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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Large differences in the diabatic heat budget of the tropical UTLS in reanalyses" *by* J. S. Wright and S. Fueglistaler

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We thank the reviewer for an insightful review that has driven substantial improvements in the manuscript.

At the reviewer's suggestion (page C2191, line 10), we have added a series of equations based on the thermodynamic equation in the following form

$$\frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T - \omega \left(\frac{\kappa T}{p} - \frac{\partial T}{\partial p} \right) = \frac{Q}{c_p}, \tag{1}$$

where the terms on the left hand side represent the change in temperature with time,

horizontal advection of temperature, and vertical advection of temperature, respectively. The term on the right hand side represents diabatic heating, which can be broken down into radiative and residual (i.e., non-radiative) components:

$$\frac{Q}{c_p} = \frac{Q_{\mathsf{rad}}}{c_p} + \frac{Q_{\mathsf{res}}}{c_p}. \tag{2}$$

The radiative term can in turn be broken down in two ways, as long-wave and short-wave radiative heating:

$$\frac{Q_{\mathsf{rad}}}{c_p} = \frac{Q_{\mathsf{LW}}}{c_p} + \frac{Q_{\mathsf{SW}}}{c_p}, \tag{3}$$

or as clear-sky and cloud radiative heating:

$$\frac{Q_{\mathsf{rad}}}{c_p} = \frac{Q_{\mathsf{clear}}}{c_p} + \frac{Q_{\mathsf{cloud}}}{c_p}. \tag{4}$$

The residual heating term can also be separated into two main individual components:

$$\frac{Q_{\mathsf{res}}}{c_p} = \frac{Q_{\mathsf{lat}}}{c_p} + \frac{Q_{\mathsf{mix}}}{c_p}, \tag{5}$$

where Q_{lat} is latent heating due to moist physics and Q_{mix} is heating due to turbulent mixing. Not all terms are available for all reanalyses. Table 1 lists the terms in the diabatic heat budget provided by each of the reanalyses examined in this study.

We have also prepared an additional figure that shows profiles of forecast temperature (prior to data assimilation), analysis temperature (after data assimilation), ozone, and cloud water content averaged over the inner tropics (10°S–10°N) for those reanalyses that have provided them. This figure addresses most of the reviewer's remaining

Table 1. Availability of diabatic heating components for each reanalysis.

	MERRA	ERAI	CFSR	JRA	NCEP
Q_{rad}	✓	✓	✓	✓	✓
Q_{LW}	✓	✓	✓	✓	✓
Q_{SW}	✓	✓	✓	✓	✓
Q_{clear}	✓	✓	–	–	–
Q_{cloud}	✓	✓	–	–	–
Q_{res}	✓	✓	✓	✓	✓
Q_{lat}	✓	–	✓	✓	✓
Q_{mix}	✓	–	✓	✓	✓

comments, and helps to clarify several of the differences we highlighted in the original manuscript.

The reviewer asked whether temperature biases in the NCEP and JRA reanalyses continued through the 2000s (page C2192, lines 11–18). We note first that for the purposes of radiation it is important to consider not only the reanalysis temperatures (after data assimilation) but also the temperatures generated by the forecast model (see panel a, which shows averages for all reanalyses but NCEP over the forecast period). Changes in assimilated data sets do affect the latter via the initial conditions, but may not correct for biases in the underlying GCM (and in fact may even exacerbate them, as the model attempts to adjust to some other equilibrium temperature distribution). We unfortunately do not currently have the temperature profile from the NCEP forecasts, but comparison of the analysis temperatures (post-assimilation) indicates a warm bias in the tropical mean temperature at 100 hPa of approximately 1 K with respect to JRA, MERRA, and CFSR, and a bias of approximately 1.5 K with respect to ERAI (magnitudes can be much larger locally). This strongly suggests that NCEP remains warm-biased at this altitude through the 2000s. The purpose here is

not to identify drifts in the reanalysis, but to relate differences in radiative heating to differences in temperature.

