Comparison of NMC Analysis Model Winds and Temperatures with Aircraft Measurements

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Case study comparisons between in situ aircraft observations of wind and temperature data and National Meteorological Center analysis fields are presented. The aircraft route, from Bahrain near the Persian Gulf to New York, lies approximately half over the data-rich area of Europe and the Middle East and half over the data-poor area of the North Atlantic. The average difference in the wind speed is found to be almost 12 m/s. Surprisingly, the wind differences are sometimes as large over the land area as over the ocean.

I. Introduction

ANALYZED fields of meteorological variables are the starting point for all weather forecasting schemes. At the National Meteorological Center (NMC), which supplies the global forecasts of winds and temperatures aloft used by nearly all domestic air carriers, sophisticated mathematical methods are used to generate the analysis fields from data collected at different times and from a variety of sources such as radiosondes and satellites.[1] Concern has been expressed[2] that the NMC products could be improved by using more data or by being updated more often. In a highly competitive environment, fuel savings of 1% from better meteorological forecasts would have a large impact on the profitability of the entire airpline industry. As discussed by Brown,[3] the NMC forecast models will be improved over time, but the NMC analyses and forecasts will still continue to be produced each 12 h. Steinberg[2] has suggested that significant improvement could result if the forecasts were updated more often using a less complicated analysis and forecasting scheme that would require less computer time than the present scheme; and Carlson and Sundararaman[4] have suggested that a nowcasting approach be applied, at least over the continental United States, by installing a network of radar installations designed to continuously measure the winds aloft.

Whatever modifications to the present system of meteorological support are finally adopted, it seems clear that a forecast can be no better than the analysis upon which it is based and a first step should be to insure that the analyses are the best possible. However, very little information from independent comparisons is available in the open literature to help judge the accuracy and bias of the NMC analyses, especially over the oceanic regions. McInturff[5] and Jasperson and Nastrom[6] have compared temperatures from aircraft observations with those from NMC analyses and Jasperson and Nastrom also compared aircraft temperatures with those from analyses of the Air Force Global Weather Center (GWC). They found that in a statistical sense, the comparisons with NMC and GWC were nearly equal. McIntuff compared a small sample of winds from the Concorde with geostrophic winds from NMC height fields and McCalla[7] recently presented a statistical comparison of NMC analyzed and forecast winds with aircraft reports over the ocean. Her study goes a long way toward filling the gap of information needed to assess the NMC analyses. Another recent study[8] illustrates that forecasts are improved by including aircraft wind data in the analysis.

However, statistical results of global or monthly mean errors are not well suited for describing how any errors occur or for ultimately diagnosing their origin and taking steps to adjust for them. For example, are the differences between the analysis and the observations random along a flight path or are they systematic due to a shift in the geographical phase of a wave in the wind field? Examination of case studies is the first step toward diagnosis of the source of differences. The purpose of this paper is to present two selected case study comparisons of NMC and observed wind and temperature data from aircraft measurements.

The route selected for the case studies given here, from Bahrain on the Persian Gulf to New York, is approximately half over the data-rich region of Europe and the Middle East and half over the data-poor North Atlantic region. The time period of the two cases studied, November 1978, is after the time when the so-called optimum interpolation analysis method was introduced at NMC, so these results should be of interest to meteorologists. This time period represents a portion of the historical archives of NMC data, a data base that provides the input to meteorological and engineering design studies of environmental conditions. It is important to be aware of problems in the historical data base; thus, our purpose in this paper is simply to provide a pilot study diagnostic comparison of NMC analysis data with observations. The data sets used and their known limitations are discussed in Sec. II and the results of the comparison analysis are presented in Sec. III. A summary is given in Sec. IV.

II. Data

In situ wind and temperature measurements at airliner cruise altitudes were taken from data collected in the Global Atmospheric Sampling Program (GASP) conducted by NASA. 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

Received Nov. 6, 1984; presented as Paper 85-0344 at the AIAA 23rd Aerospace Sciences Meeting, Reno, Nev., Jan. 14-17, 1985; revision received March 29, 1985. This paper is declared a work of the U.S. Government and therefore is in the public domain.

