Mean global surface pressure series evaluated from ECMWF reanalysis data

By KLAUS P. HOINKA*
Institut für Physik der Atmosphäre, DLR, Germany

(Received 21 October 1997; revised 27 February 1998)

SUMMARY

Time series (1979–93) of the global mean surface pressure are determined using data provided by the ECMWF ReAnalysis (ERA) project. Total pressure, water vapour pressure and dry-air pressure are evaluated. It is shown that a trend of only 0.01 hPa per decade exists for the total surface pressure whereas that of the water vapour surface pressure is 0.05 hPa per decade. This underlines the homogeneous character of the time series of ERA data, at least for the integral quantities surface pressure and water vapour surface pressure.

KEYWORDS: Homogeneity Reanalyses Time series Water vapour

1. INTRODUCTION

Since the early 1980s the European Centre for Medium-Range Weather Forecasts (ECMWF) has provided time series of globally analysed data in spherical harmonics. However, the entire time series of these data, from 1979 until 1993, suffers from the fact that several changes and modifications in the assimilation and analysis schemes have been introduced during that period. One example is the introduction of a new analysis scheme in August 1985. Trenberth et al. (1987; hereafter TCO) gave a list of modifications in the ECMWF assimilation/analysis system implemented between 1979 and 1985. The period from 1985 until 1993 is discussed by Trenberth and Guillemot (1994; hereafter TG). Similar homogeneity problems with the time series of the National Meteorological Center global analysis were reported by Schubert and Munteanu (1988). The changes implemented led the ECMWF to warn users of long time series of the ECMWF data. For instance, TG showed that the mean global surface pressure was very sensitive to modifications in the analysis schemes. They observed a trend of about 1 hPa per decade in both the total surface pressure and the water vapour pressure. They pointed out that these trends are '...confounded by system changes in the analyses at ECMWF'. Therefore, climatological studies based on data which are not of serial type (as those of the ECMWF ReAnalysis (ERA) project) might be disturbed by non-homogeneous and non-climatological artefacts and must therefore be considered with caution.

In 1993 a new analysis scheme was introduced at the ECMWF. Therefore it was a natural decision to implement the ERA project with the aim of providing a complete time series of data with global coverage all determined by the same assimilation and analysis schemes as those applied since 1993 (Gibson et al. 1997). Besides the main advantage of applying one analysis procedure to the entire time series, the second important point is that all available observational data were considered in the analyses. Because the operational analyses have to be done within a limited period of time, they consider only those observational data that are available before the analysis starts. Data which arrive after this so-called cut-off time are not considered in the operational analysis. This means that the observation density was improved for the ERA analyses.

The reanalysis data are expected to have a much more stable time series, but this has to be thoroughly checked. Therefore, the purpose of this paper is to show that the time series of the mean surface pressure, based on ERA data, does not contain significant trends. The total surface pressure and the water vapour surface pressure were chosen because both parameters are sensitive integral quantities. A further important point is that the data

* Corresponding address: Institut für Physik der Atmosphäre, DLR, Postfach 1116, D-82230, Wessling, Germany.
used have a spatial resolution of 1.125° in latitude and longitude; additionally there is an improvement in the vertical resolution of the data that are used for the determination of the integral quantity water vapour surface pressure. So, the data used here have a much better resolution than those in previous studies.

2. Data

The 15-year time series of global analyses starting January 1979 and ending December 1993 is considered. The ECMWF supplies these data in two versions: standard pressure-level data with 17 levels, and model-level data with 31 levels. Here the latter version is used because it contains nearly twice the number of levels. Among other parameters the data set contains pressure and humidity at the 31 levels as well as the surface pressure. The vertical profile data are used to evaluate the vertical integral of humidity which finally results in the surface pressure of water vapour. The total surface pressure is available directly at the surface level. For the climatic purpose of the present work it is sufficient to confine the analyses to one time per day, 12 UTC. The grid resolution used is 1.125° in latitude and longitude. This is the resolution that contains the maximum of physical information because the analysis scheme applied in the ERA project is based on the truncation T106.

The archived surface pressure corresponds to a surface of ‘mean’ orography. The ECMWF representation is spectral so that the surface has extensive ripples over the ocean, arising from Gibbs phenomenon (ringing). Because of this, the model surface pressure represents the real surface pressure field only to a certain extent. For various purposes, e.g. the determination of the mass of the global atmosphere, it is therefore necessary to re-evaluate the surface pressure in order to get a better estimate of the real surface pressure (see, for example, TG). The purpose of this paper is to test the homogeneity of the data series; therefore it is not necessary to re-evaluate the model surface pressure. For the present test it is sufficient to show that the mean global surface pressure provided by the analysis does not contain trends like those observed by using the time series of the operational ECMWF analyses. This would be a corroboration that the ERA data series is homogeneous, at least for the parameters under consideration.

