A Comparison of NMC and GWC Analysis Field Temperatures with Aircraft Measurements

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ABSTRACT

Comparison between *in situ* aircraft observations of temperature and National Meteorological Center and Global Weather Central analysis fields of temperature is presented for a continental and oceanic flight route. The standard deviations of the temperature differences over several hundred flights are found to be 2.5 and 3.5°C for the continental and oceanic route, respectively. A bias towards warm temperatures of about 0.85°C for the analysis fields was found for the oceanic route. Only small differences are found between the NMC and GWC analysis field temperatures.

1. Introduction

Analysis fields of meteorological variables are used as input into the National Meteorological Center (NMC) operational forecast models. In addition, these fields are commonly used with experimental prediction models and in a variety of diagnostic research studies. Lately, these analyses have captured the interest of researchers who incorporate them into climate studies. With the availability of the NMC global analyses through the National Center for Atmospheric Research (NCAR), their use will undoubtedly continue to grow. As these fields are used more and more in ways not anticipated by their operational origins, questions arise as to the constraints and practical limitations that should accompany their use. The fundamental questions of accuracy and bias must be considered.

These analysis fields are generated by sophisticated mathematical methods from data collected at different times from a variety of sources such as rawinsondes, ocean buoys, and satellites (e.g., Kistler and Parish, 1982). The analyses are actually designed to handle broad scales of motion and, as a result, they tend to be relatively smooth; also possible effects from combining inhomogeneous data sets are unknown. In addition, the analyses reflect a number of choices such as quality control, concept of balance, and assimilating model in their design and execution. For some purposes, such as input to operational forecast models, these choices may be desirable, while for other purposes they may be undesirable. Very little information from independent comparisons is available to help judge the suitability of analysis fields for different applications. To our knowledge, the only study of this problem was made by McInturff (1978), who compared Aircraft Integrated Data Systems (AIDS) data from the Concorde with data obtained from rawinsondes and satellites. Unfortunately, only a small set of AIDS data was available, and comparison data were not space or time interpolated. However, good agreement was found between AIDS data and radiosonde reports when the two were nearly coincident in space and time, and there was better agreement between AIDS data and the 100 mb analysis field temperatures when the analysis was determined primarily by radiosonde rather than from satellite data.

The pilot study presented in this paper utilizes a much more extensive data set, but the approach used is similar to that of McInturff. *In situ* temperature measurements are compared with analysis fields of temperature produced by NMC and by the Air Force Global Weather Central (GWC). The purpose is simply to provide this diagnostic comparison. The data sets used and the known limitations associated with each of them are discussed in Section 2, while the results of the comparison analysis are presented in Section 3. A summary is presented in Section 4.

This work was accomplished as part of an engineering study of the temperatures to which aircraft are exposed; thus it considers only temperature. The available data include wind information, but an analysis of wind differences and similarities will have to await a future, more complete, study.

2. Data

In situ temperature measurements at airliner cruise altitudes (approximately 9–13 km) were taken from data collected in the Global Atmospheric Sampling Program (GASP). This program grew out of early suggestions by Steinberg (1973, 1977) that commercial aircraft be used as platforms for routine collection of additional atmospheric and meteorological data. The data collection phase of GASP lasted from March 1975 to July 1979. During this period, up to four commercial B747 aircraft in routine service were instrumented to obtain measurements of aerosols, trace constituents and meteorological variables (Perkins, 1976, and Perkins and Papathakos, 1977). The GASP system was automated to record data at nominal 5 min intervals during flights above 5.791 km (19,000 feet). When turbulence was encountered, or on entire selected flights, data were recorded at 4 s intervals, but for this study only 5 min interval data were retained. Temperatures were measured with a Rosemount temperature sensor for which the expected rms error is considerably less than 1°C (Stickney *et al.,* 1981). The temperature data, however, were recorded only in whole degrees Celsius.

The entire GASP data set consists of nearly 7,000 flights covering 273 different routes and detailed profiles from a few flights are presented in Section 3. However, most of the flight data presented in this study come from the two routes between New York–San Francisco and San Francisco–Tokyo. These two routes were selected to provide comparative results at similar latitudes over a data-rich continental region and over a relatively data-poor oceanic region.

The NMC and GWC data were taken from the 47 × 51 point octagonal Northern Hemisphere grid. The grid points over the region of interest are spaced at intervals ranging from 2.5 to 3.5 degs of latitude. This grid allows features in the analysis field greater than 550 to 800 km to be represented. On the assumption of a 250 m s^{-1} (500 knot) ground speed, these distances correspond to a 36–52 min time interval for the aircraft. Therefore, the aircraft resolution is a factor of 3 to 5 times finer than the gridded analysis fields.

