# Using ERA-40 products to verify and improve the Met Office climate model

**Richard P. Allan, Mark A. Ringer, Anthony Slingo**

*Hadley Centre, Bracknell, UK*

## 1. Introduction

Accurate measurements of the Earth's climate system and its variability on a variety of time and space-scales are vital in verifying and improving the quality of climate model simulations. However such comparisons are impeded by incomplete observational coverage. Reanalyses address this problem by using the limited array of observations to continually force a model via an assimilation system, thereby providing information as to the true nature of the atmosphere on a grid suitable for consistent comparison with climate and numerical prediction models. The degree to which observational information is lost or spurious climate signals created in the assimilation process is not fully understood and therefore requires careful checking of reanalysis products. Thus, with the aim of utilising the ECMWF 40-year reanalysis data (ERA-40) in conjunction with observations to verify the Met Office climate model, the present study seeks to:

- Evaluate the quality of ERA-40 data currently available
- Understand what are the strengths and weaknesses of ERA-40
- Develop exploratory techniques for using observations and ERA-40 data to evaluate the climate model, concentration on the radiation budget

## 2. Simulated Radiation Budget and Water Vapour

We first assess the top of atmosphere radiation budget and determinant parameters such as column water vapour and cloud amount produced by ERA-40. Figure 1 shows the zonal mean differences relative to observations for ERA-40 and the Hadley Centre climate model, HadAM3 (Pope et al, 1999) during 1989. The outgoing longwave radiation to space (OLR) is systematically overestimated by ERA-40 compared to the Earth Radiation Budget Satellite (ERBS) measurements (e.g. Ramanathan et al., 1989) and generally provides a worse simulation than HadAM3 in all but equatorial regions. Further, the clear-sky OLR produced by ERA-40 shows agreement with ERBS to within the instrument uncertainty, suggesting that the clouds in ERA-40 do not provide a strong enough greenhouse effect. The top of atmosphere absorbed solar radiation (ASR) also provides a poorer simulation than HadAM3 with a severe underestimation in the tropics and an overestimation in the extra-tropics compared with ERBS. On closer inspection it is found that deep convective clouds in ERA-40, although corresponding with the strongest observed shortwave cloud radiative forcing (SWCF), are far too reflective. Further, the radiative effect of clouds over the open tropical ocean is also too strong. Conversely the signal of stratocumulus cloud appears absent with overestimation of ASR in these regions.

