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A comparison of operational global analyses from the European Centre for Medium Range Weather Forecasts (ECMWF) and the National Meteorological Center (NMC)

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ABSTRACT

A comparison of the analyses from the ECMWF/WMO Global Analysis Dataset produced by the European Centre for Medium Range Weather Forecasts (ECMWF) and the operational analyses of the National Meteorological Center (NMC) is made for an average of five Januaries and five Julys during the period 1980–1984 to assess the utility of these datasets for climate and other studies. The time and zonal mean, the square root of the zonally averaged standing eddy variance and the square root of the zonally averaged transient eddy variance are computed for the differences in the analyses of the horizontal wind components, temperature, geopotential, and specific humidity. A "reliability" measure which compares the variance of the differences to observed variances is used to assess the datasets. The results indicate that monthly means and daily analyses of the five variables are not reliable in the tropics nor in the south polar regions. In general, reliable monthly means and daily analyses are found in the mid-latitudes of the Southern Hemisphere and in the extra-tropical Northern Hemisphere, with the exception of the daily analyses of specific humidity which are reliable only in the extra-tropics of the Northern Hemisphere during January.

1. Introduction

Routine global analysis and forecasting is performed by several numerical forecast centres, and provides a convenient source of data for climate research. At the present time, the most readily available global objective analyses are the operational analyses of the National Meteorological Center (NMC) and the analyses contained in the ECMWF/WMO Global Analysis Dataset produced by the European Centre for Medium Range Weather Forecasts (ECMWF).

Since objective analyses are increasingly being used for the calculation of general circulation statistics, their utility for that purpose should be assessed. Daley and Mayer (1986) discuss four methods used to estimate the difference between an objective analysis and the true state of the atmosphere. The first of these involves making a forecast from an objective analysis and determining the forecast error as a function of time. Extrapolation of the error back to the initial time provides a global estimate of the initial error or quality of the initial analysis. The second is to do the objective analysis using a statistical interpolation technique (Lorenc, 1981) with its resulting estimate of the analysis error, the third is a comparison of two objective analyses valid for the same time (Lau, 1984) and the fourth is an Observation System Simulation Experiment (OSSE) (Daley and Mayer, 1986).

The present study adopts the third approach. A comparison is made of the analyses of the wind components (u, v), temperature (T), geopotential (Φ), and specific humidity (q) from the NMC and the ECMWF/WMO datasets for January and July for the 5-year period from 1980 to 1984. The method of direct comparison of the two objective analyses is used since it is the only method available to users of the data who are not involved in its production and because of its simplicity and straightforwardness.

2. Data

The NMC operational analysis procedure is described in McPherson et al. (1979). It is a three-dimensional statistical interpolation scheme which locally updates a nine-level primitive equation model every six hours. In this system the fields are updated on the model's sigma surfaces rather than on the analysis pressure surfaces. The analyses are available on 12 pressure levels, 50 mb, 70 mb, 100 mb, 150 mb, 200 mb, 250 mb, 300 mb, 400 mb, 500 mb, 700 mb, 850 mb and 1000 mb as grid point values on a global 2.5 degree by 2.5 degree latitude-longitude grid. The temporal resolution of the data is 12 hours; however, there are missing observation times.

Operational analysis systems are continually changed and upgraded. It is often difficult to learn the details of these changes and rather more difficult to determine their influence on the objective analyses. Miller and Krueger (1984) list without comment, the following "major" changes in the NMC analyses during 1980 to 1982. In May 1980, the grid point model was replaced by a spectral model and an adiabatic non-linear normal mode initialization was introduced. In January 1982, the mass-wind field relationship was changed and in August 1982, multivariate analysis was incorporated. They were not able to determine the precise changes in the analyses with any degree of confidence.

The ECMWF/WMO dataset contains a subset of the *initialized* objective analyses produced by the ECMWF. The ECMWF analysis system is described in Bengtsson et al. (1982). It is a three-dimensional multivariate optimum interpolation system and uses the Machenhauer (1977) non-linear normal mode initialization scheme which initializes five vertical modes. The analyses are available on only seven pressure levels, 100 mb, 200 mb, 300 mb, 500 mb, 700 mb, 850 mb and 1000 mb as point values on a global latitude-longitude grid with a resolution of 2.5° by 2.5°. The analyses are available once per day at 1200 GMT and there are no missing analyses during the 5-year period.

Arpe et al. (1986) have listed some important changes to the ECMWF analysis system. From December 1980 onwards, the analysis increments were interpolated from the analysis pressure levels to the model sigma levels. Previously, the entire analysis had been interpolated which resulted in excessive smoothing. In April 1981, the smooth orography used in the model was replaced by a more realistic one. The adiabatic initialization scheme was replaced by one which included diabatic affects in September 1982, resulting in an improvement of the analysis of the Hadley circulation. April 1983 saw the replacement of the grid point model by a spectral model which used an envelope orography. In May 1984 several aspects of the analysis system were revised (Shaw et al., 1984) and a diurnal cycle in the model's radiation calculations was introduced.

As a quality control measure in this study, the January and July monthly means of the zonally averaged transient eddy variances for the 5 fields being compared were computed and examined separately for each dataset in order to identify fields which might have been damaged during archival and transmission. As a result of this procedure, it is believed that no seriously defective analyses have been used in the comparison.

3. Analysis

Difference statistics are computed from the two datasets at the 100 mb, 200 mb, 300 mb, 500 mb, 700 mb, 850 mb and 1000 mb levels at 1200 GMT for each day of the 5 Januaries and 5 Julys between 1980 and 1984. Even though the datasets contain analyses of many fields, a comparison is made only for the horizontal wind components, temperature and geopotential height converted to geopotential. The relative humidity is changed to specific humidity and a comparison is made on the five lowest pressure levels. If an NMC observation time is missing, the corresponding observation time in the ECMWF/WMO dataset is also removed.