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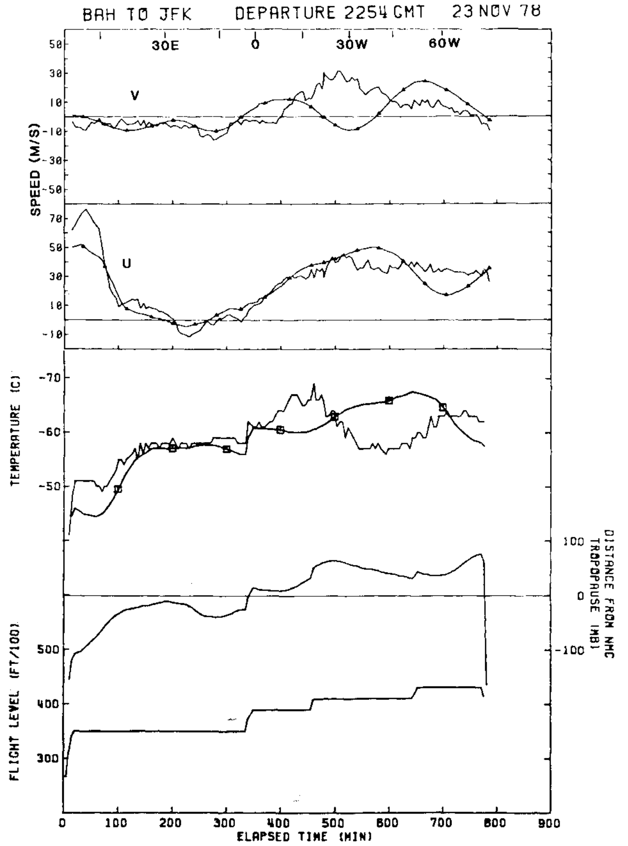

Fig. 1 Flight profile from BAH to JFK beginning on 23 Nov. 1978 (aircraft longitude is indicated near the top).

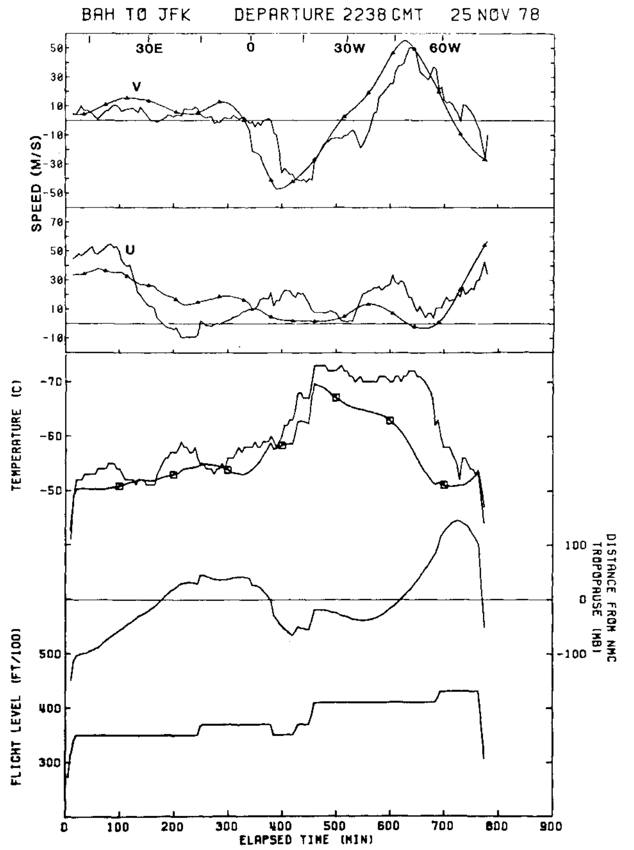

Fig. 2 Flight profile from BAH to JFK beginning on 25 Nov. 1978 (aircraft longitude is indicated near the top).