In the original manuscript we stated that JRA has a systematic cold temperature bias in the lower and middle stratosphere (page 8818, lines 8–10). Upon further review, this statement appears to be wrong: the JRA forecast model is biased cold relative to the other reanalyses in the upper troposphere (below 100 hPa) but warm in the lower stratosphere (from 100 hPa up to 50 hPa and above). The biases in the tropical mean profile at these levels approach magnitudes of ± 4 K, with the minimum bias located near 100 hPa. The lack of long-wave radiative heating in JRA relative to the other reanalyses may be attributable to this warm bias in the tropical lower stratosphere in the JRA forecast model. This has necessitated substantial revision of the paragraph on page 8818, lines 5–21.

We have provided the annual mean ozone profiles used by each reanalysis model in calculating radiative heating, as suggested by the reviewer (page C2192, line 8). We also show the ozone field generated by the ERAI model (which is not used in radiative calculations) and profiles from 13 SHADOZ stations in the inner tropics. All of the models appear to overestimate ozone concentrations in the tropical upper troposphere and lower stratosphere with respect to the SHADOZ profiles, including those models that use predicted ozone for radiative calculations (MERRA, CFSR, and JRA).

Following the reviewer's suggestion (page C2192, line 6), we have also included a panel that summarises profiles of cloud water content (panel d; mixing ratios averaged over the model forecast step). Cloud water content is the most consistent 3-dimensional cloud quantity provided by these reanalyses (3-dimensional cloud fraction is also available for three of the five data sets). Differences in cloud water content are very large, and imply substantial differences in the treatment of convective anvils by different models. These differences hint at explanations for the differences in upper tropospheric diabatic heating among reanalyses, and the discussion of cloud radiative forcing in section 4 has been modified to reference this figure. However, a full examination of how these differences interact with the model radiation schemes is beyond the scope of this paper and will be explored in future work.

Finally, we thank the reviewer for pointing out the more appropriate citation for the S-RIP project (page C2192, lines 19–22), which we will use in the revised manuscript.

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 8805, 2013.

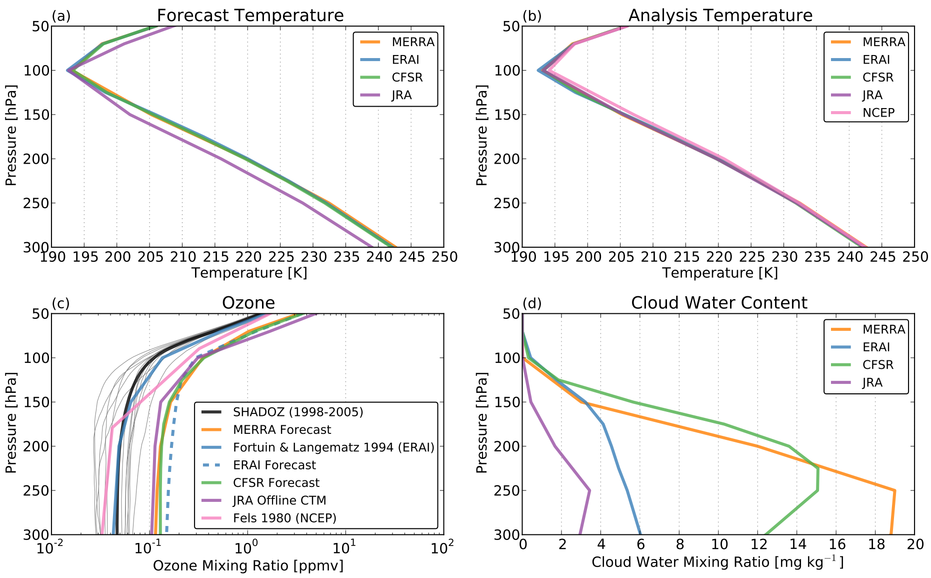

Fig. 1.