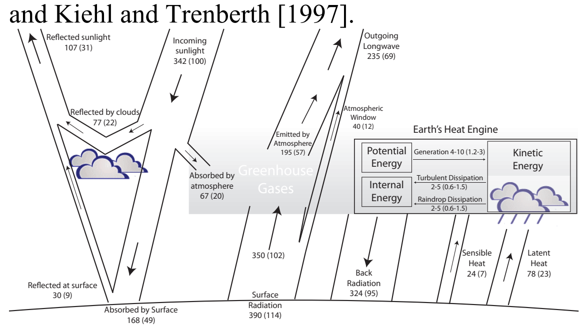
Planetary Atmospheres as Heat Engines, G. Schubert[1] and J. Mitchell[2], [1]Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095-1567, schubert@ucla.edu, [2]Department of Earth and Space Sciences, University of California, Los Angeles, CA, 90095-1567, mitch@ess.ucla.edu.

We review the workings of the Earth's atmospheric heat engine and describe the energy exchanges that occur to support the atmospheric circulation. The heat absorbed by the atmosphere increases its internal and gravitational potential energies. We review estimates of the standing reservoirs of internal, potential, and kinetic energies. A very small percentage of potential energy is converted into kinetic energy to maintain the circulation against dissipation, which irreversibly converts it to internal energy (Figure 1). The thermodynamic efficiency of the atmospheric heat engine can be defined as the fraction of the radiative imbalance at the surface converted to the kinetic energy of the motions. This is equivalent to the ratio of the frictional energy dissipation to the convective heat flux. Estimates of this ratio for Earth are several percent, approaching the Carnot efficiency of about 10%. We apply these concepts to the atmospheres of Venus, Mars and Titan and highlight where observations are needed to quantify their reservoirs and fluxes of energy.

The rate of dissipation of atmospheric kinetic energy is the most uncertain of the quantities entering the energy budget. Only recently has it been shown from satellite observations that frictional dissipation in the microphysical shear zones surrounding falling raindrops is comparable to the turbulent dissipation of kinetic energy [Pauluis and Dias, 2012]. Rainfall might also be a significant source of dissipation on Titan but it is not likely to be important for Mars or Venus [Lorenz and Renno, 2002]. The breaking of upward propagating internal gravity waves generated by convection and flow over the surface topography is another source of dissipation and is possibly dominant on Venus [Izakov, 2010].

Figure 1. Flow of energy in the Earth's atmosphere. Fluxes are in units of W m^{-2}. Numbers in parentheses are percentages of the absorbed solar radiation. Numerical values are based on Peixoto and Oort [1992] and Kiehl and Trenberth [1997].



References:

Izakov, M. N. (2010), Dissipation of buoyancy waves and turbulence in the atmosphere of venus, Solar System Research, 44(6), 475-486.
Kiehl, J. T., and K. E. Trenberth (1997), Earth's annual global mean energy budget, Bulletin of the American Meteorological Society, 78(2), 197-208.
Lorenz, R. D., and N. O. Renno (2002), Work output of planetary atmospheric engines: dissipation in clouds and rain, Geophysical Research Letters, 29(2).
Pauluis, O., and J. Dias (2012), Satellite Estimates of Precipitation-Induced Dissipation in the Atmosphere, Science, 335(6071), 953-956.
Peixoto, J. P., and A. H. Oort (1992), Physics of Climate, American Institute of Physics, New York.