Accuracy of atmospheric energy budgets

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Issues relevant to achieving an accuracy of better than 10 W m^{-2} in the atmospheric energy balance are explored from the standpoint of the formulation and computational procedures using the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) (referred to as NCEP) and European Centre for Medium Range Weather Forecasts (ECMWF) reanalyses. The focus is on the vertically integrated energy components, their monthly tendencies, transports and divergences using the most accurate computations in model and pressure coordinates. Approximate equations have often been used previously; although relatively small compared with the moist static energy, kinetic energy fluxes should be taken into account as divergences can exceed several tens of W m^{-2}. Changes in energy storage terms over a month are not negligible as they are typically over 25 W m^{-2} in storm track regions. Transports of energy are meaningful only if the mass budget is closed.

Typical magnitudes of the divergence of sensible heat and potential energy are very large (several hundred W m^{-2}) but partly cancel when combined as dry static energy, reflecting the role of isentropic flow. The latent energy and sensible heat contributions are strongly positively correlated because of the dominance of low level flow, and hence, the latent energy divergence also cancels a large component of the dry static energy divergence, leaving a modest residual. This arises from the dominance of moist adiabatic processes in the tropics and subtropics as the net transports depend on departures in the vertical from the saturated adiabatic lapse rate. Careful numerical treatments are required because small errors in the large terms that should cancel can be amplified. Common assumptions that diagnostics can be computed on model terrain-following coordinates, which therefore vary from day to day as the surface pressure changes, lead to errors in energy budgets of order 5 W m^{-2} owing to the co-variability of energy terms with surface pressure.

How well model coordinate results can be replicated in pressure coordinates and with data from a post processor developed at NCAR has been explored along with the role of vertical resolution. The standard 17-level reanalysis pressure level archive does not adequately resolve the atmosphere, and we propose a new set of 30 pressure levels that has 25 mb vertical resolution below 700 mb and 50 mb vertical resolution in the rest of the troposphere. The diagnostics revealed major problems in the NCEP reanalyses in the stratosphere that are inherent in the model formulation, making them unsuitable for quantitative use for energetics in anything other than model coordinates. In addition, small flaws are found in the ECMWF post-processing onto pressure levels. These stem from the way the vector fields are truncated, which is a necessary step to avoid aliasing before putting the values out on a 2.5°grid. Moreover, it is desirable to compute the grid point values exactly rather than interpolating them from the Gaussian grid, as currently done by ECMWF. The diagnostic results computed with 30 levels replicate the full model level vertically-integrated energy divergences to within about 2 W m^{-2} over the ocean, while errors exceed 10 W m^{-2} in small spots over Greenland, Antarctica and the Himalayan-Tibetan plateau complex.

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