The two datasets are compared by computing the zonally averaged mean square difference between the two datasets. This statistic can be expanded in the following manner:

$$[\overline{D\,D}] = [\bar{D}][\bar{D}] + [\bar{D}^*\bar{D}^*] + [\overline{D'D'}] \quad (1)$$

where D is the difference obtained by subtracting the ECMWF/WMO analyzed value of a variable from the corresponding NMC analyzed value. The brackets represent a zonal average and the asterisk a deviation from it, while the overbar represents a time average and the prime a departure from it.

The 1st term on the RHS of (1) is a measure of the difference of time and zonal averages. The 2nd term, which is referred to as the "standing eddy" term, reflects systematic geographical differences between the two analyses and the 3rd or "transient eddy" term is a measure of the typical day-to-day differences. Alternately, the sum of the first two terms may be regarded as a measure of how well the analyses can provide a measure of a monthly mean quantity on a pressure surface while the sum of all three terms is a indication of the fidelity of the daily analyses.

The approach of computing the statistics of the differences used in the present study differs from that of Lau (1984) who computed the differences of the statistics computed separately from each of the datasets. If one adopts the latter method, the results must be displayed on global pressure surfaces in order to ascertain the agreement or lack of agreement between the datasets. Using only the differences between zonally averaged statistics, one cannot infer the agreement between the two datasets and a comparison of multi-level datasets requires a large number of figures.

In using the present approach, the agreement between the two datasets can be assessed using only zonally averaged statistics with a resulting reduction in the number of figures. In doing so, however, information on the longitudinal distribution of the differences is lost.

The existence of relatively large standing eddy and transient eddy components of the differences does not necessarily imply poor agreement between the analyses if the differences are small compared to the observed standing eddy and transient eddy variances. Hence, in addition to examining the absolute difference terms, the differences relative to the observed variance are also examined. This is done by expressing the standing eddy variance term and the transient eddy variance term of the RHS of (1) as a fraction of the observed standing eddy and transient eddy variances respectively. These normalized variances are defined as:

$$V_{se} = [\bar{D}^*\bar{D}^*]/[\bar{X}^*\bar{X}^*]_{obs}, \quad (2)$$

$$V_{te} = [\overline{D'D'}]/[\overline{X'X'}]_{obs}, \quad (3)$$

where V_{se} is the standing eddy normalized variance, V_{te} is the transient eddy normalized variance and $X = \{u, v, \Phi, T, q\}$.

As the normalized variances become larger and larger, the analyses become increasingly less reliable. In the results that follow, the analyses are termed "reliable" if the normalized variances are 0.5 or less. This is an arbitrary choice, and for certain applications, differences of this magnitude may not be acceptable, while for others, the data may be considered "reliable" at even higher values of the normalized variance.

Small differences between the two datasets may nevertheless give rise to large values of the variance ratios where the observed variances are small. In such cases, the variance ratios are not a particularly appropriate measure for comparing the datasets. This difficulty occurs mainly near the poles for the standing eddy terms since both the standing eddy differences and the observed standing eddy variances are small there. In the following results, large isolated values of V_{se} near the poles are not taken into account when comparing the datasets.

The low-level pressure surfaces intersect the Earth's surface and the data producers generate fictitious subterranean values in order to make the fields continuous. Some applications, for example, spectral analysis of the data make use of these subterranean values and they are compared between the datasets as well.

4. Results

The global RMS differences as a function of pressure are given in Table 1 for the horizontal wind components, geopotential, temperature and

Table 1. *Global RMS differences between the NMC operational analyses and the ECMWF/WMO dataset during January and July for the period 1980–1984*

January					
p (mb)	u (ms^{-1})	v (ms^{-1})	Φ (m^2s^{-2})	T (K)	q (gkg^{-1})
100	6.2	5.1	470	2.6	
200	5.5	5.0	330	2.2	
300	5.6	4.8	320	1.6	0.2
500	4.0	3.7	240	1.6	0.8
700	3.8	3.2	230	2.1	1.8
850	3.5	3.0	230	2.4	2.4
1000	3.8	3.4	260	4.5	3.3

July					
p (mb)	u (ms^{-1})	v (ms^{-1})	Φ (m^2s^{-2})	T (K)	q (gkg^{-1})
100	6.8	5.2	690	2.2	
200	6.4	5.3	570	2.4	
300	6.2	5.2	520	1.8	0.2
500	4.5	3.9	370	2.0	1.0
700	4.2	3.6	300	2.9	2.2
850	3.8	3.3	270	3.6	3.3
1000	3.5	3.3	320	5.9	3.4

specific humidity for January and July. The minimum differences in the wind and geopotential occur at the 850 mb level and between temperatures near the 300 mb level. The specific humidity field shows the largest differences in the low levels where moisture is a maximum. Table 1 also shows that the differences tend to be larger in July than in January when the poorly observed Southern hemisphere is the more active.

Similar global RMS differences between the ECMWF FGGE Level III-b and the NMC FGGE Level III-a datasets for January and July 1979 are given by Lambert (1985). A comparison of those results with the present ones shows that the differences are qualitatively and quantitatively similar in spite of the fact that one set of differences applies to the FGGE year with its augmented observing systems.

Three latitude-pressure cross-sections in each figure display the results in terms of eqs. (1–3). The upper cross-section shows the time and zonal mean with shaded negative values. The middle cross-section displays the square root of the standing eddy term using solid contours and the standing eddy normalized variance, V_{se}, of eq. (2) using dashed contours. Values of this "reliability measure" greater than 0.5 are shaded. The lower cross-section displays the square root of the transient eddy term using solid contours and the transient eddy normalized variance, V_{te}, of (3) using dashed contours. Values greater than 0.5 are again shaded. A non-uniform contour interval is used to display the normalized variances, with the lowest contour value at 0.5, and successive contour values are double the previous one. An indication of those regions for which appreciable "subterranean" data are present is given by the dotted line, for which, one-half of the grid points contributing to the zonal average lie below ground.