measurements of aerosols, trace constituents, and meteorological variables.[9,10] The GASP system was automated to record data at nominal 5 min intervals during flight above 5.8 km. 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. Winds were taken from the onboard computer connected with the inertial navigation system and have an uncertainty of 5%. Winds were recorded to the nearest knot (about 0.5 m/s) and degree. McPherson and Rasch[11] found that the aircraft winds compare very well with radiosonde data over North America using ASDAR data from one flight. Temperatures were measured with a Rosemount temperature sensor[12] for which the expected rms error is considerably less than 1°C, although temperature data were recorded only in whole degrees Celsius. The entire GASP data set consists of nearly 7000 flights covering 273 different routes. The route selected for the case studies given here, from Bahrain to New York, is approximately half over the data-rich region of Europe and the Middle East and half over the data-poor North Atlantic region.

The NMC wind and temperature 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 about 2.5-3.5 deg of latitude, allowing features in the analysis fields greater than 550-800 km to be represented. Assuming a 250 m/s (500 knots) ground speed, these distances correspond to a 36-52 min time interval for the aircraft. Therefore, the aircraft resolution is a factor of three to five times finer than the gridded analysis fields.

The quality and sources of data used to construct the NMC analyses have changed over time and the evolution of the NMC data assimilation system has been discussed by Kistler and Parrish.[1] In brief, all available radiosonde and satellite data are gridded through use of an optimum interpolation scheme that uses the previous 12 h forecast as a first-guess field. The data used here were obtained from the archive files maintained at the National Center for Atmospheric Research. Corresponding data from the GWC analyses were not available for the times used here.

III. Analysis

Flight profiles of wind, temperature, and aircraft altitude are given in Figs. 1 and 2. The zonal wind u, meridional wind v, and temperature curves based on NMC data are identified by symbols. The corresponding flight tracks are shown in Figs. 3 and 4, superposed on the NMC 200 hPa (mb) height and temperature analyses for the times nearest the end of each flight. To aid comparison of the flight profiles with the maps, the aircraft's longitude is indicated near the tops of Figs. 1 and 2. The NMC data were interpolated to the location of the GASP aircraft linearly with respect to location and time. Wind data are from the 200 mb level (Fl 390), while temperature data were interpolated to the aircraft flight level at each point linearly with respect to the logarithm of pressure. Interpolation between the gridded fields further acts to smooth the features. The GASP data were used with no smoothening and this difference must be kept in mind when comparing them with the NMC data. The temperature comparisons were discussed previously by Jasperson and Nastrom[6] and are included here to illustrate that more insight of the comparison can be achieved by using all available meteorological variables simultaneously. The lower panels in Figs. 1 and 2 show the aircraft flight level and the distance from the tropopause (in mb). The tropopause level was determined from NMC gridded fields, interpolated in space and time to the location of the GASP aircraft. (At the flight levels considered here, 10 mb distance from the tropopause corresponds to approximately 1000 ft.)

In Fig. 1, the NMC and GASP winds agree fairly well over the data-rich land area in the eastern hemisphere. Some relatively minor differences are noted, but except near 50°E

