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13. Precipitation Correction in the ERA-40 Reanalysis

Alberto Troccoli and Per Kållberg

European Centre for Medium-Range Weather Forecasts
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Precipitation Correction in the ERA-40 Reanalysis

Alberto Troccoli and Per Kållberg

Research Department

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Abstract

The excessive precipitation in the tropical regions, particularly after 1991, is seen as the most serious drawback of the ERA-40 reanalyses. This drawback stems from weaknesses of the humidity scheme utilised in the assimilation system. Motivated by the need to use ERA-40 precipitation fields to force ocean model integrations, a post-processing procedure is applied to the oceanic precipitation fields in order to compensate for this shortcoming.

A simple two-step procedure is adopted for this purpose. First, a pseudo-climatology is generated by blending one particular ERA-40 period (i.e., the 1964-1972, which is one of the least affected by the humidity scheme) with precipitation observations. Second, the remaining ERA-40 periods are corrected so as to minimise the distance to the pseudo-climatology, with the constraint that the water budget should be zero. Since the ERA-40 mean evaporation field is fairly constant, the imposed water budget constraint implies that the mean corrected precipitation is very similar for each of the five periods in which ERA-40 was processed. Comparisons with precipitation estimates show a considerable improvement of the corrected precipitation field.

1 Introduction

The ECMWF 40-year reanalysis project ('ERA-40') has recently reached its completion. These reanalyses of the state of the atmosphere from September 1957 to August 2002 provide a very high quality reference atmospheric state for quite a long period and complement the hitherto available NCEP/NCAR 50-year and ECMWF ('ERA-15') 15-year reanalyses.

In addition to analysis of the basic atmospheric variables such as pressure, temperature, wind, humidity and ozone content, ERA-40 also provides estimates of many diagnostic variables, such as precipitation, energy and momentum fluxes. The precipitation estimates considered in this work are extracted from short-range (+24h) forecasts run during the data assimilation.

Evaluation shows excessive amounts of precipitation over tropical oceans when compared to independent estimates (GPCP, http://precip.gsfc.nasa.gov and [1]) during the latter parts of ERA-40. This has been found to be due to a fundamental problem in the variational analysis of humidity over tropical oceans in areas of high density observations, such as satellite radiances. Pre-satellite years are however not noticeably affected since there were very few observations of free atmosphere humidity. The increased precipitation with time might also be part of the climate signal, but our estimates indicate that the first order effect is indeed due to the humidity analysis deficiency. We will therefore assume that the real average precipitation during the 45 years does not vary significantly.

Precipitation is an essential component of the fields used to force ocean models. Since in the European Project ENACT (Enhanced Ocean Data Assimilation and Climate Prediction) the choice was made to use the daily averages of the ERA-40 fields to force the various ocean models taking part in the project, a solution to the excessive precipitation issue had to be sought. This paper presents the solution adopted in the context of ENACT but which might have wider applications. The procedure and its assumptions are presented in section 2. Results are discussed in section 3 and a brief summary is given in section 4.

2 The precipitation correction

For the purpose of this investigation, the ERA-40 reanalysis was divided in five consecutive periods: 1958-1963, 1964-1972, 1973-1978, 1979-1988 and 1989-2001. Four main assumptions (or constraints) are adopted in order to calculate the magnitude of the precipitation correction, which will be different for each period: 1) The ERA-40 precipitation field for the reference period should conform to (be consistent with) the observed precipitation field. A pseudo-climatological precipitation is the product of this evaluation; 2) The water budget, precipitation minus evaporation, has to be zero in a global sense for each period; 3) The evaporation field is treated as error-free; 4) The temporal variability is not affected to first order.

In particular, the second assumption may be applied in two ways: a) by calculating the precipitation minus evaporation (PmE) for the entire globe (i.e., land plus ocean) or b) by calculating the same budget but for the ocean area only. In the latter case, the river runoff contribution has to be considered too, i.e., (P+R-E) should balance out. Since the original objective of this investigation was to use precipitation as an ocean model forcing, the second approach was taken. It has been tested, however, that the two approaches, a) and b), give very similar results (see section 3).