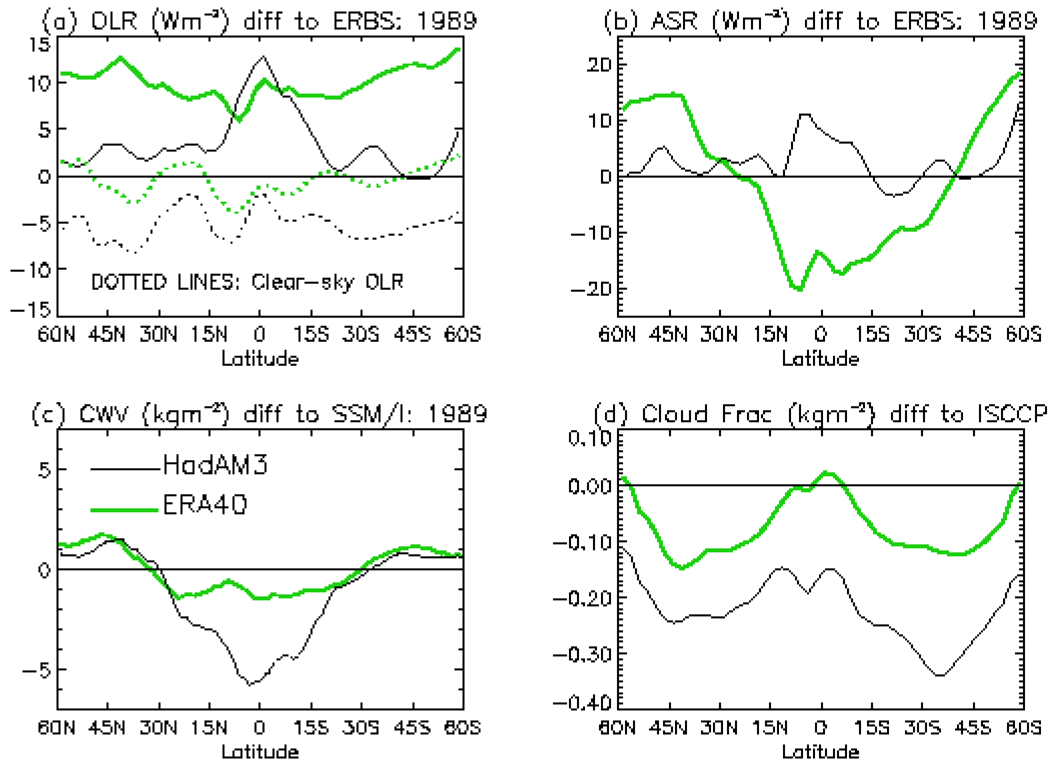


*Figure 1: Zonal mean OLR, ASR, CWV and cloud fraction differences to observations for 1989: ERA-40(thick) and HadAM3 (thin).*

Comparison of ERA-40 column integrated water vapour (CWV) with SSM/I observations (Wentz, 1997) are good. This is perhaps unsurprising given the assimilation of the SSM/I data into ERA-40 but nevertheless indicates the potential use of ERA-40 water vapour in the evaluation of climate models. The underestimation of tropical water vapour in HadAM3 is evident in Figure 1c. The cloud fraction differences to ISCCP observations (Rossow and Schiffer, 1991) for ERA-40 and HadAM3 show similar latitudinal structure. It is not yet clear whether this results from similar biases in the ERA-40 and HadAM3 models or a systematic bias in the observations. However, the higher values of cloud fraction in ERA-40 relative to HadAM3 appear more realistic based on comparison with ISCCP. This reinforces the conclusion that the cloud distribution in ERA-40 is reasonable (see also Chevallier et al., 2001), although the radiative effect of the cloud is unrealistic.

## 3. Low-Latitude Mean Monthly Variability

Also important for the evaluation of model physics, and especially relevant for the estimation of feedbacks in the climate system, are the time dependent variability of the radiation budget and its determinant parameters. For example, Slingo et al. (2000) used clear-sky radiation budget and water vapour derived from ERA-15 to diagnose information on the water vapour feedback and gauge the accuracy of climate simulations. However, the variability of temperature and water vapour in ERA-15 is influenced by some artefacts of the observing system (e.g. Trenberth et al. 2001) and therefore requires the careful checking of such variations in the present reanalysis.

Figure 2 (top) shows how the low latitude ERA-15 CWV variability (dashed line) diverges significantly from both the NCEP/NCAR reanalysis (Kalnay et al., 1996) and HadAM3 values. Over the ocean (bottom), the observed fluctuations are in greater agreement with NCEP and HadAM3 than with ERA-15. We also plot the

ERA-40 data from 1989-1991 which appears to show reasonable agreement of the seasonal variations with the observations. There is a hint of systematic moistening over this period, mainly over land, although this is also evident in the NCEP data. The variability of ERA-40 water vapour appears superior to ERA-15.