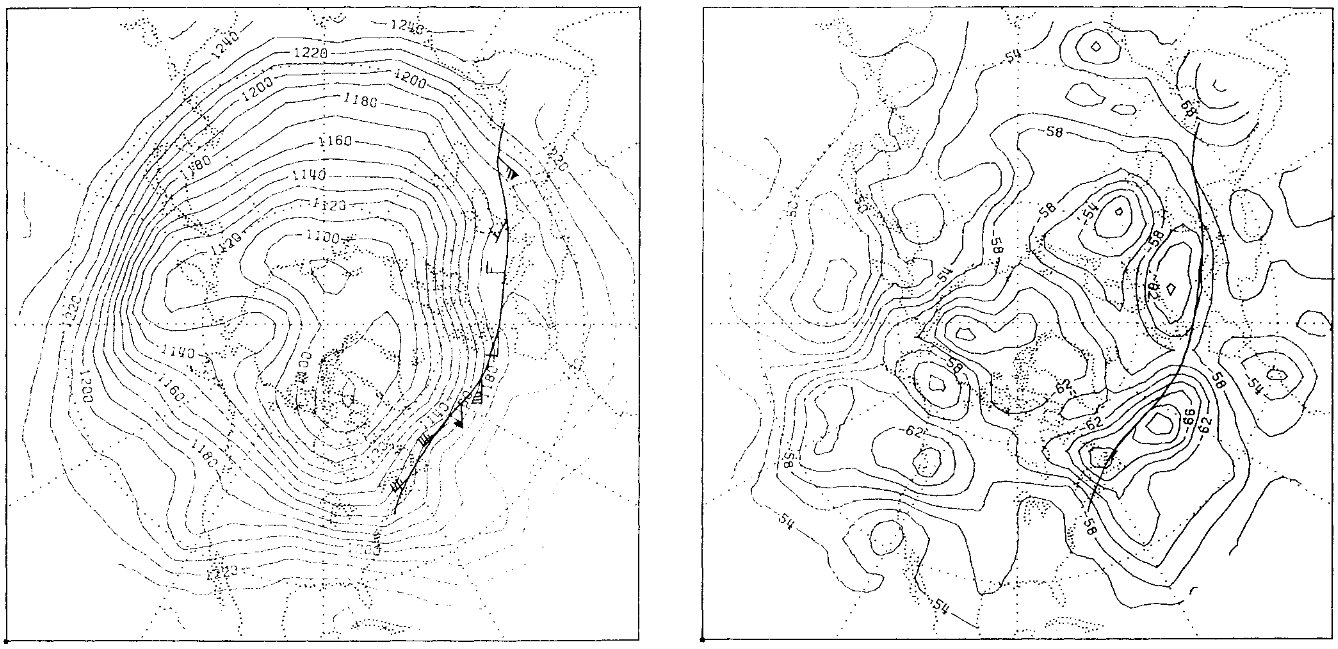

Fig. 3 Pressure height map at 200 hPa from NMC grids for 24 Nov. 1978, 1200 GMT. The GASP flight route is shown, with wind vectors indicated each 15° longitude (half barb = 5 m/s; full barb = 10 m/s; flag = 50 m/s). Pressure contours are labeled in dm.