The total surface pressure, $p_s$, and the water vapour surface pressure, $p_w$, are determined daily for the period from 1979 until 1993. The latter is computed from the specific humidity $q$ using

$$p_w = \int_{p_s}^{p_t} q \, dp.$$ 

The integration is carried out by using finite differences and assuming that the top level, $p_t$, is 10 hPa. The $p_w$ has the units of hPa and when divided by gravity $g$ and by the density of water, taken as 1000 kg m$^{-3}$, is expressed as millimeters of liquid water. TG pointed out that ‘... both ($p_s$, $p_w$) are measures of the water vapour loading of the atmosphere, the only way to check on the reality of trends is to examine also the dry-air surface pressure ($p_d$)’. This is evaluated by: $p_d = p_s - p_w$. The time series of the deviations from the global means are determined by removing the zonal mean and the zonal annual cycle from the original data. The global average is then obtained by weighting the gridded data value by the corresponding representative grid area.

3. Results

Table 1 shows mean orographic heights. Apparently, the global mean topographic height depends strongly on the database and on the resolution of data. TCO reported a
value of 237.3 m derived from the 1°/6° latitude–longitude topography prepared by the US Navy Fleet Numerical Oceanography Center. Based on the T42 version of the ECMWF model TG arrived at a global mean topographical value of 237.4 m. The corresponding mean value, as obtained with the 1.125° resolution, is 238.9 m. The values arising from a 1.125° grid are slightly larger than those of TCO and TG. The hemispheric mean values behave correspondingly. Table 2 gives a comparison of mean surface pressures. Table 3 summarizes water vapour surface pressures from various sources. TCO estimated the mean global pressures as 984.4 hPa for $p_s$, 981.6 hPa for $p_d$, and 2.8 hPa for $p_w$ for the period from 1979 until 1985; for 1985–93 the values are: 984.7, 982.1, and 2.6 hPa, respectively.

Based on the ERA data, the mean values for the entire period from 1979 until 1993 are 984.5, 982.2, and 2.4 hPa, respectively. The mean $p_s$ is about 0.2 hPa smaller in magnitude
than that determined by TG because the mean global orography used here is about 1.5 m larger.

The water vapour surface pressure \( p_w \) is 2.37 hPa and corresponds to 24.2 mm of precipitable water. The water vapour surface pressure as determined by Källberg (1998) is 2.38 hPa (24.3 mm). This weak difference of 0.4% between both estimates might be caused by different ways of calculating, e.g. Källberg (1998) used the data on a Gaussian grid. For the period from 1988 to 1992 he showed that the ERA average is about 0.04 hPa wetter than the corresponding value derived from the data provided by the NASA* Water Vapor Project (Randal et al. 1996). Källberg also pointed out that the daily mean values obtained from 00 06, 12, and 18 UTC are similar to the noon value. This suggests that it is sufficient to consider only the 12 UTC time series. Global estimates based on observed and analysed data range between 2.29 and 2.48 hPa (Ross and Elliott 1996; Randal et al. 1996) which means that the magnitude of 2.37 hPa is in good agreement with observed estimates. The reanalysed time series reproduce the integral quantity water vapour surface pressure much better than was the case for the operational analysis (TCO; TG).

Figure 1 shows the global and hemispheric mean \( p_s \), \( p_w \), and \( p_d \) annual cycles as departures from their annual means. The hemispheric amplitudes for all three pressures are very similar in magnitude and month to those for 1979–85 (TCO) and 1985–93 (TG). This is also the case for the global annual cycles of \( p_s \) and \( p_w \). The seasonal variation in \( p_s \) is between −0.18 and +0.22 hPa which is similar to that given by TCO. The annual cycle of \( p_w \) ranging between −0.11 and 0.14 hPa is not as strong as that determined by TG for the shorter period from 1985 until 1993. The reason for this might be that the observational input database is different. However, a similar value of the annual variation of global \( p_w \) of 0.36 hPa is derived from satellite data (Wittmeyer and Vonder Haar 1994). The mean annual cycles of the area-weighted \( p_s \) and \( p_w \) as functions of latitude reveal similar structures and amplitudes as those reported by, for example, TG. Therefore they are not reproduced here.