The quality and sources of the data used to construct the analysis fields have changed over time. Descriptions of the NMC data assimilation system and its evolution are described by McPherson *et al.* (1979), Tracton *et al.* (1980) and Kistler and Parrish (1982). In summary, the NMC analyses represent the "final" analysis which, before September 1978, was a Flattery analysis and after that date an optimal interpolation analysis. We have no similar documentation for the GWC data. The comparison analysis presented in this paper used data in the 1975–1979 time frame and thus may not be fully representative of earlier or later time periods.

3. Analysis

Individual flight profiles were plotted for several of the GASP flights. Four of these were selected for illustration (see Figs. 1–4). These flight profiles consist of aircraft flight level, distance from the NMC tropopause, the GASP measured static air temperature with NMC and/or GWC interpolated temperatures, and aircraft latitude and longitude, all as a function of elapsed flight time. Values for the NMC and/or GWC temperatures were linearly interpolated to each aircraft observation with respect to horizontal position and time and also with respect to the logarithm of vertical pressure. Because the analysis fields were available at 0000 and 1200 GMT, interpolated values were never more than six hours from a map time. Also, as the fields were available at 500, 400, 300, 250, 200, 150 and 100 mb pressure levels, the flight levels were usually less than 25 mb from a map surface. Nevertheless, this space and time interpolation within the analysis fields acts to smooth them out even more. The GASP data were used here as reported, with no smoothing. This difference must be kept in mind when considering the comparisons presented next.

Figures 1 and 2 show two examples where there are substantial temperature differences between the *in situ* and analysis field temperatures. In these examples, large scale temperature features are not represented well by the analysis fields over the north-

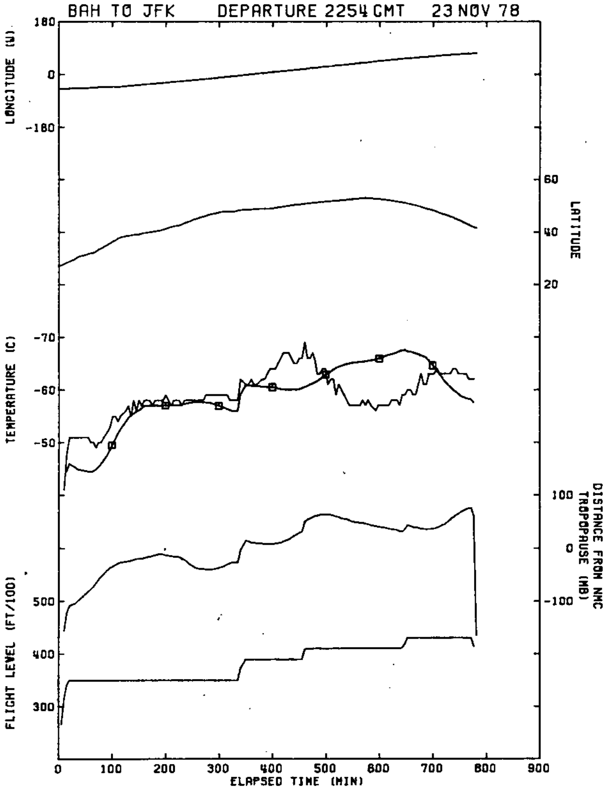

FIG. 1. Flight profile from Bahrain Island (BAH) to New York (JFK) 23 November 1978. Curves represent aircraft flight level, distance from the NMC tropopause, ambient air temperatures from GASP (no marking), NMC (square boxes on curve) latitude and longitude. (Flight Level 300 corresponds to 9.1 km and 500 corresponds to 15.2 km.)

