

Homework 2  
Due 3 May 2017

### 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 ( $30^{\circ}\text{S}$  to  $30^{\circ}\text{N}$ ) 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 cases 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  $\eta$  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  $(\lambda, \phi, p)$  coordinate system.

*Note: You may find the following form of the divergence in spherical coordinates useful (with  $r$  the radial,  $\lambda$  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

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