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Global observational energy budget studies

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The energy budget of the geofluids comprises components that are physically quite different like, e.g., the radiative flux and the advective flux. Early estimates of the global energy budget have often been based on measuring one component and then using the budget as requirement to infer the unmeasured balancing component. For example, it has long been common practice to estimate the global heat transport managed by oceanic and atmospheric currents through indirect budgeting from pure radiation measurements. This approach, used in an ingenious way by the pioneers in global budgeting, is yet limited in that the components are not independent so that the results cannot be validated.

Observational studies of the past two decades have yielded new independent measurements of most of these components with unprecedented completeness of coverage and accuracy of observation. An important aspect of the improvement in data quality has been the advent of data assimilation. Thus it seems possible today to use the budget laws not so much for determining unknown components as residuals but rather as a test if the independently measured quantities add up to zero. Further, we can ask for a new evaluation of the global energy budet and to face the deeper problems that result from the tremendous improvement in overall data quality. The purpose of this talk is to report specifically about the atmospheric budgets of *total energy* and of *available potential energy*.

Total energy comprises sensible, potential, kinetic and latent energy. According to the first law of thermodynamics, the budget is exactly free of sources. So only the time tendency of total energy is to be determined as well as the divergence of the corresponding 3D-flux vector. Complete monthly budgets calculated with aid of the global ERA-40 dataset show that the governing balance is between the divergence component of the *horizontal* energy fluxes (that are advectively controlled and routinely observable in situ on the gridscale by the synoptic network) and the divergence component of the *vertical* energy fluxes (that are radiatively and convectively controlled and are not observable in situ). Both components of the 3D-energy flux divergence in the global geofluid system are of opposite sign: The vertical energy flux is convergent (due to convection) in the tropics and divergent in high latitudes (due to radiation); this is balanced by the horizontal energy flux which is divergent in the tropics (export of heat to the extratropics) and convergent in the high latitudes (balance of net heat loss due to terrestrial radiation). Compared with these two strong balancing terms the time tendency (the *storage*) of energy is practically negligible. We present estimates of this balance, discuss the various contributing components and show that the independently determined budget components (storage, horizontl flux divergence and vertical flux divergence) add up to zero within a few percent.

In discussing the budget of atmospheric available potential energy we aim at estimating the missing link in the classical Lorenz cycle. According to the original theory of Margules (Vienna, 1905) and Lorenz (Chicago, 1955) the level of kinetic energy K of the global atmosphere is kept constant against friction by drawing from the available potential energy A. The reservoir of A is constantly filled by differential heating. The conversion C from A to K is made by the vertical flux b of buoyancy. Lorenz and subsequent researchers were forced to restrict estimates of the conversion rate to the gridscale component of C. Still missing is the sub-gridscale component. With the progress of the last two decades in diagnosing the sub-gridcale component of b it appears feasible now to attack the task of estimating the sub-gridscale component of C and thereby to complete the work of Margules and Lorenz. We have tried to estimate C_{sub} for the global atmosphere and came up with some 2...3 W/m^2 which doubles the previous estimates of the global conversion rate. However, our method to calculate b has been preliminary in estimating the sub-gridscale buoyancy flux. Thus our estimate of C_{sub} has an error of 30...50 %. It is therefore necessary to find new ways to determine observationally the routinely unobservable sub-gridscale vertical buoyancy flux.

Budget studies are inevitably incomplete because they can only answer the question *how* big the fluxes (and the storage terms and the source terms) are; the question *why* the fluxes are of this specific size cannot be answered by budget studies. Yet to verify the balance of independently opposing quantitites is not only satisfying. It is the sheer quantitative background against which possible mechanistic explanations must be scrutinized for validity.