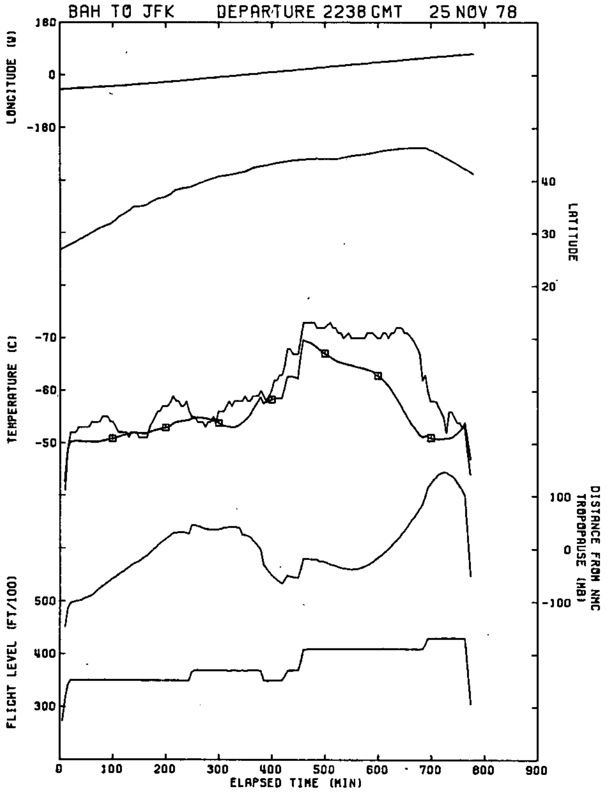

FIG. 2. As in Fig. 1, but for 25 November 1978.

western Atlantic Ocean. Figure 1 shows good agreement over most of the first half of the flight, and Fig. 2 moderately good agreement over the first half. Note that the apparent discontinuities in the analysis field temperatures and the distance from the tropopause are a result of changes in the aircraft flight level.

Figures 3 and 4 show much better agreement between the *in situ* and analysis field temperatures. The analysis field does not depict the severity of the cold air pocket between 375 and 525 min in Fig. 3, even though it has an horizontal extent of about 2000 km. This tendency to underestimate the temperature extremes was found to be typical in a study of thermally extreme (cold) flights (Jasperson and Nastrom, 1983). The agreement in Fig. 4 is very good. The analysis fields cannot be expected to depict the high frequency temperature spikes at 750 min in Fig. 3 and 220 minutes in Fig. 4. It is also of interest to note that the NMC and GWC analysis field temperature depict the temperature profile similarly. Differences tend to be less than 2°C, and often the two curves will bracket the *in situ* GASP temperature.

No effort has been made in this pilot study to filter the GASP data in order to remove high frequency variations. Inspection of differences, as in Fig. 1, illustrates the point that there are some long-wave features in the GASP data not found in the analysis fields. Also, the differences over the ocean have a bias as discussed next.

In order to obtain a statistical comparison between the GASP and NMC/GWC temperatures, the New York–San Francisco and the San Francisco–Tokyo routes were chosen. These routes totalled 146 and 108 flights, respectively. Figure 5 presents the frequency distribution of the differences in temperature between interpolated NMC analysis field temperatures and the GASP for the two routes. The continental route has relatively narrow and symmetric distribution of temperature differences while the oceanic route has a wider distribution as well as a noticeable bias. The means and standard deviations for the two routes are −0.01°C, 2.65°C, and 0.85°C, 3.55°C, respectively. This positive bias of the mean value of the oceanic route is surprising. It was noted in Figs. 3 and 4 that the NMC analyses underestimate cold extremes, presumably due to smoothing. For the same reason we could expect the NMC fields to miss warm extremes, in which case the mean difference of NMC from GASP would be near zero (as it is over the land route in Fig. 5). The nearly 1°C warm bias over the oceanic route could be the result of only cold extremes being missed or overestimating all the transoceanic temperatures. Nevertheless, resolution

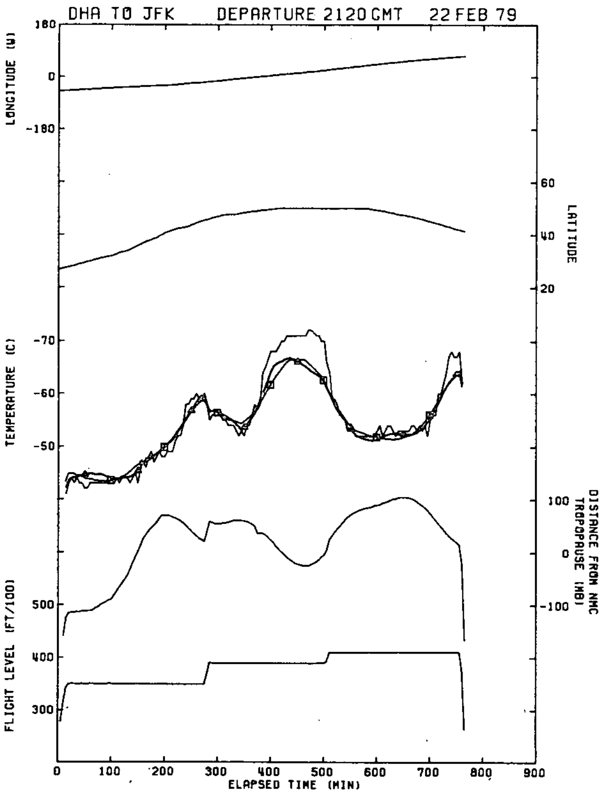

FIG. 3. As in Fig. 1, but from Dhahrain (DHA) to New York (JFK) 22 February 1979. Temperature curve with triangles denotes GWC analysis.

