Climate Dynamics
Summer Semester 2018

UNIVERSITÄT LEIPZIG

Homework 3
Due 9 May 2018

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).

(a) Plot the zonal mean, climatological mean all-sky albedo of the Earth as observed from satellite.

(b) Compare this to the albedo for clear-sky conditions.

(c) 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?

(d) How much energy would the system gain if there were no clouds?

Problem 2 The outgoing terrestrial radiation

(a) Plot the zonal mean, climatological mean all-sky outgoing terrestrial radiation of the Earth as observed from satellite.

(b) Compare this to the case without clouds.

(c) What is the net loss in terrestrial radiation in the tropics in one year?

(d) 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

$$\eta = R/T \tag{1}$$

(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):

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

with

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