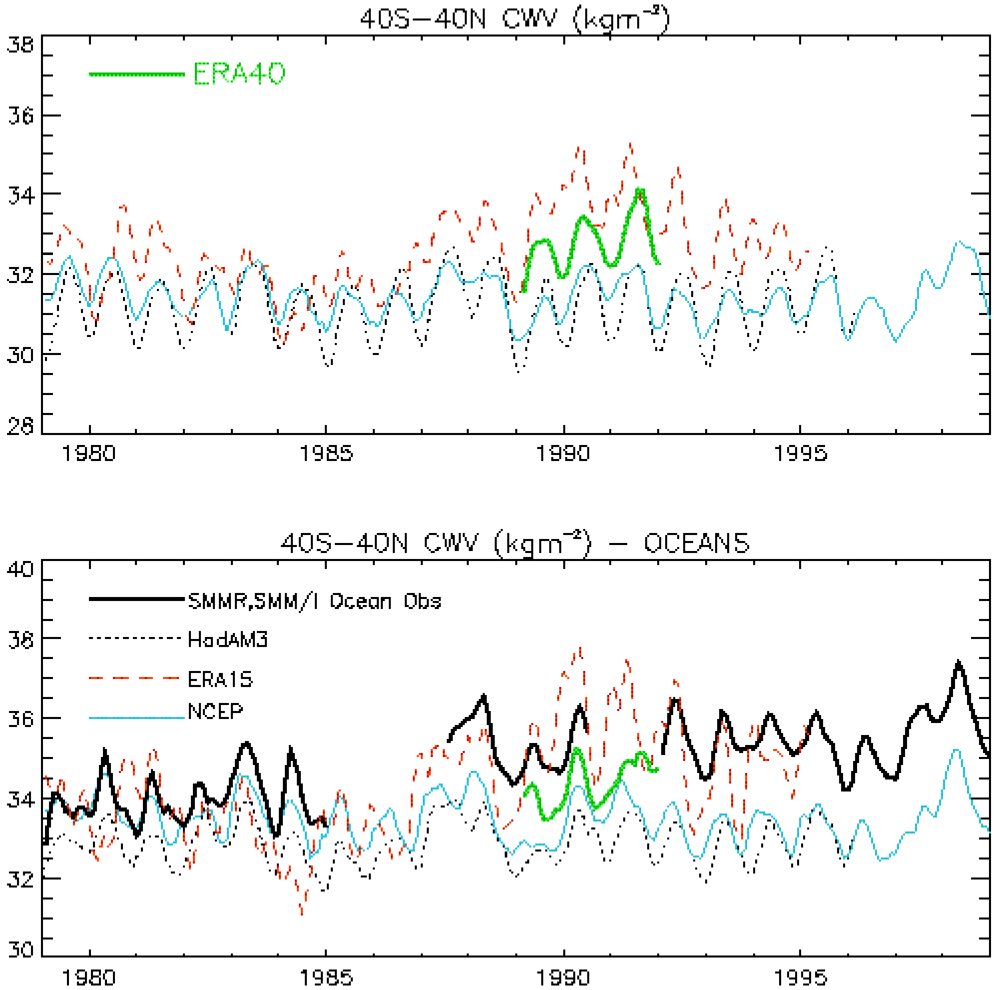


*Figure 2: Monthly variability of column integrated water vapour, CWV (kgm$^{-2}$) for ERA-15, ERA-40 and NCEP/NCAR reanalyses, HadAM3 simulations and SMMR and SSM/I ocean-only observations*

Plotting the variation of the top of atmosphere radiation budget (not shown) again highlights the systematic biases described in the previous section. However, the low-latitude seasonal variation of OLR and ASR appear reasonable compared with observations. The ERA-40 clear-sky OLR variations are similar to ERA-15, which show greater variation than the observations. It is not yet clear whether the inconsistent sampling of clear-sky fluxes between observations and models explain some of this discrepancy.

## 4. Exploiting ERA-40 DATA for Climate Model Evaluation

In the previous sections we have established the potential usefulness of water vapour and clear-sky OLR produced by ERA-40 for use in the verification of climate model simulations. However, the all-sky radiation budget appears poor. This is a result of the cloud radiative properties rather than being a problem with the cloud amount and its distribution by the atmospheric circulation. Thus it is more beneficial to utilise the dynamical parameters provided by ERA-40, in conjunction with observed radiation budget data to enhance our ability to evaluate the cloud radiative effect simulated for a given dynamic regime. However we first must establish whether such dynamical parameters are reasonable and further demonstrate consistentcy with the atmospheric circulation simulated by HadAM3. Figure 3 compares 500 hPa vertical velocity (ω) from ERA-40, the NCEP/NCAR reanalysis (Kalney et al., 1996) and HadAM3 for low-latitudes.

