

Homework 3
Due 8 May 2019

Problem 1 Albedo

The observations from the Clouds and the Earth's Radiant Energy System (CERES) satellite instrument (<http://ceres.larc.nasa.gov>) are available as climatological means in `/home_local/quaas/data/CERES_EBAF_*__9999.nc`, where `lwup` is the terrestrial outgoing, `swinc` the solar incoming, `swup` the solar reflected, and `net` the net radiation flux density. "cre" is short for "cloud radiative effect" (the all-sky minus clear-sky fluxes), and "clr" is short for clear-sky fluxes (counting only pixels with no clouds present).

- Plot the zonal mean, climatological mean all-sky albedo of the Earth as observed from satellite.
- Compare this to the albedo for clear-sky conditions.
- How much energy does the system gain in the tropics (30°S to 30°N) in one year in the solar spectrum? By how much would this heat the ocean to a depth of 100 m if the ocean covered the entire tropics?
- How much energy would the system gain if there were no clouds?

Problem 2 The outgoing terrestrial radiation

- Plot the zonal mean, climatological mean all-sky outgoing terrestrial radiation of the Earth as observed from satellite.
- Compare this to the case without clouds.
- What is the net loss in terrestrial radiation in the tropics in one year?
- What would the energy loss be if there were no clouds?

Problem 3 Entropy export

The entropy flux density η of black-body radiation is related to the energy flux density by

$$\eta = R/T \quad (1)$$

- (a) Calculate the TOA solar entropy flux by treating the sun as a black body. Use the same properties (solar radius, solar surface temperature, mean solar distance) as in last week's homework.
- (b) Calculate the TOA terrestrial entropy flux by treating the Earth as a black body at emission temperature $T_e = 255$ K.
- (c) What would happen if the Earth could not export such a vast amount of entropy to space?

Problem 4 Latitude–longitude coordinate system

Derive the continuity equation in the (λ, ϕ, p) coordinate system.

Note: You may find the following form of the divergence in spherical coordinates useful (with r the radial, λ the azimuthal, and $-\pi/2 \leq \phi \leq \pi/2$ the polar coordinate):

$$\nabla \cdot \mathbf{A} = \frac{1}{r^2} \frac{\partial}{\partial r} (r^2 A_r) + \frac{1}{r \cos \phi} \frac{\partial}{\partial \phi} (A_\phi \cos \phi) + \frac{1}{r \cos \phi} \frac{\partial A_\lambda}{\partial \lambda} \quad (2)$$

with

$$\mathbf{A} = A_r \hat{\mathbf{r}} + A_\phi \hat{\boldsymbol{\phi}} + A_\lambda \hat{\boldsymbol{\lambda}} \quad (3)$$