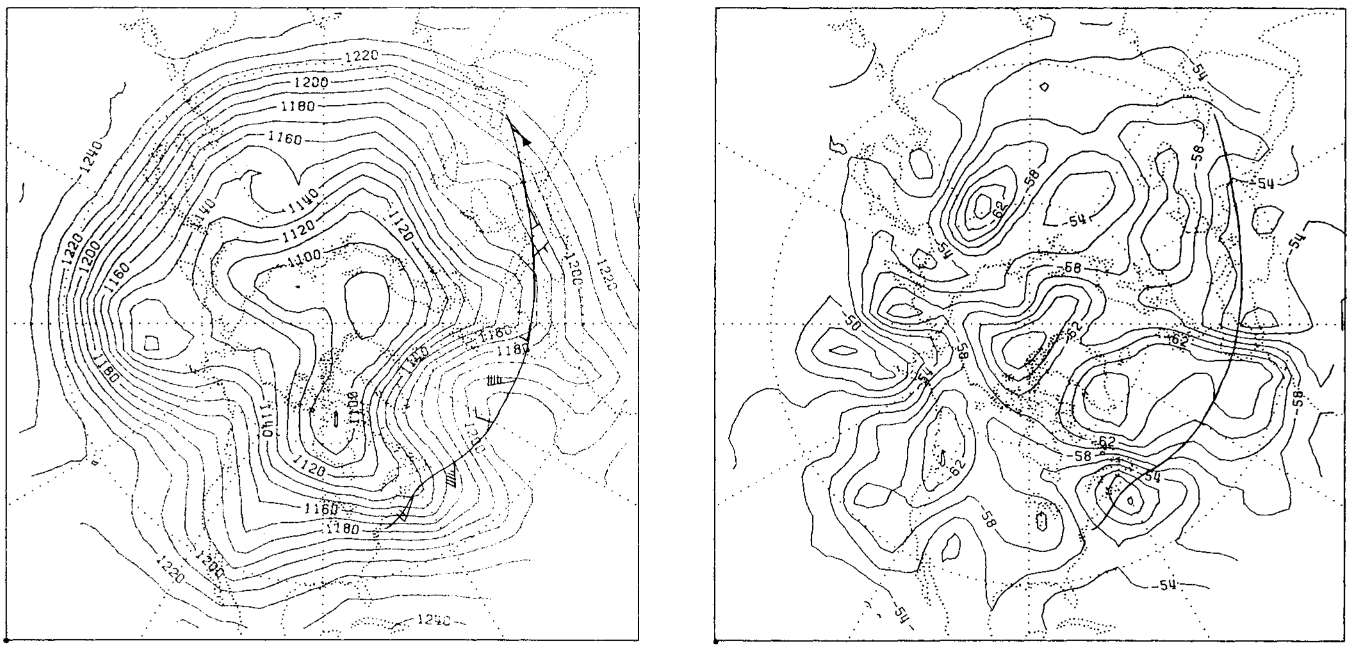

Fig. 4 As in Fig. 3, except for 26 Nov. 1978, 1200 GMT.

they are less than 10 m/s. Over the ocean, at elapsed times greater than 350 min, however, the NMC data appear to have a wave structure that is barely supported by the GASP data. In fact, the meridional wind suggests they are out of phase. Suggestion of a wave is stronger in the GASP temperature data, but again the wave phase seems reversed between the GASP and NMC data. The wave in the NMC wind data can be deduced from Fig. 3 by applying the geostrophic approximation, that winds are parallel to the height contours and their speed is inversely related to the spacing of the contours. The axis of a wave trough is seen near 15°W and a wave ridge is seen near 45°W. The net effect of this wave in the average differences between the GASP and NMC data is very small, especially for the zonal wind speed, as shown by the summary statistics in Table 1, although the average absolute value of the differences is 7.5 m/s in u and 11.5 m/s in v. Note that changes in aircraft altitude produce discontinuities in the temperature curves in Figs. 1 and 2, but have small influence on the GASP wind curves. This implies that comparison with the NMC winds at the 200 mb level is justified, especially as our primary goal is to compare the qualitative features of the differences along the flight routes.

In Fig. 2, the main feature in the meridional wind profile is a wave over the North Atlantic, between about 5°W and 65°W. This wave is present, but with smaller amplitude, in the zonal wind profile. Both NMC and GASP data show this wave, although the GASP data indicate it is positioned about 10° longitude farther west than the NMC data. For example, NMC places the axis of the ridge, where winds switch from southward to northward, at 27°W while the GASP data show

Table 1 Summary of wind comparisons between GASP and NMC data, m/s

	Flight departure date			
	23 Nov. 78		25 Nov. 78	
	u	v	u	v
Average GASP-NMC	0.5	3.3	2.0	−1.4
Standard deviation of difference	9.4	15.2	14.4	13.5
Average absolute difference (|GASP-NMC|)	7.5	11.4	13.0	10.4

it at 37°W. At first glance, the NMC temperature analysis over this region appears 10-15°C too warm compared with the GASP data. However, if the NMC temperature data were shifted about 10° longitude westward, as suggested by the wind comparison above, the temperature differences would be significantly reduced. This case illustrates that simultaneous comparisons of wind and temperature data help to better understand the observed differences with the NMC fields.

In the eastern hemisphere in Fig. 2, at elapsed times less than about 350 min there are large differences between the GASP and NMC zonal wind curves. Near 20°E the NMC data show westerly (eastward) winds at 15 m/s, while the aircraft actually encountered easterly winds at 10 m/s, a 25 m/s (50 knots) difference. The differences in the meridional wind curves in this region are small and irregular, while the GASP temperature curve suggests a feature with wavelength near 15° longitude was present. The GASP zonal wind curve, on the other hand, is dominated by a large-scale variation between 45°E and 0°E, which one would expect is usually detected by the NMC analyses.