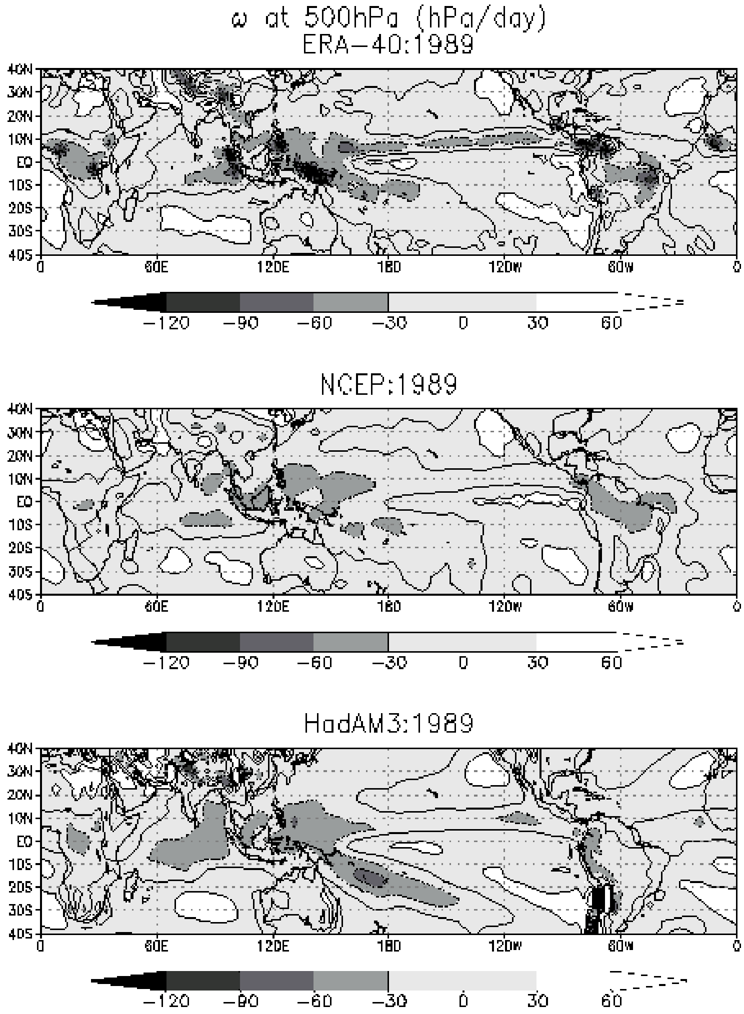


*Figure 3: 500 hPa vertical velocity, ω (hPa/day) for 1989: ERA-40, NCEP and HadAM3.*

There is broad consistency between ERA-40 and HadAM3 vertical velocity, although limited regions of much stronger upward motion are apparent in ERA-40. The NCEP upward motion in convecting region is weaker than HadAM3 and ERA-40 and is likely underestimated (Trenberth and Guillemot, 1998). We conclude that ERA-40 vertical velocity may be used to subsample observed fields such as cloud forcing such that the cloud radiative effect of certain dynamic regimes may be consistently compared with the model. Figure 4 shows an exploratory study in which we compare the longwave and shortwave cloud forcing simulated by versions of the Hadley Centre climate model, sub-sampled to concentrate on strongly convective dynamic regimes in the tropics, with observed cloud forcing and ERA-40/NCEP vertical velocity.

