local Thermodynamic Equilibrium

Merge in heating rates from Fomichev 15μm and near-IR schemes ~65km

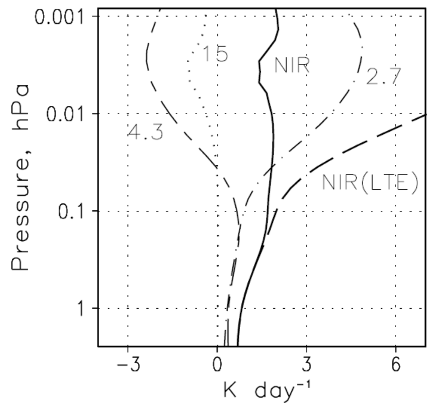
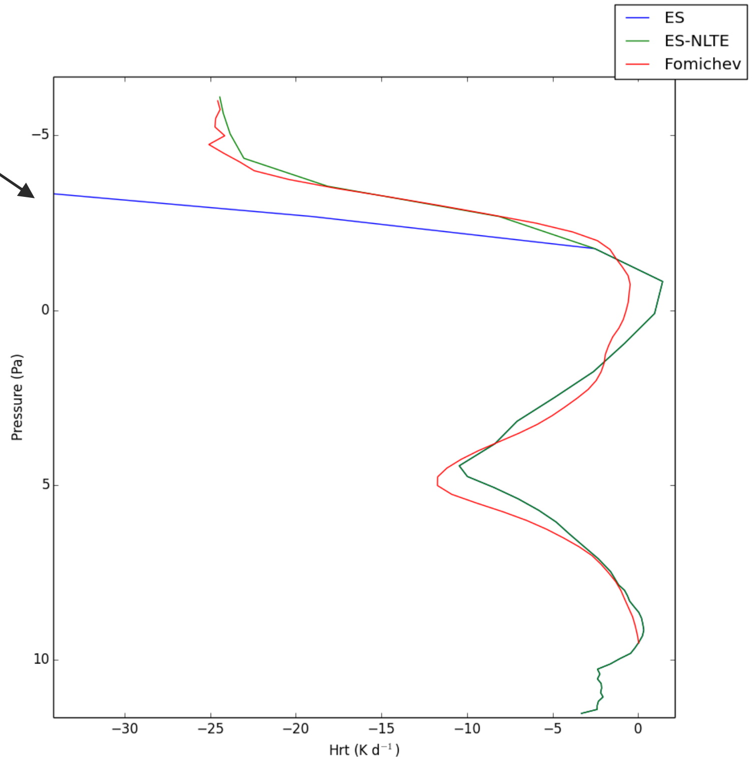


Figure 1. Total solar heating in the near-IR CO_2 bands for an overhead sun and contributions to it from different CO_2 bands: NIR, total heating due to solar energy absorption in the near-IR CO_2 bands; labels 2.7, 4.3, and 15 refer to the contributions of the 2.7 μm, 4.3 μm, and 15 μm bands, respectively (see text for details); and NIR(LTE), the same as NIR but in the case of LTE. A tropical atmosphere and a CO_2 concentration of 360 ppm are considered.



Comparison between Socrates LTE and Fomichev non-LTE cooling (pressure scale is natural log, helpfully!)

Future extension of Socrates for non-LTE:

- Eventually plan to replace Fomichev schemes with Socrates non-LTE treatment run consistently through whole atmosphere.

- First run for absorption of solar radiation and divide flux between direct heating and contributions to source functions at other wavelengths.

- Then run for thermal emission using a non-LTE source function (which becomes Planckian under LTE conditions).

Speculative… more research needed!

Questions