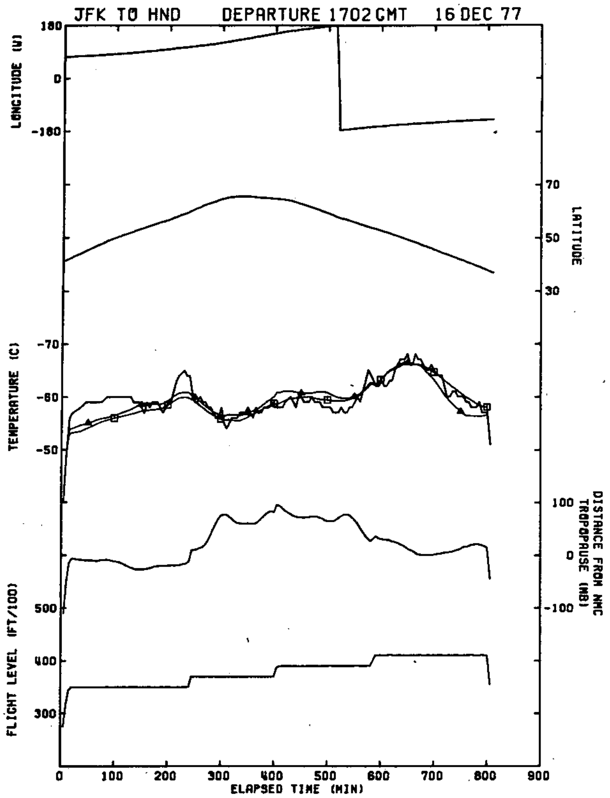

FIG. 4. As in Fig. 1, but from New York (JFK) to Tokyo (HND) 16 December 1977. Temperature curve with triangles denotes GWC analysis.

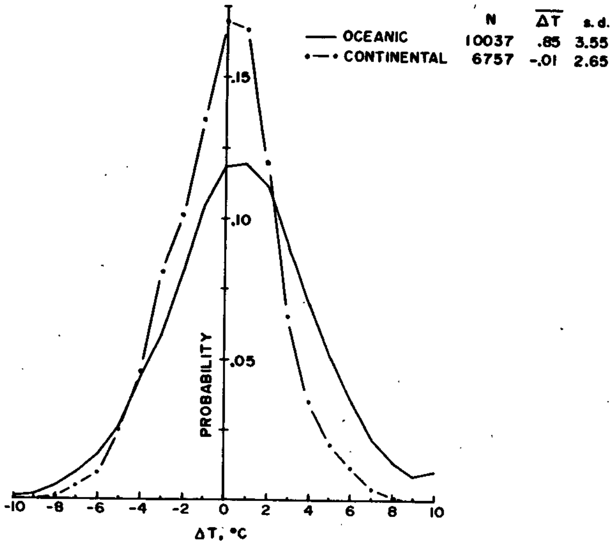

FIG. 5. Distribution of differences between the GASP and NMC analysis field temperatures ($\Delta T = T_{\text{analysis field}} - T_{\text{GASP}}$) for an oceanic and a continental route. The number of observations (N), the average temperature difference ($\overline{\Delta T}$), and the standard deviation (s.d.) for each route are given in the figure.