Because the largest differences in precipitation appear in the oceanic tropical band, the correction is evaluated only for the latitudinal range between 30°S and 30°N over the ocean. No attempt is made to refine the correction to be longitude-dependent.

The minimisation procedure only involves a single coefficient, α, calculated as the solution of the following system:

$$\begin{cases} \overline{P_C} = \frac{\sum_j \left[P_j - \alpha(P_j - P_{Oj})\right] d_j}{\sum_j d_j} \\ \overline{P_C} + \overline{R} - \overline{E} = 0 \end{cases} \qquad \text{with } P_{Oj} = P_j \text{ for } \mid \text{latitude} \mid > 30^\circ \tag{1}$$

which can be reduced to the simple equation:

$$\alpha = \frac{\left(\overline{P} + \overline{R} - \overline{E}\right)}{\left(\overline{P} - \overline{P_O}\right)} \tag{2}$$

where P is the original ERA-40 precipitation (and $\overline{P}$ its mean), P_O is either the observed or the pseudo-climatological precipitation (and $\overline{P_O}$ its mean). Note that, in any case, its value coincides with the original ERA-40 precipitation outside the $\pm 30^\circ$ band. $\overline{P_C}$ is the mean corrected precipitation, $\overline{E}$ is the mean evaporation and $\overline{R}$ is the mean river runoff ($\overline{R}$ is assumed to be about 10% of $\overline{E}$). The mean of these variables are weighted according to the latitudinal length, d_j, j being the latitudinal index.

3 Results

The reference period was chosen to be that for 1964-1972 because, for this period, there are enough observations to constrain the model fields but, at the same time, not too many humidity observations to disrupt the precipitation field. Next, the pseudo-climatological precipitation is derived by combining the 1964-1972 period with the 1979-2001 GPCP climatology, by solving (2). If the mean evaporation were constant for all the five periods, which is approximately valid, it would be equivalent to calculate α for the remaining periods using either the derived pseudo-climatological precipitation or the GPCP climatology. However, the former solution was chosen because, by combining ERA-40 with GPCP, a potentially useful reference field is obtained.

As the ERA-40 precipitation field has consistently larger values than GPCP in the tropical band (cf. green dotted line and grey solid line in Figure 1a), the value of α is positive and equal to about 0.25 (see last column in table 1). The corrected precipitation for the 1964-1972 period is shown as a green solid line in Figure 1a. As can be seen, the main difference in the corrected precipitation, compared to the original field, is in the 0°

and 15°S band. In Figure 1b the corresponding PmE field before and after the correction is shown in green as a dashed and solid line, respectively.

