Climate Dynamics
Summer Semester 2019

UNIVERSITÄT LEIPZIG

Homework 5
Due 29 May 2019

In this homework set, we will look at the energy budgets of the climate system (the radiative fluxes at the top of the atmosphere) and of the atmosphere (the radiative fluxes at the top of the atmosphere and the radiative, latent-heat and sensible-heat fluxes at the surface). We will also look at the meridional energy transport required to balance the energy budgets. The data we will use once again comes from the ERA–Interim reanalysis.

The `/home_local/quaas/data/ERA_fluxes.nc` contains $2^\circ \times 2^\circ$ monthly means of top-of-atmosphere solar and terrestrial radiative fluxes S_{TOA}, R_{TOA}, surface solar and terrestrial radiative fluxes S_s, R_s, and surface latent and sensible heat fluxes F_{LH}, F_{SH}. They also contain precipitation and evaporation. The sign convention for these fluxes is positive downward.

This week's files have their quirks. (Welcome to real-world data.) The fluxes are accumulated over 24-hour model runs; because the fluxes are accumulated over $24 \cdot 3600$ s, their units are J m^{-2}.

Problem 1 Energy budgets

(a) Plot the zonal–temporal means of the net solar and terrestrial radiative fluxes at the top of the atmosphere, R_{TOA}, F_{TOA}. Also calculate the global means of these fluxes and of their difference $\Delta F_{\mathrm{TOA}} = F_{\mathrm{TOA}} + R_{\mathrm{TOA}}$. Is the energy budget for the total climate system balanced? What are the implications of this comparison for using ERA–Interim to diagnose climate change in the recent past?

(b) Recall that the radiative energy budget for the atmosphere is

$$R_a = S_{\mathrm{TOA}} - S_s + R_{\mathrm{TOA}} - R_s. \tag{1}$$

Plot the zonal–temporal mean of R_a and calculate its global mean.

(c) In the global mean, the radiative energy deficit of the atmosphere is balanced by the latent and sensible heat fluxes from the surface. The sum of all these terms (with the downward-positive convention for all fluxes) is

$$\Delta F_a = S_{\mathrm{TOA}} - S_s + R_{\mathrm{TOA}} - R_s - F_{\mathrm{LH}} - F_{\mathrm{SH}} \tag{2}$$

Plot the zonal–temporal mean of ΔF_a and calculate its global mean. Does the atmospheric energy budget balance?

How do your results compare to current estimates of fluxes at the surface and TOA (Wild et al., 2015)?

Note: when calculating the global mean of a field A, remember to weight according to latitude, i.e.,

$$\frac{\int_{-\pi/2}^{\pi/2} [\bar{A}] \cos\phi \, d\phi}{\int_{-\pi/2}^{\pi/2} \cos\phi \, d\phi}$$

Problem 2 Meridional energy transport

As we saw in lecture, the steady-state climate is maintained by meridional energy transport that balances the energy surplus at low latitudes and energy deficit at high latitudes. In this problem we will try to reproduce the results of Trenberth and Caron (2001).

Energy conservation at latitude ϕ implies the following balance between northward meridional energy transport $N(\phi)$ and the local zonal–temporal mean energy budget $\Delta F(\phi)$:

$$\frac{dN}{d\phi} = \int_0^{2\pi} d\lambda \, R_E^2 \, \Delta F(\phi) \cos\phi = 2\pi R_E^2 \, \Delta F(\phi) \cos\phi \tag{3}$$

Note that the energy transport has units of W.

(a) Plot the northward energy transport required to balance the TOA energy budget $\Delta F_{\mathrm{TOA}}(\phi)$. If you found a global net imbalance in Problem 1, the transport will violate a boundary condition ($N = 0$ at the north and south poles). You can correct the flux by subtracting the global mean imbalance from it.

(b) Plot the northward energy transport required to balance the atmospheric energy budget $\Delta F_a(\phi)$. If you found a global net imbalance in Problem 1, the transport will violate a boundary condition ($N = 0$ at the north and south poles). You can correct the flux by subtracting the global mean imbalance from it.

(c) Since heat transport by land is negligible, the atmospheric and oceanic energy transports must sum to the transport required to balance the TOA energy budget. Use this argument to calculate and plot the northward oceanic energy transport.

What are the relative contributions by atmosphere and ocean to the poleward energy transport? How does your result compare to Figures 2 and 7 in Trenberth and Caron (2001)?

Problem 3 Stream function

Use the files `/home_local/quaas/data/ERA_V_zonmean_mean.nc` and `ERA_W_zonmean_mean.nc` to calculate and plot the mass streamfunction Ψ_M.

Note: see p. 12 of the Lecture 5 slides for the definition of the mass streamfunction.

Problem 4 Tropical circulation

(a) As we know from lecture, the Hadley circulation has a strong seasonal cycle. Using the files `/home_local/jmuelmenstaedt/ERA_jja.nc` and `ERA_djf.nc`, plot the contours of the streamfunction for DJF and JJA.

(b) `ERA_jja.nc` and `ERA_djf.nc` also contain the fractional cloudiness. Overlay the cloud cover as a heat map.

(c) Plot the geographic distribution of convective precipitation in `/home_local/jmuelmenstaedt/ERA_jja_pr.nc` and `ERA_djf_pr.nc`. Explain the features of the seasonal cycle.