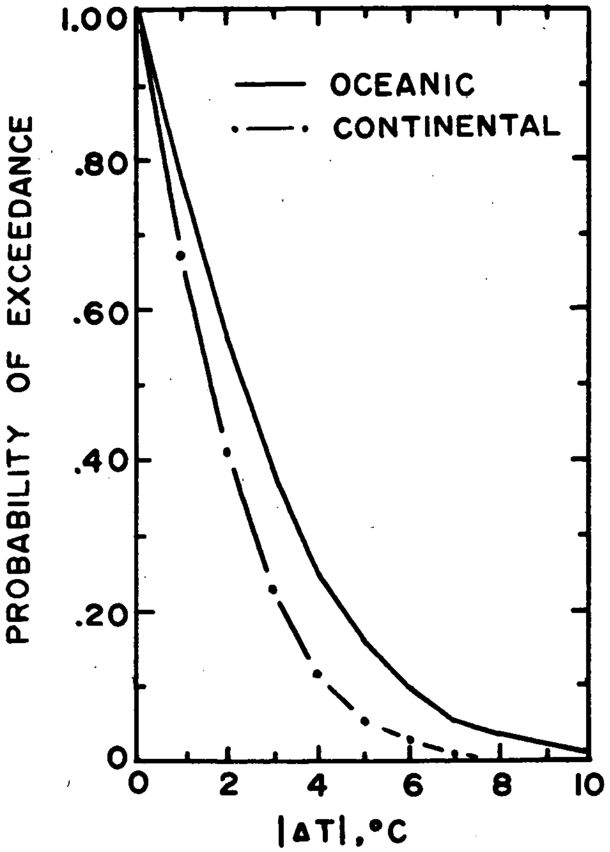

FIG. 6. Probability of exceedance between the GASP and NMC analysis field temperatures for an oceanic and a continental route.

of the question is beyond the scope of this brief paper. The number of observations in each figure is the actual number of observations recorded by the GASP aircraft. Because atmospheric temperatures are correlated over distances of a few hundred miles, these numbers do not reflect the number of independent observations. A reduction in these numbers by about a factor of 6 would approximate the number of independent observations (Nastrom and Jasperson, 1983).

Figure 6 presents the probability of exceedance distributions for the GASP/NMC temperature differences for each of the two routes. The figure shows that there is a 50% probability that the temperature differences will be greater than 1.7°C and 2.4°C for the continental and oceanic routes, respectively, and only a 10% probability that the differences will be greater than 4.3°C and 6.0°C for the two routes, respectively.

A comparison between the GASP temperatures and the NMC and GWC analysis field temperatures is presented in Fig. 7. The statistical differences between the NMC and GWC temperatures is relatively small although there is a tendency for the GWC temperatures to have a cold bias relative to NMC temperatures for the continental route.

The data were stratified in several other ways as

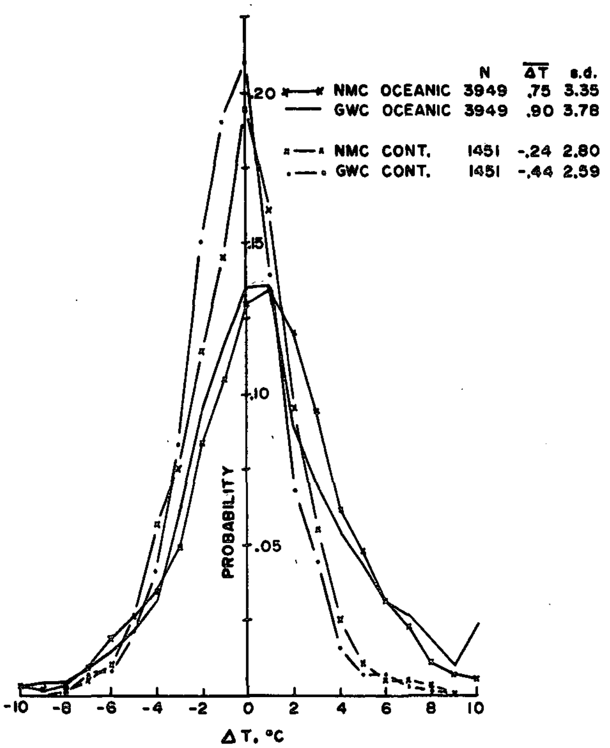

FIG. 7. As in Fig. 5, but only for observations which are common to all three data sets.

shown in Table 1a. These included the difference in time between the GASP observations and the nearest map time, and the difference in pressure between the GASP and map pressure. In neither case was there a pattern of improvement that suggested that the differences depend upon length of interpolation times or upon vertical distances. This result could be due to the fact that there are many temperature features too small to be represented on the analysis grid, i.e., the errors due to horizontal smoothing are larger than the errors due to small separations in time or in the vertical. For example, examination of individual flights shows that there are often major features that are not fully reproduced on the analysis grid. Furthermore, cases not cited here have shown that this misrepresentation occurs over more than one consecutive period. The size of the temperature difference variance associated with these two sources overshadows any variance due to time or space interpolation between maps.