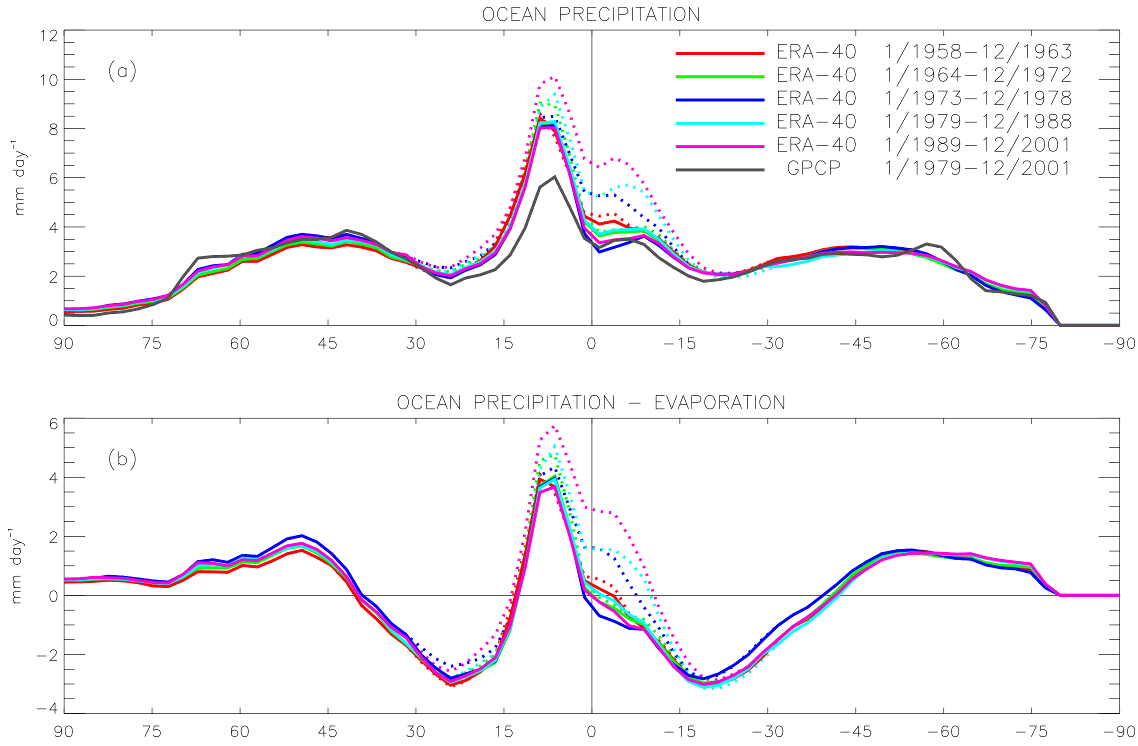

Figure 1: (a) Mean zonal precipitation for the five ERA-40 periods and GPCP 1979-2001 climatology. (b) Mean zonal precipitation minus evaporation for the five ERA-40 periods. Dashed lines are the original ERA-40 fields whereas the solid lines are the corrected ones.

OCEAN MEAN VALUES (mm day^{-1})							
Period	$\overline{P}$	$\overline{E}$	$\overline{PmE}$	$\overline{P_C}$	$\overline{P_C mE}$	$(\overline{P_C}+\overline{R}-\overline{E})$	α
1958-1963	3.20	3.33	-0.30	3.16	-0.34	-0.004	0.39
1964-1972	3.24	3.27	-0.20	3.12	-0.32	0.005	0.25
1973-1978	3.40	3.16	0.07	3.10	-0.23	0.09	1.40
1979-1988	3.43	3.29	-0.04	3.14	-0.33	0.003	0.95
1989-2001	3.72	3.27	0.29	3.10	-0.34	-0.008	1.02
GPCP (1979-2001)	2.82						

Table 1: Mean values for precipitation, Evaporation, PmE, corrected precipitation ($\overline{P_C}$), corrected PmE ($\overline{P_C mE}$) and ($\overline{P_C}+\overline{R}-\overline{E}$). The last column shows the values for the alpha coefficients calculated by using equation (2).

The fact that there is still a significant discrepancy between the corrected precipitation and the GPCP climatology might imply either non-negligible errors in the ERA-40 evaporation field, which would therefore be overestimated, or an underestimation of the GPCP precipitation. Since the latter only gives an estimate of precipitation over the ocean and in order to avoid further imbalances in the ERA-40 fields, we opted to consider the evaporation as error-free, as stated by the third assumption.

The same procedure is then applied to the remaining four periods but, in this case, the derived pseudo-climatology precipitation is used in place of the GPCP climatology. The results are again shown in Figures1a-b and in Table 1. As shown by the penultimate column in Table 1, with the applied precipitation corrections, the water balance, ($\overline{P_C}$+$\overline{R}$–$\overline{E}$), turns out to be well closed, that is its value is less than 1% of the precipitation and evaporation values (the dominant terms in the balance). The sole exception is the 1973-1978 period which, however, is affected by both errors in the precipitation at latitudes poleward of $\pm 30^\circ$ and in the evaporation field (see for instance the low PmE values just south of the equator in Fig. 1b). These errors have a different origin from the humidity scheme. They are likely to be connected to problems with the bias correction of some IR-channels on the VTPR instrument on early NOAA satellites.

When the precipitation correction is accounted for in the global precipitation field[1], the water budget is markedly improved (Table 2), except for a slight worsening in the period 1958-1963 (for this period, a coding error in some humidity observations lead to too dry analyses with reduced precipitation amounts). In particular, comparison of the third and fifth columns of Table 2 highlight the considerable reduction in the wet bias, especially for the more recent periods, i.e., from 1973 onward.