IV. Summary

Analysis fields of meteorological variables provide the initial conditions for all forecasts. Because of the features of the data assimilation model used at NMC, the rms vector wind error between the input data and the final analysis is known to be about 6 m/s (12 knots).[1] This pilot study compared the NMC winds with observations from the GASP data set along a route that is approximately half over the ocean and half over a relatively data-rich land area. The flights were chosen to match those used in an earlier comparison study of temperature data. Surprisingly, the differences between the GASP and NMC data were as large over the land area as over the ocean in one case. In both cases, the average absolute differences given in Table 1 are about twice as large as the known difference between the input data and the final analysis, although the standard deviations of the differences are about the same magnitude as found by McCalla.[7] In our cases, we see that the differences are not random or uniformly biased, but arise from shifts in the long wave patterns between the observations and the analyses.

Due to the small sample of data used here firm conclusions regarding any problems with the NMC analyses cannot be drawn, nor has any attempt been made to diagnose the cause of the differences found. Possible reasons for the differences include errors in the input data at NMC, reliance on the first-guess field due to the lack of data at NMC, errors in the GASP data, problems of interpolation or extrapolation, among others. Despite the limitations of this study, it is suggestive of what could be learned with a larger data comparison including diagnostic checks of the differences found. Also, it should serve to alert meteorological and engineering design researchers using the archived NMC analyses to consider the limitations of the NMC fields when interpreting their results.

References

[1]Kistler, R. E. and Parrish, D. F., "Evolution of the NMC Data Assimilation System, September 1978—January 1982," *Monthly Weather Review,* Vol. 110, 1982, pp. 1335-1346.

[2]Steinberg, R., "MERIT—A Man/Computer Data Management and Enhancement System for Upper Air Nowcasting/Forecasting in the United States," *Proceedings Nowcasting II Symposium*, European Space Agency, Norrkoping, Sweden, Sept. 1984.

[3]Brown, J. A., "Aviation Forecast Guidance from the National Meteorological Center," Paper presented at Sixty First Annual Meeting, Transportation Research Board, Washington, D.C., Jan. 18-22, 1982.

[4]Carlson, H. C. and Sundararaman, N., "Real-Time Jetstream Tracking: National Benefit from an ST Radar Network for Measuring Atmospheric Motions," *Bulletin of the American Meteorological Society,* Vol. 63, 1982, pp. 1019-1026.

[5]McInturff, R. M., "A Comparison of AIDS Data from the Concorde with Data Obtained from Rawinsonde and Satellite," *Preprints, Fourth Symposium on Meteorological Observations and Instrumentation,* American Meteorological Society, Boston, 1978.

[6]Jasperson, W. H. and Nastrom, G. D., "A Comparison of NMC and GWC Analysis Field Temperatures with Aircraft Measurements," *Journal of Climate and Applied Meteorology*, Vol. 23, 1984, pp. 1421-1426.

[7]McCalla, M. R. P., "Verification of NMC's Spectral Model Jet Level Oceanic Winter Season Forecasts by Use of Aircraft Data," *Monthly Weather Review,* 1985, in press.

[8]Barwell, B. R. and Lorenc, A. C., "A Study of the Impact of Aircraft Wind Observations on a Large-Scale Analysis and Numerical Weather Prediction System," *Quarterly Journal of the Royal Meteorological Society,* Vol. 111, 1985, pp. 103-130.

[9]Perkins, P. J., "Global Measurements of Gaseous and Aerosol Trace Species Using Automated Instrumentation on 747 Airliners," NASA TM-73810 (NTIS N78-13670/2GI), 1976.

[10]Perkins, P. J. and Papathakos, L. C., "Global Sensing of Gaseous and Aerosol Trace Species Using Automated Instrumentation on 747 Airliners," NASA TM-73810 (NTIS N78-13670/2GI), 1977.

[11]McPherson, R. D. and Rasch, G. E., "An Example of ASDAR Winds in the NMC Analysis," *Preprints Fourth Symposium on Meteorological Observations and Instrumentation,* American Meteorological Society, Boston, 1978.

[12]Stickney, T. M., Shedlov, M. W., Thompson, D. I., and Yakos, F. J., "Rosemount Total Temperature Sensors," Rosemount, Inc., Minneapolis, Tech. Rept. 5755, 1981.