The data were also stratified by the condition of whether or not a grid level existed between the tropopause and the aircraft altitude. The assumption was that the temperature changes between grid levels that did not encompass the tropopause would be subject to less interpolation error than between levels encompassing the tropopause. No evidence was found to support this assumption, however.

Table 1b is analogous to Table 1a, except that only the GASP data which had both corresponding NMC and GWC data are included. The conclusions remain the same even though the numbers of observations are reduced.

4. Conclusions

Analysis fields of meteorological variables are commonly used by research meteorologists for a variety of different purposes. With the archiving of the NMC fields at NCAR and the acceptance of their continuing improvement, particularly over data-sparse regions of the globe, their use will undoubtedly increase. Yet, to our knowledge, numbers defining the characteristics or accuracy of these analyses are not commonly available.

Specific comparisons at airline cruise altitudes (near the 200 mb level) between independent *in situ* observations of temperature and NMC and/or GWC analysis fields have been presented in this paper. Also, temperature difference statistics for two long routes, one continental and one oceanic, have been presented. For the continental route, the NMC temperature differences show a mean near zero and a standard deviation near 2.5°C though the GWC fields appear to be biased slightly towards colder temperatures (mean = −0.36°C). The oceanic route, on the other hand, shows a standard deviation near 3.5°C and a bias towards warm temperatures for both the NMC and GWC fields (mean = 0.85 and 0.88°C, respectively). These differences, representing thousands of data points, are relatively large when one considers that the standard deviation of the observed GASP temperatures at a constant altitude is only about 10°C. Overall, there appears to be only a small difference between the NMC and the GWC temperature analysis fields. Stratification of the temperature difference data by small time difference or vertical distance from an analysis map does not produce any systematic improvement in the statistics. Examination of several individual flights suggests that this is partially due to the high frequency structure that the analysis fields are not expected to reproduce. However, it also appears to be a reflection of the large-scale temperature differences that sometimes are not represented properly over several consecutive analysis maps. Stratification of data into observations that had at least one analysis level between the tropopause and the aircraft also did not produce any significant change in the statistics.

Only the time period between March 1975 and July 1979 is specifically reflected in the results presented. Changes in the statistics as a result of recent changes or improvement in the quantity or quality of data assimilated into the analysis fields cannot be stated. However, the statistics presented in this paper reflect characteristics of the analysis fields present for

TABLE 1. Statistics for the temperature differences between the GASP and NMC and GWC temperatures for the oceanic and continental routes for two data stratifications.

	Oceanic						Continental					
	Mean		Standard deviation		Number		Mean		Standard deviation		Number	
Stratifying variables	NMC	GWC	NMC	GWC	NMC	GWC	NMC	GWC	NMC	GWC	NMC	GWC
(a) All available data												
Time (h)												
2	0.82	1.03	3.73	3.75	4352	1790	0.14	−0.03	2.67	2.92	2022	561
4	0.96	1.08	3.65	3.85	7926	3149	0.32	−0.11	2.58	2.54	4038	1007
6	0.85	0.88	3.55	3.75	10037	4064	−0.01	−0.36	2.65	2.56	6757	1557
Pressure (mb)												
10	1.13	0.55	3.57	3.62	2501	1061	−0.26	−0.62	2.73	2.68	2422	444
20	0.69	0.65	3.45	3.61	7874	3323	0.01	−0.33	2.56	2.39	5604	1296
Pressure level between aircraft and tropopause	0.62	0.65	3.43	3.82	6955	2968	−0.26	−0.79	2.68	2.61	4921	865
(b) All common data												
Time (h)												
2	0.77	1.07	3.39	3.82	1675	1675	−0.08	−0.22	3.25	3.09	455	455
4	0.96	1.10	3.31	3.89	3034	3034	−0.09	−0.22	2.77	2.59	901	901
6	0.75	0.90	3.35	3.78	3949	3949	−0.24	−0.44	2.80	2.59	1451	1451
Pressure (mb)												
10	0.68	0.56	3.13	3.73	946	946	−0.90	−1.06	2.98	2.76	338	338
20	0.65	0.66	3.31	3.64	3208	3208	−0.18	−0.43	2.70	2.41	1190	1190
Pressure level between aircraft and Tropopause	0.57	0.65	3.29	3.86	2864	2864	−0.75	−0.84	2.77	2.61	843	843

more than 4.5 years of data. The study should serve a useful purpose—to alert researchers who use these analysis fields that they should be sensitive to the possible limitations and biases of the analyses.

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