It is expected that the annual cycle for \( p_d \) should be completely constant. Figure 1 exhibits a variation in the mean global \( p_d \), however, of less than 0.1 hPa which is slightly greater in magnitude than that reported by TCO. The annual cycle varies between −0.06 and +0.08 hPa. As shown earlier the annual variation of \( p_s \) is similar to that published elsewhere whereas the annual variation of \( p_w \) is weaker than observed. It is suggestive that the \( p_d \) variation comes from the weaker \( p_w \) variation. It is not clear what might have caused this degradation in results for the ERA data series in comparison with the operational analysis series. One possibility could be that the input database used is different, as mentioned in the introduction.

Figure 2 gives time series of the departures in \( p_s \), \( p_w \), and \( p_d \) from their corresponding mean annual cycles for the period from 1979 to 1993. These figures should be compared with Figs. 5 and 6 of TCO and Fig. 4 of TG. They show that during short periods of time, changes in the deviations appeared particularly in the time series of water vapour surface pressure. Figure 2 clearly shows that no steps appeared in any of the time series presented although they did with operational ECMWF data. The standard deviations of the series of daily values are the following: 0.10 hPa for \( p_s \), 0.07 hPa for \( p_w \), and 0.12 hPa for \( p_d \). The values for the time series of monthly mean data are: 0.05 hPa for \( p_s \), 0.06 hPa for \( p_w \), and 0.08 hPa for \( p_d \). Corresponding standard deviation values are not published for the data series of the operational analyses, with one exception for \( p_s \), for which TCO reported a monthly value of 0.1 hPa. The correlation coefficients of the global variations are the following: 0.8 between \( p_s \) and \( p_d \), −0.6 between \( p_w \) and \( p_d \), and less than 0.1 between

* National Aeronautics and Space Administration.
Figure 1. Mean annual cycle for 1979–93 of the departures from the annual mean of (a) total surface pressure $p_s$, (b) water vapour surface pressure $p_w$, and (c) dry-air surface pressure $p_d = p_s - p_w$. Values are shown for the northern (NH), southern (SH) hemisphere and the globe.

$p_s$ and $p_w$. Again, from the literature corresponding values are not available for the data series of the operational analyses.

The very important result shown by TCO and TG was that the series in $p_s$ and $p_w$ are not stationary for the operational ECMWF data series. An increase in total surface pressure of about 0.5 hPa between 1985 and 1993 was determined. Here, however, the trends for the three pressure series based on the new ERA data are much weaker: $-0.01$ for $p_s$, $+0.05$ for $p_w$, and $-0.06$ for $p_d$, all in hPa per decade. The confidence levels of these trends, tested by the non-parametric Mann–Kendall trend test (Sneyers 1990), are: 80% for $p_s$ and 99% for $p_w$ and $p_d$. The very weak trends show very clearly the homogeneous character of the time series of the ERA data, at least for surface pressure and humidity. In Fig. 2,
even if the trends in $p_w$ are small, there is evidence of decadal variability. This points to a shortcoming of the ERA data, the cause of which is under investigation (Källberg (1998), personal communication).

4. CONCLUSION

The sensitive integral quantities total air pressure, water vapour pressure and dry-air pressure were checked from model data at T106 truncation of the ECMWF ReAnalysis project. The main findings are:
(i) the trends per decade are $-0.01$ hPa for $p_s$, $+0.05$ hPa for $p_w$, and $-0.06$ hPa for $p_d$; these trends are much weaker than those for the time series of the operational data;
(ii) the standard deviations are $0.10$ hPa for $p_s$, $0.07$ hPa for $p_w$ and $0.12$ hPa for $p_d$;
(iii) the magnitude of the mean global water vapour surface pressure is in good agreement with observed estimates; the reanalysed time series reproduce it much better than was the case for the operational analysis until 1993;
(iv) the mean annual cycle in the water vapour surface pressure is slightly weaker than that for the time series of the operational data; and
(v) the departures from the mean annual cycle of the mean dry-air surface pressure exhibits variations of less than $0.1$ hPa.

The present diagnosis is useful background information for data providers as well as for future users. The analysis presented shows that the time series of ERA data is very stable, at least for the integral quantities discussed. This emphasises that these data are an excellent database for studying global climatic features.

ACKNOWLEDGEMENTS

The data were provided by the ECMWF within a ‘Special project’ under the title ‘The climatology of the global tropopause’. Per Källberg (ECMWF) is thanked for providing additional information.

REFERENCES

Källberg, P. 1998 ‘Aspects of the re-analysed climate. ERA description’. ECMWF ReAnalysis Project Report Series No. 2. ECMWF, Reading, UK