Fig. 1 displays the results for the January zonal wind. The time and zonal mean shows that the large differences occur in the tropics and in the south polar regions where the observed temporally and zonally averaged zonal winds tend to be weak. This suggests that the datasets cannot give a reliable measure of even such a heavily averaged field in the tropics and in the south polar area. The two datasets agree rather well in the area of the tropospheric jets with typical differences of 1 ms^{-1}. The largest differences are found above the tropospheric jet in the winter hemisphere. This is a data sparse region and the large differences could arise from the difference in the systematic errors of the two models used in the analysis systems.

The middle cross-section shows a similar behaviour for the standing eddy results. Both the standing eddy differences and the normalized standing eddy variance have comparatively large values in the tropics and in the south polar regions indicating that monthly means of the standing eddy zonal wind are unreliable in these areas. The transient eddy results also show the tropical and south polar difficulties but indicate that useful information is present in a typical daily analysis for the mid-latitudes of the Southern Hemisphere and the extra-tropical Northern Hemisphere. As might be expected, the analyses of the Southern Hemisphere mid-latitudes are less reliable than those of the Northern Hemisphere since the transient eddy variance of its differences is typically four times that of the Northern Hemisphere mid-latitudes.

The July results for the zonal wind are displayed in Fig. 2. The character of the differences in July is similar to that of January showing large differences in the tropics, over Antarctica and above the winter hemisphere's tropospheric jet. There are especially large values of the differences of the time and zonal mean near the South Pole and in this area the two analyses do not even agree on the sign of the mean zonal wind. Both the standing eddy and the transient eddy differences in the mid-latitudes of the Northern Hemisphere are slightly small than those of January while in the Southern Hemisphere mid-latitudes the standing eddy and the transient eddy differences are slightly higher than those of January. The shaded values of V_{se} near the North Pole are probably the result of small differences and low variability as discussed in the previous section and consequently have been disregarded in assessing the data.

Fig. 3 gives the results for the meridional wind for January. The differences of the time and zonal means are of the same order of magnitude as observed values indicating questionable reliability of this difficult to observe field. The standing eddy differences show large values in the polar regions, the tropics and the upper level sub-tropics. The normalized variance indicates that reliable monthly means can be obtained from the datasets except in the tropics and the south polar regions. A similar result is shown by the transient eddy statistics for a typical daily analysis.

The July results for the meridional wind are displayed in Fig. 4. As was the case for the zonal wind, the July meridional wind results are very similar to the January results. The main difference is that there has been a slight increase in the differences in the mid-latitudes of the Southern Hemisphere.

Fig. 5 gives the results for the January temperature field. The differences in the time and zonal mean are of the order of 1K except in the upper levels over Antarctica and in a few locations at the 1000 mb level. Much of the 1000 mb level lies below the ground and the differences present at this level are strongly influenced by the procedures used to extrapolate below ground during the production of the analyses.

The standing eddy results show the largest differences at 1000 mb and near the South Pole. The normalized variance shows that a monthly mean chart is not reliable in the tropics and in the upper levels in the Southern Hemisphere. The transient eddy differences show large values in the Antarctic and the upper levels in the tropics. The normalized variance indicates that a typical daily analysis from the mid-latitudes and north polar regions is reliable except at 1000 mb.

The July results for the temperature are given in Fig. 6 and they delineate nearly the same areas where the data would be considered reliable as the January results, accompanied by a slight increase in the differences in the mid-latitudes of the Southern Hemisphere. Near the North Pole, there has been a deterioration of the quality of a typical daily analysis as shown by the values of the transient eddy variance ratios which are near 0.5.

Fig. 7 gives the January results for the geopotential. The largest differences in the time and zonal means occur near 100 mb especially over Antarctica Differences in the tropics are generally small. The standing eddy results show large values in the south polar regions and the normalized variance suggests that monthly means based on the two datasets will not be reliable in the tropics and in the south polar regions. The transient eddy results show large differences near the poles and in the upper levels. The normalized variance indicates that a typical daily analysis in the mid-latitudes is reliable with the Southern Hemisphere data being less reliable than those of the Northern Hemisphere.

The July geopotential results are displayed in Fig. 8. There are large differences in the time and zonal mean in the south polar areas reaching nearly 3000 m^2s^{-2} at the South Pole indicating that time and zonal means cannot be computed with confidence in the Antarctic. The character of the standing eddy and the transient eddy results are similar to those of January, suggesting that monthly means on pressure surfaces and typical daily analyses are not reliable in the tropics and over Antarctica.

Fig. 9 displays the January results for the specific humidity. The time and zonal means obtained from the two datasets are reliable except