GLOBAL MEAN VALUES (mm day^{-1})				
Period	$\overline{P}$	$\overline{PmE}$	$\overline{P_C}$	$\overline{PmE_C}$
1958-1963	2.93	-0.028	2.90	-0.053
1964-1972	2.99	0.073	2.90	-0.014
1973-1978	3.19	0.36	2.97	0.13
1979-1988	3.19	0.24	2.97	-0.026
1989-2001	3.40	0.46	2.93	-0.002
GPCP (1979-2001)	2.63			

Table 2: Mean values for precipitation ($\overline{P}$), PmE, corrected precipitation ($\overline{P_C}$) and corrected PmE ($\overline{PmE_C}$).

To have an appreciation of the spatial distribution of the precipitation field and its correction, ERA-40 fields have been averaged over the period for which GPCP estimates are also available, i.e., the period 1979-2001. Figure 2 shows the original ERA-40 precipitation field, i.e., before the correction is applied. There is an extensive tropical band where precipitation is between 7 and 30 mm day^{-1} which is distinctly larger than the precipitation reported by the GPCP climatology (see Figure 3). For instance, in regions such as near Indonesia and west of Panama, precipitation exceeds 10 mm day^{-1} (Fig. 2), which is about 7-10 mm day^{-1} larger than GPCP (Fig. 3). More generally, differences between the original ERA-40 and GPCP are typically about 2-7 mm day^{-1} in the tropical oceans (Fig. 3).

Applying the precipitation correction to the ERA-40 analyses markedly reduces their spatial difference with the GPCP. Typical differences are now about 1.5-4 mm day on the positive side, i.e., ERA-40 wetter than GPCP. Some regions, such as the western tropical Pacific ocean and eastern tropical Indian ocean, are however drier than GPCP by about 1.5-2 mm day. Given the presence of positive and negative differences it appears to be possible to further reduce the differences between ERA-40 and GPCP. We have not attempted this fine tuning as this would involve having good knowledge of additional information, e.g. errors in the ERA-40 precipitation, which is an unknown itself.

[1] The correction has been applied to the oceanic component only.

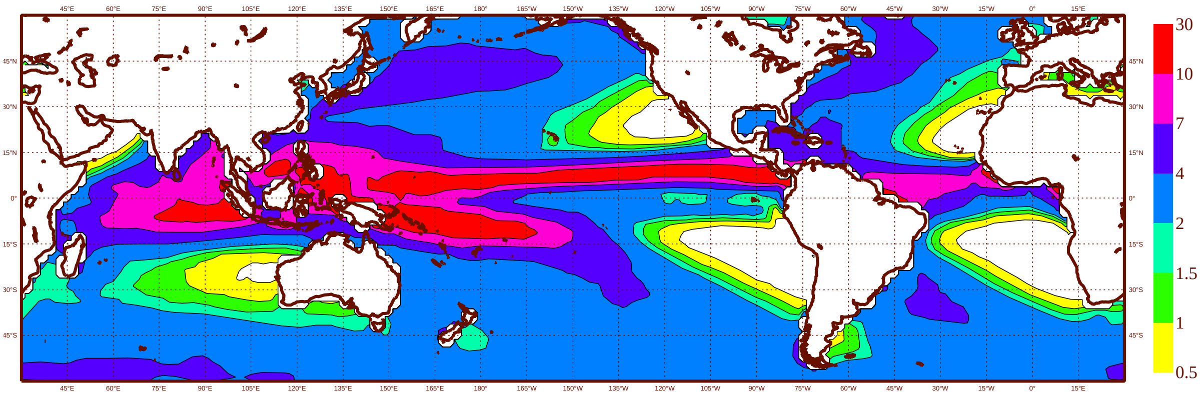

Figure 2: Original ERA-40 precipitation field averaged over 1979-2001 (in mm day $^{-1}$).