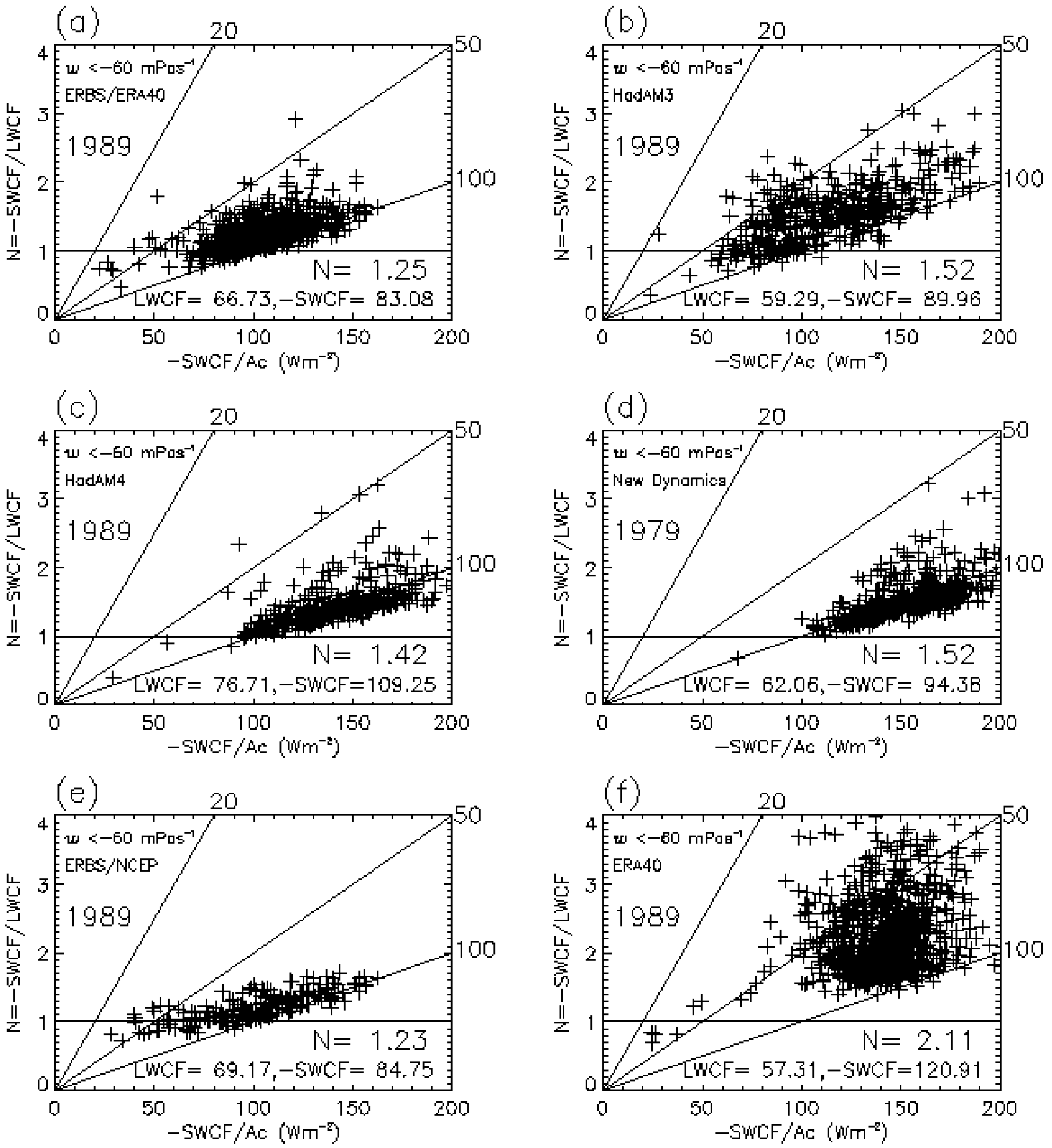


*Figure 4: Analysing tropical cloud radiative effect in the strongly convecting regimes using data from ERA-40, NCEP, ERBE, HadAM3, HadAM4 and HadGAM (new dynamics) for the JJA season. Diagonal contours show the longwave cloud forcing (LWCF).*

In Fig. 4 we use the method described in Cess et al (2001) who computes the ratio of SWCF and LWCF (which to first order is independent of cloud fraction) thus providing information on cloud top emission and optical depth. In Allan et al. (2001) we adapted the Cess method sampling only by regime such that the properties of cloud in similar dynamic regimes may be compared. Finally to remove the dependence of CF on cloud fraction, we normalise by cloud amount thus approximating the radiative effect were the skies completely overcast. This increases consistency between different data/model output. Sampling only points in which $\omega < -0.06$ hPas$^{-1}$ ensures sampling of strong convection. Using ERA40 $\omega$ samples more points than using NCEP $\omega$. However, the distribution of observed CF is similar using both sets of vertical velocities and the ratio of mean SWCF to LWCF (N) is about 1.2 for both (suggesting weak domination of SWCF over LWCF).

In Fig. 4b, HadAM3 displays higher N for a given scaled SWCF, symptomatic of too much low altitude cloud influencing the top of atmosphere radiation budget. For updated versions of HadAM3 (HadAM4 and new dynamics) this problem is reduced, although the deep convective cloud appears overly reflective. Using ERA-40 radiation budget parameters and vertical velocity, the overestimation in optical depth and underestimation of cloud greenhouse effect can be clearly seen. The adapted Cess technique allows the identification of problems with cloud radiative properties, that may be unclear from merely comparing the radiation budget (which are influenced by cloud amount in addition to the cloud properties).

## 5. Conclusions

Using observations and climate model simulations of the top of atmosphere radiation budget data and its determinant parameters, we evaluated the quality of the currently available ERA-40 data and its potential application to climate model verification. The main conclusions are:

- Clear-sky radiation budget and water vapour distribution for low latitudes are reasonable. Further analysis of the interannual variability is required to assess the quality of these products and whether they will be of use in the evaluation of climate models.
- The all-sky top of atmosphere radiation budget is poor, mainly due to the unrealistic radiative effects of cloud. The cloud greenhouse effect is underestimated in the tropics while tropical convective clouds are too reflective. Also the stratocumulus cloud influence on the radiation budget is unrealistically small. However, seasonal variability of fluxes seem reasonable.
- While the cloud radiative effect in ERA-40 is poor, the cloud distribution and the atmospheric circulation appear consistent with observed radiation and cloud fields.
- Subsampling of observations using ERA-40 dynamical parameters may provide a valuable technique for verifying the climate model developed within the Met Office.

## 6. References

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