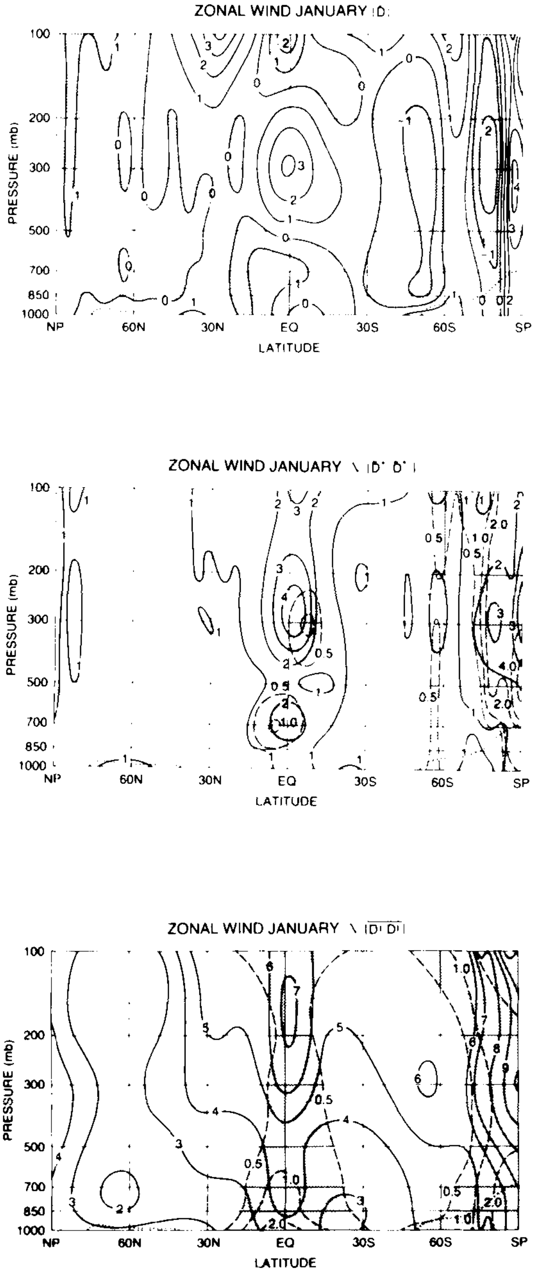

Fig. 1. The upper chart is the time and zonal average of the difference $[\bar{D}]$, between the NMC operational analyses and the ECMWF/WMO dataset for the zonal wind in ms^{-1} for an average of 5 Januaries from 1980 to 1984. The middle chart gives the square root of the standing eddy difference in ms^{-1} in solid contours and gives the standing eddy normalized variance in non-uniformly spaced dashed contours with values of 0.5 or greater shaded. The lower chart gives the square root of the transient eddy difference in ms^{-1} in solid contours and the transient eddy normalized variance in non-uniformly spaced dashed contours with values of 0.5 or greater shaded.

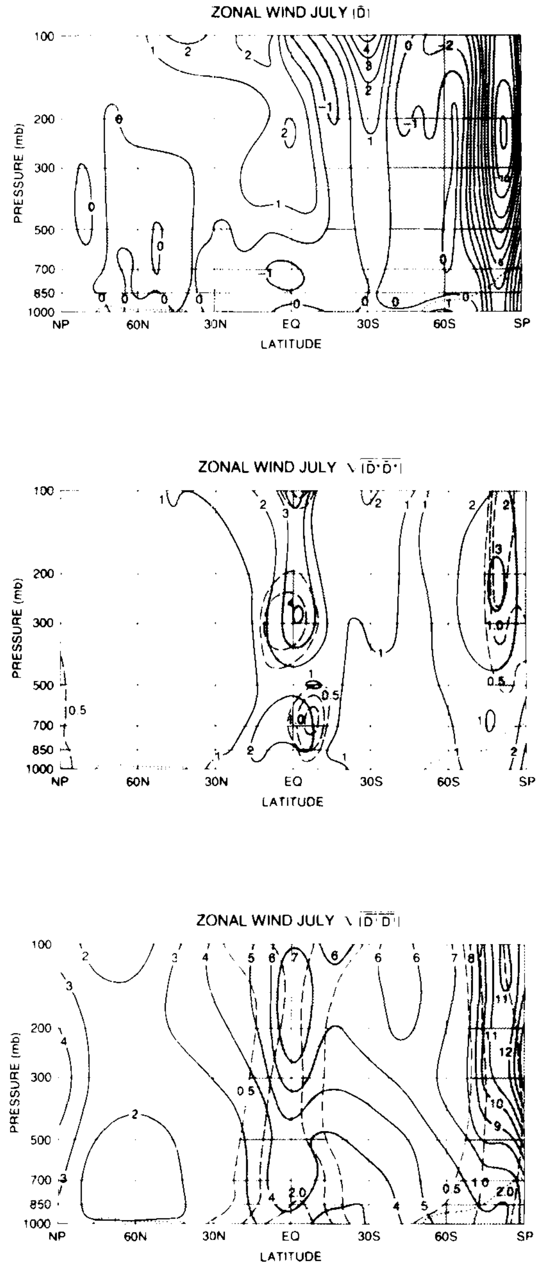

Fig. 2. Same as Fig. 1 except for July.

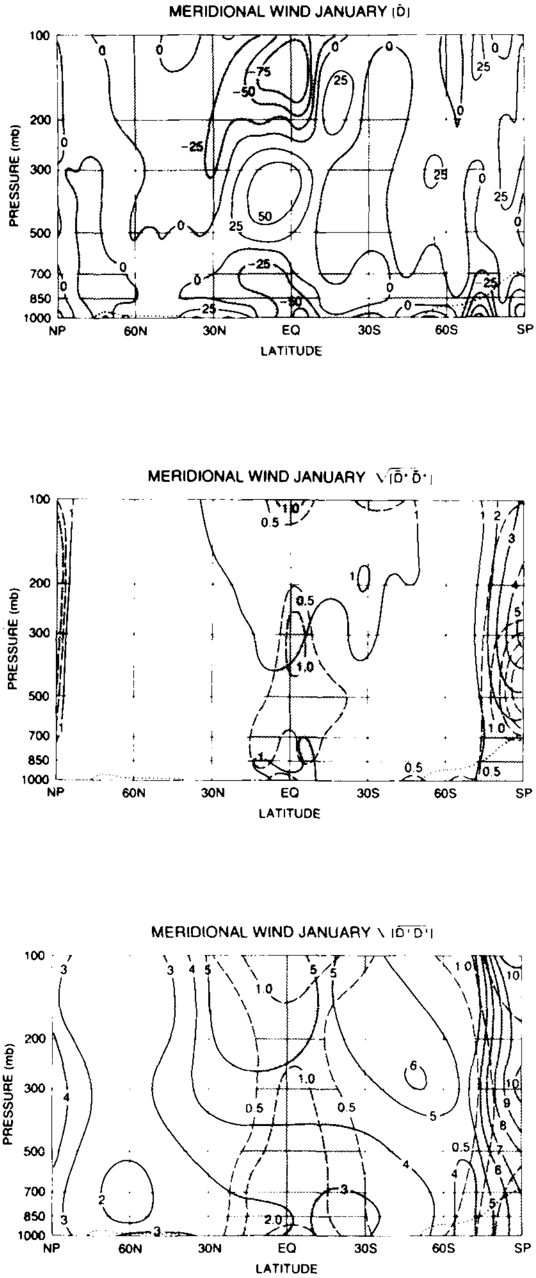

Fig. 3. Same as Fig. 1 except for the meridional wind. The units of $[\bar{D}]$ are cms^{-1}.