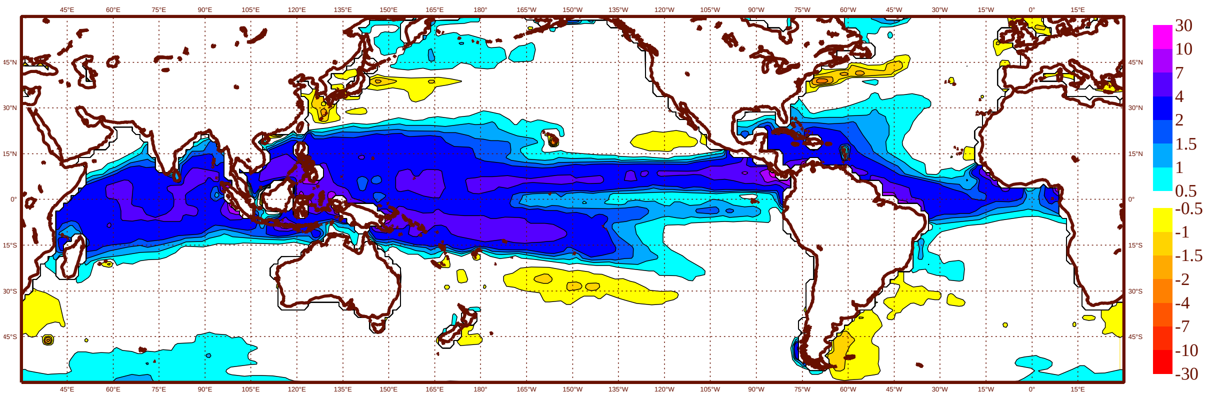

Figure 3: Difference between original ERA-40 precipitation and GPCP averaged over 1979-2001 (in mm day $^{-1}$).

4 Summary and discussion

A method to correct the excessive tropical precipitation over the oceans in the ERA-40 reanalysis has been presented. The basic idea of this method is the closure of the water budget. To this end, the assumption was made that the evaporation field is only affected by second order errors; for our purposes the evaporation is error-free.

The precipitation correction is only applied as a function of latitude and is different for each of the five periods in which the ERA-40 production phase was performed. The calculated correction coefficients are available from the authors. The daily fields modified using these coefficients are currently being used to force the ocean models participating in the ENACT project.

In this work, the precipitation correction has only been applied to the tropical oceanic areas, which are the places which display the largest errors. However, some large biases are also present over tropical land areas. For instance, a wet bias in excess of 5 mm day^{-1} is present over Africa (between 10°S and 10°N, not shown). A suggestion for future work might be to consider similar ways to correct precipitation biases over land.

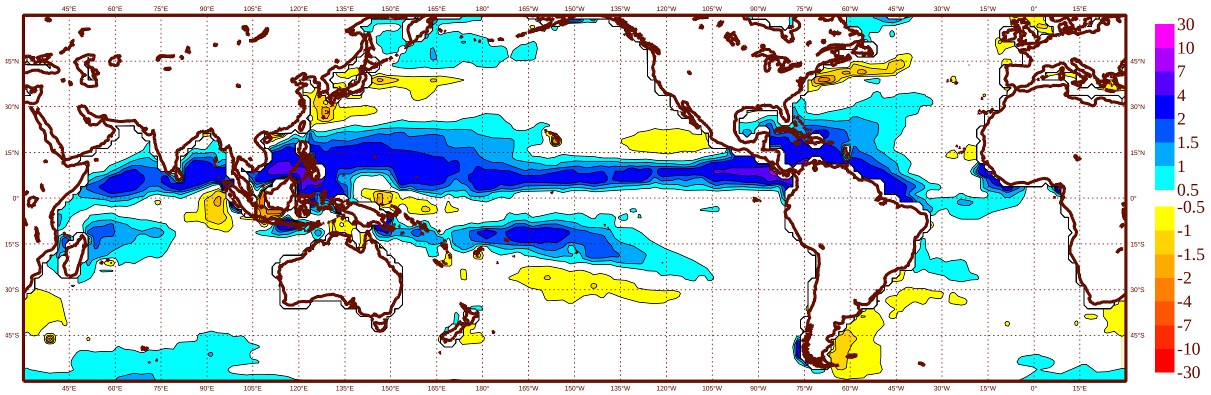

Figure 4: Difference between corrected ERA-40 precipitation and GPCP averaged over 1979-2001 (in mm day $^{-1}$).

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References

[1] G. J. Huffman, R. F. Adler, P. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, A. McNab, B. Rudolf, and U. Schneider. The Global Precipitation Climatology Project (GPCP) combined precipitation data set. *Bull. Am. Meteorol. Soc.*,, 78:5–20 (incl. cover), 1997.