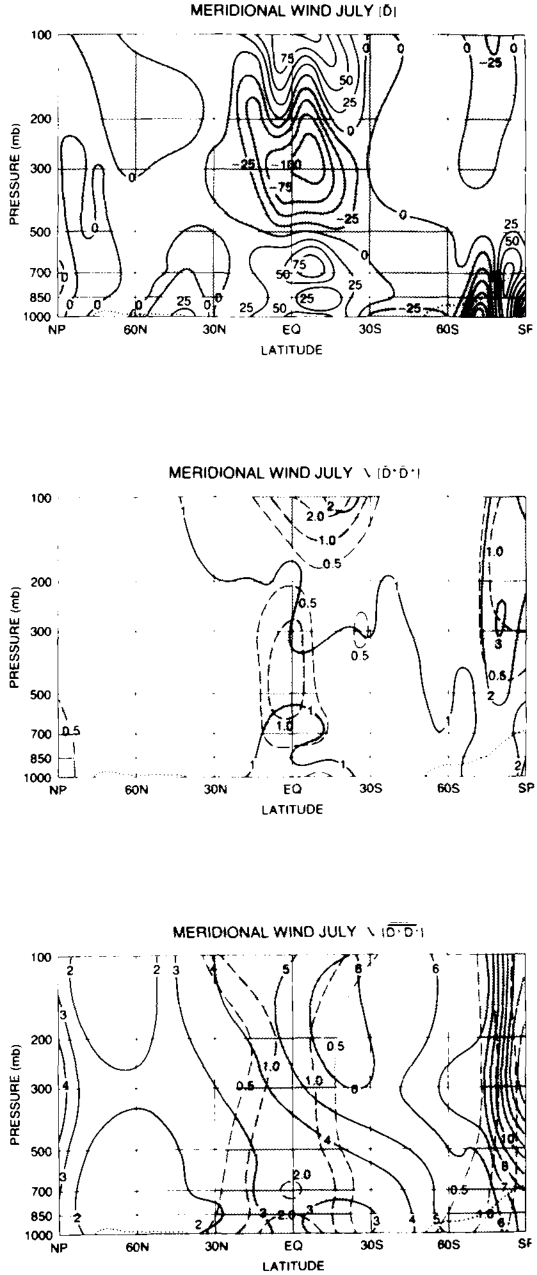

Fig. 4. Same as Fig. 3 except for the meridional wind for July.

in the southern polar region where the differences are as large as the observed values. The standing eddy results show, as expected, that the largest differences occur in the low levels in the tropics. In the figure, values of the normalized variance greater than 1.0 are shaded, instead of the 0.5 used in the previous figures. The normalized variance indicates that monthly means are reli-

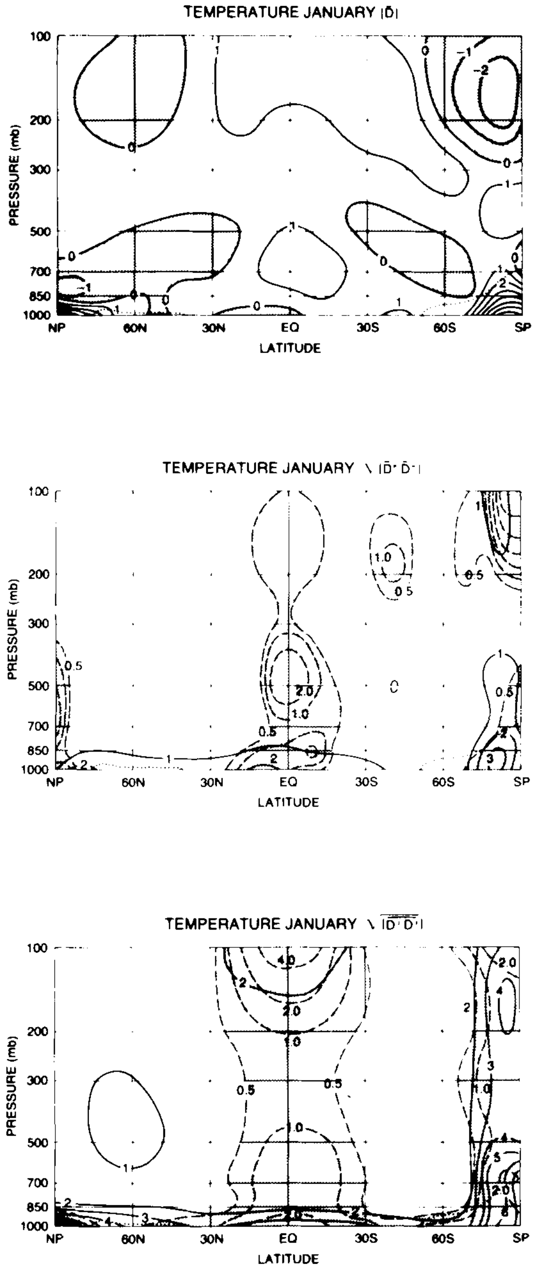

Fig. 5. Same as Fig. 1 except for the temperature with the differences in K.

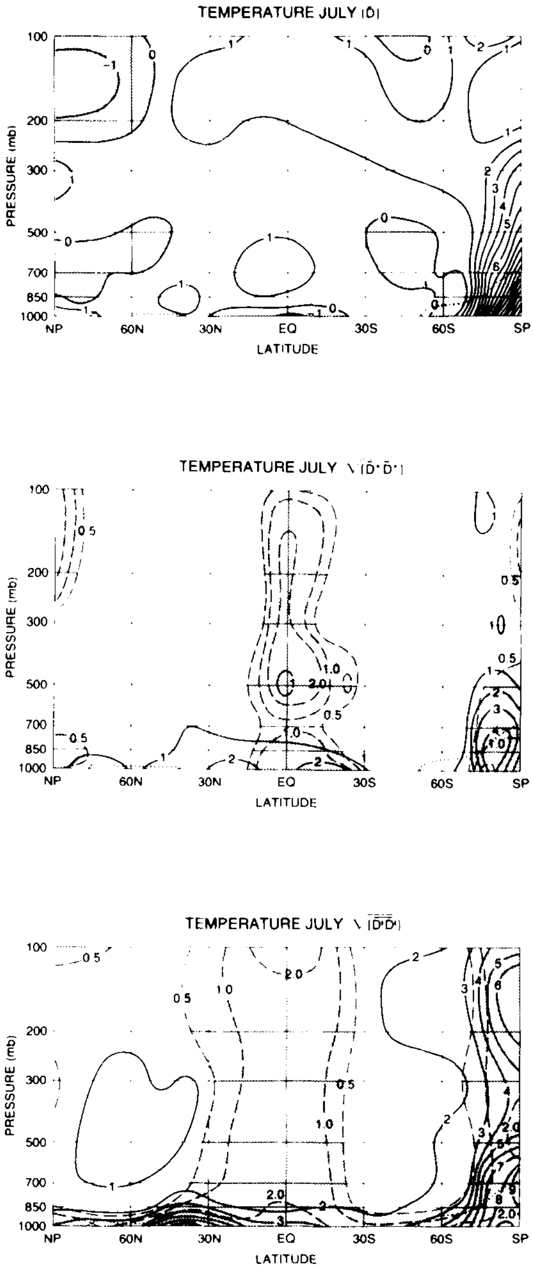

Fig. 6. Same as Fig. 5 except for the temperature for July.

able in the mid-latitudes of the Northern Hemisphere, in the sub-tropics of the Southern Hemisphere and in the low pressure trough surrounding Antarctica. The transient eddy statistics show the largest differences in the tropics and the normalized variance indicates that a typical daily analysis of specific humidity is reliable only in the mid-latitudes of the Northern Hemisphere between 500 mb and 850 mb.

The July results for the specific humidity are

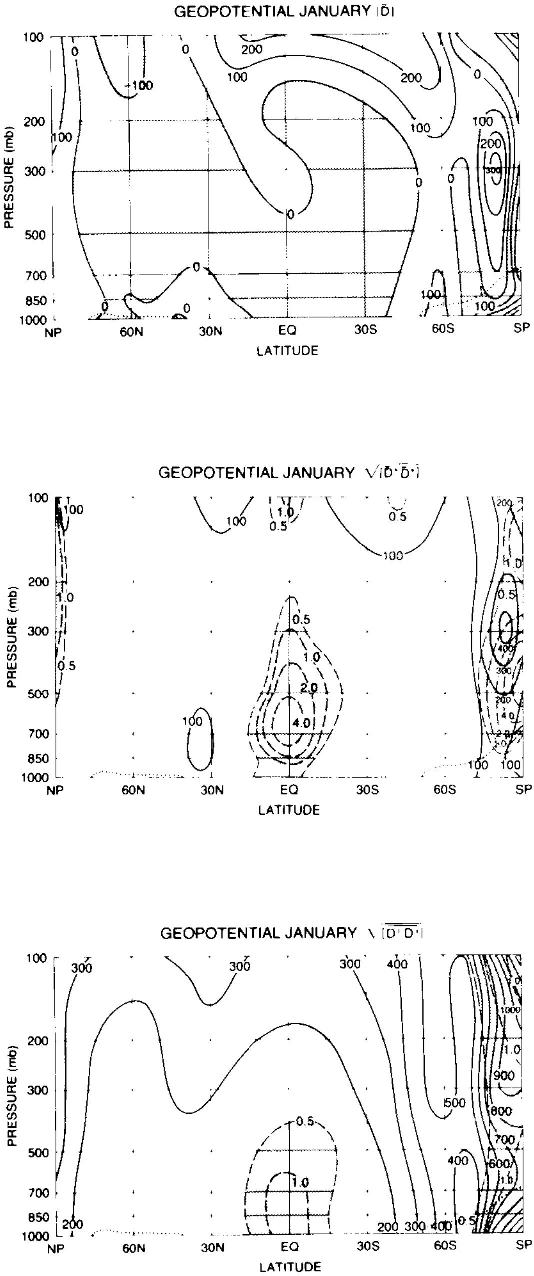

Fig. 7. Same as Fig. 1 except for the geopotential with the differences in m^2s^{-2}.

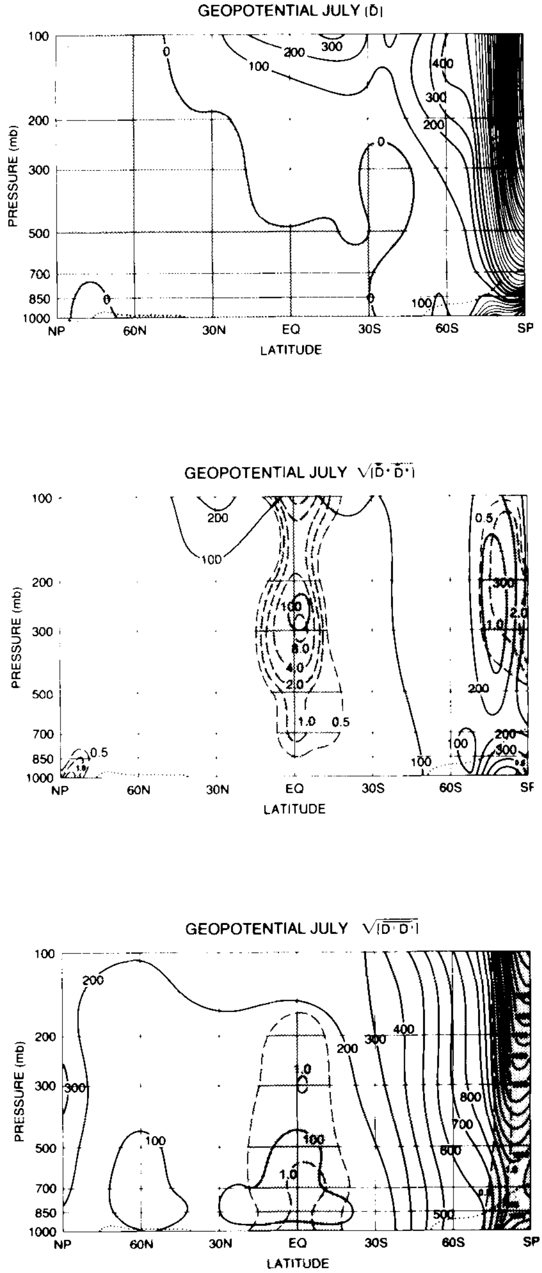

Fig. 8. Same as Fig. 7 except for the geopotential for July.

given in Fig. 10. These results show an overall deterioration of reliability compared to that of January. The standing eddy normalized variance and the transient eddy normalized variance indicate that, except for a few small areas, reliable measures of monthly means and typical daily analyses cannot be obtained from the two datasets during July.

It is interesting to compare the difference statistics for January and July year by year. One

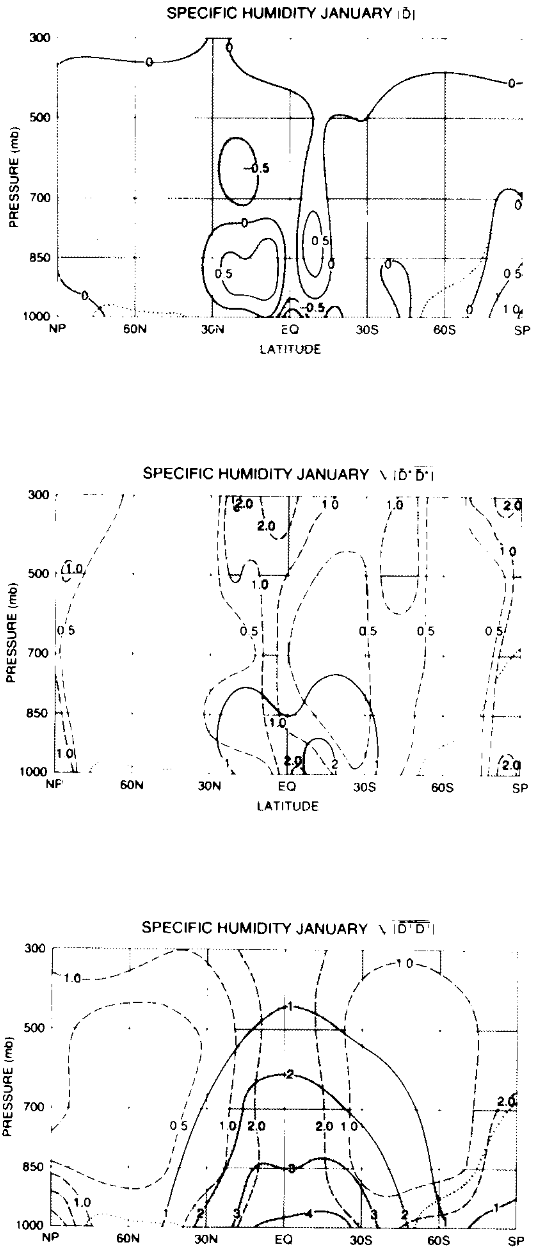

Fig. 9. Same as Fig. 1 except for the specific humidity and values of the normalized variances are shaded for 1.0 and above. The differences are in gkg^{-1}.

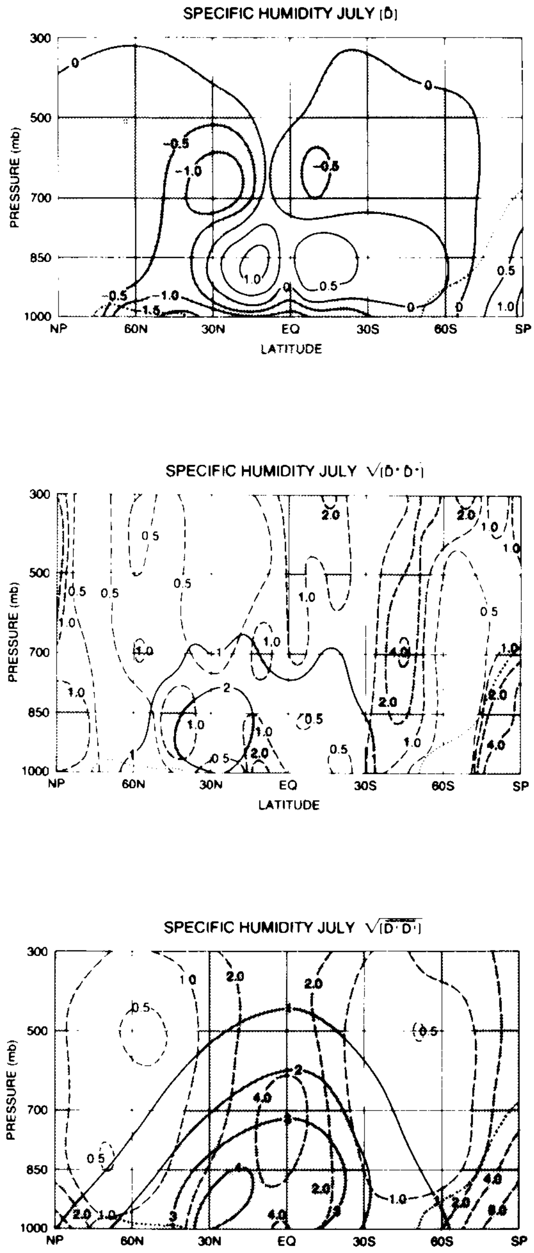

Fig. 10. Same as Fig. 9 except for July.

would hope to see a decrease in the differences with time as improvements are made to the objective analysis procedures used at NMC and at ECMWF. It must be remembered, however, that changes in the RMS differences might also result from the year to year variability of the circulation and changes in the observing network. Fig. 11 displays the RMS differences for the Northern and Southern Hemispheres for

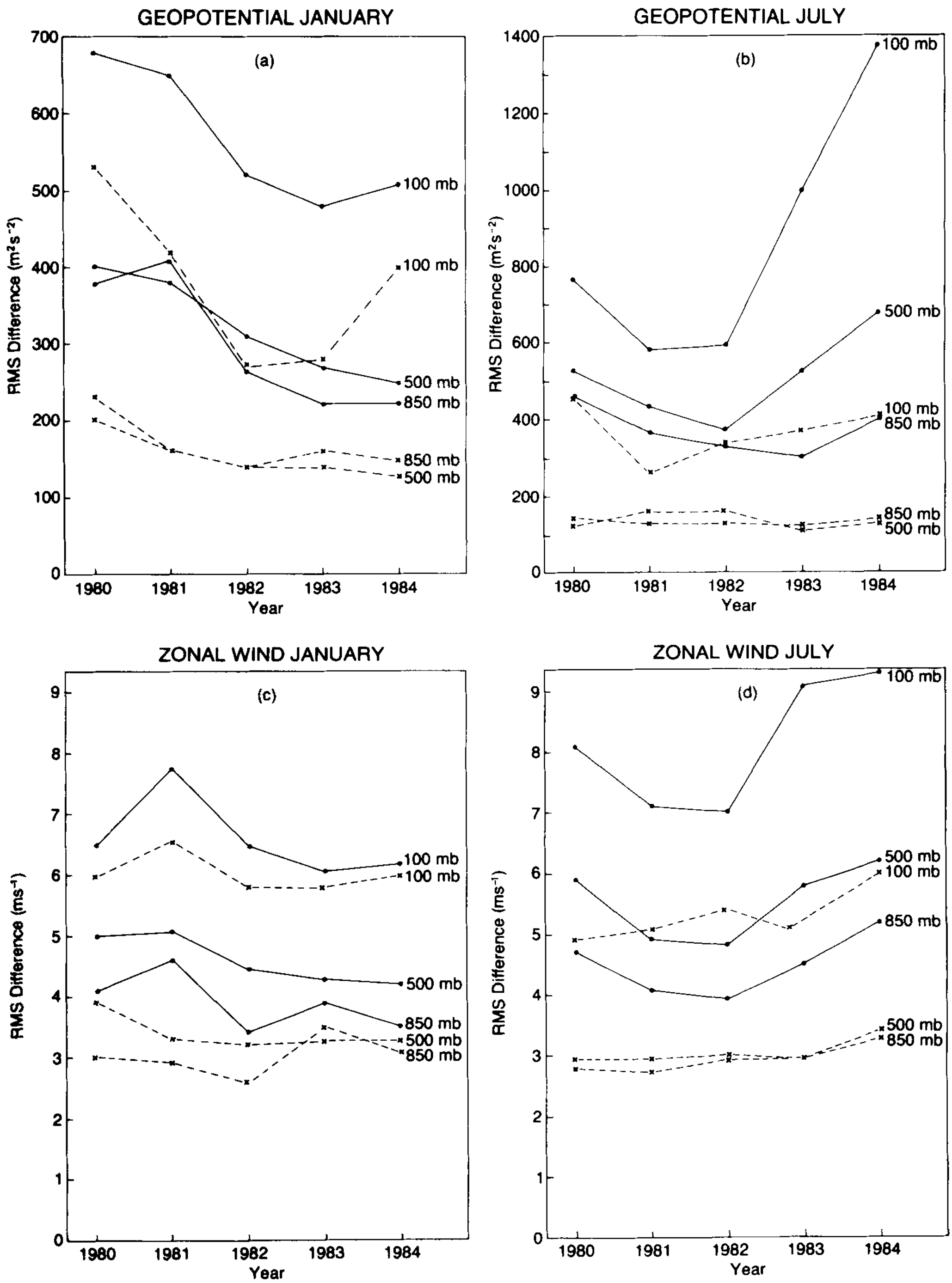

Fig. 11. The global RMS differences between the NMC operational analyses and the ECMWF/WMO dataset as a function of year for the Southern (solid lines) and the Northern (dashed lines) Hemispheres. (a) Zonal wind for January. (b) Zonal wind for July. (c) Geopotential for January. (d) Geopotential for July.

the zonal wind and the geopotential for January and July for each of the 5 years. The January results show nearly constant or slowly decreasing differences for both hemispheres over the five year period. The results for July show nearly constant or slightly increasing differences in the Northern Hemisphere while in the Southern Hemisphere, a noticeable decrease in the differences is followed by a striking increase in 1983 and 1984.

5. Summary and conclusions

The ECMWF/WMO dataset and the NMC operational analyses are compared for the five year period 1980–1984 for January and July for the horizontal wind, temperature, geopotential and specific humidity. With the exception of the specific humidity, the results suggest that, on the average, the daily analyses of the mid-latitudes of Southern Hemisphere and the extra-tropical Northern Hemisphere are reliable. There is a serious lack of agreement between the analyses in the tropics and over Antarctica where even monthly means cannot be computed with confidence. For the specific humidity, a typical daily analysis is reliable only for the Northern Hemisphere mid-latitudes during January and monthly means are reliable only in the mid-latitudes of both hemispheres.

Comparison of the OSSE results for November 1979 described in Daley and Mayer (1986) with the dataset comparison results of the present study shows good agreement in delineating the areas where reliable general circulation statistics can and cannot be obtained. The Southern Hemisphere mid-latitude errors tend to be smaller in the Daley and Mayer results, which implies greater confidence in the Southern Hemisphere than does the present study. It also should be noted that Daley and Mayer displayed the square root of the variance ratios rather than the variance ratios used in the present study.

The large differences in the tropics are not unexpected. The results of Daley et al. (1986) who studied errors in the analysis of planetary-scale flow, showed large errors in the tropics which were mainly the result of inhomogeneity of the observing network. Hence, it is probable that tropical analysis problems will continue for sometime.

When assessing the quality of datasets by direct comparison, it is difficult to make a definitive statement concerning the quality of the individual datasets. If the differences between the datasets are large it is not clear whether this results from only one of the analyses being poor or both of them. Finally, one must be cautious in extending the results of this study to data outside the 5-year period, since changes in the analysis systems and the observation network may change the character of the analyses.

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