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Characteristics of FGGE Level IIIa Data Sets from the NMC Global Data Assimilation System

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by

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I. INTRODUCTION

The first global weather experiment of the WMO's global atmospheric research program (FGGE or GWE) is a major international effort to comprehensively observe the global atmosphere. The observational data are classified into two levels: Level I are the raw observations, e.g., radiance measurements, and Level II are processed observations, e.g., layer-mean temperatures. The designation Level III is used to indicate an analysis of the observational data into a three-dimensional spatial array. Two further designations, a and b, are appended to the level designations--'a' implies that the data are assembled in near real time, whereas 'b' implies that the data are collected in a nonreal time mode.

As one of its contributions to the United States effort in support of the global weather experiment, the National Meteorological Center of the National Weather Service undertook to produce Level IIIa data sets--i.e., analyses of near real time observations. This committment was to be accomplished within the framework of NMC's operational mission, but had to take into account two important factors--the large number of observations to be provided by new instruments and the nonsynoptic scheduling of the observations.

It is the purpose of this paper to highlight the principal characteristics of the data assimilation system being used by NMC to fulfill its commitment to produce its FGGE Level IIIa data sets. It is hoped that this information will be useful to prospective users of these data which are being archived at the NOAA National Data Records Center in Asheville, North Carolina.

II. THE COMPONENTS OF THE DAS

The data assimilation system (DAS), introduced into NMC operations on 21 September 1978, is comprised of a numerical weather prediction model and an objective analysis system. A full description of this system is being published (cf. McPherson et al., 1979). The DAS is scheduled to run on the computer 9 hours after the synoptic hours, 00 and 12 GMT; thus the system runs twice each day. Each computer run is composed of four steps:

1. An analysis is made for the previous synoptic hour using data that were observed within (plus or minus) 3 hours of that synoptic hour. These data will be between 6 and 12 hours old by the time of the computer run.

2. Using this analysis, the numerical weather prediction model carries out a forecast to a valid time 6 hours beyond the synoptic hour. This prediction constitutes a first-guess for the state of the atmosphere.

3. The first guess is updated--i.e., an analysis is performed--using data observed within (plus or minus) 3 hours of the guess' valid time, viz., synoptic hour plus 6 hours. These data will be between 2 and 6 hours old by the time they are used.

4. The numerical weather prediction model now employs its updated forecast to initiate another 6-hour prediction. This new forecast will be used as a first-guess for the synoptic hour analysis in the next computer cycle of the DAS.

The archived Level IIIa data are restricted to the analysis produced for the synoptic hour in step 1. Because the DAS is run within the generally tight time schedule of the operational computer system, it is possible for sporadic difficulties to disrupt the production of the Level IIIa analysis data set. In such instances the data set will be missing on the archived tape. It is also possible that the trouble might arise after the initial analysis has been made in step 1; then, the Level IIIa data will appear on the archived tape, but the subsequent analyses will not reflect the normal assimilation of data as outlined above.

IIa. The Numerical Prediction Model

A global finite-difference primitive equation numerical model is used in the DAS. It employs a 2.5° lattice of latitudes and longitudes, and has nine layers of vertical resolution partitioned into six equal mass tropospheric layers and three equal mass stratospheric layers in the interval between 50 mb and the tropopause. The model includes parameterizations of all standard physical processes. For more information on this model, reference may be made to NMC Office Note 178 (Stackpole, 1978) which is available to limited numbers on request. For use in data assimilation, the model incorporates a dynamic initialization method reported by Dey (1979).

IIb. The Objective Analysis Model

The DAS uses the objective analysis model developed by Bergman (1979). This is a system that permits one to take into account the stochastic aspects of observations and forecast guess fields. The system is termed multivariate, optimum interpolation, because wind and mass data are permitted to mutually interact, in accord with their statistical structure, in order to determine the statistically optimal representation of the several fields.

The statistical framework necessary to specify the system combines empirical data and a theoretical model based on the thermal wind equation. The exigencies of operational production time constraints have been accommodated by restricting the general method.

The analysis is carried out using the residual between the forecast first guess and the observed data. In final form, the analysis of each parameter is a weighted combination of up to ten observations. The weights are determined by solving a system of simultaneous equations with coefficients reflecting the auto- and cross-correlations existing among the data and the analysis parameter. The selection of the ten (or less) observations is made on the basis of the correlation of the observed parameters with the analysis parameter. The correlation is generally inversely proportional to the error variance associated with the observed datum. Thus the analysis reflects the most accurate and highly correlated observations, in combination with the first guess estimates provided by the forecasts.

IIc. Objective Analysis Method

The analysis system is designed to update the dependent variables of the prediction mode, viz., the surface and tropopause pressures, and the layer mean values of temperature, zonal and meridional wind components, and the specific humidity.

The surface pressure is updated first using only reported surface pressures. This update is done on the full 2.5° grid of the prediction model. The analysis uses the departures from the United States standard atmosphere's pressure at the elevation of the observation. After analysis the field is filtered using a spherical harmonic analysis, rhomboidally truncated at wavenumber 34.

The tropopause pressure is updated on a 5° subset of the prediction model's grid. This analysis uses reported tropopause pressures only and constrains the result by climatological norms. The reconstruction of the full grid array of tropopause pressure is accomplished through representation of the data with a rhomboidal 24 spherical harmonic fit.

The sigma coordinate system is redefined using the updated surface and tropopause pressures. This defines new layer mean pressures. The model's dependent variables are interpolated the small vertical distance necessary to account for this adjustment of the layer-mean pressures.

The guess values of the layer-mean dependent variables are then filtered using a spherical harmonic operator. The tropospheric variables are fit with rhomboidal 34 truncation; the stratospheric variables are fit with rhomboidal 24 truncation. The filtered 2.5° grid data are next used to construct residuals at all observation points through bilinear interpolation to the positions of the observations.

The upper air variables are then analysed on a 5° subset of the grid. The analysis uses the multivariate, optimum interpolation method outlined earlier. These updated values are then represented by the spherical harmonic filter--again using rhomboidal 34 and 24 truncation in the troposphere and stratosphere, respectively. The filtered residuals are reconstructed on the 2.5° grid and added to the previously filtered first guess.

We note that the filtering outlined above is necessary to avoid destabilization of the continuing data assimilation system, and we also note that the harmonic resolution is not less than that used in NMC's routine operational global analysis system.

III. THE TYPICAL DATA BASE

During the first 8 months of the operational use of the DAS, most of the data sets associated with FGGE have been introduced. Specific dates on which particular data sets were introduced are:

Japanese satellite cloud-tracked winds	8 Jan 79
Drifting buoys	11 Jan 79
TIROS in Southern Hemisphere	5 Mar 79
TIROS in Northern Hemisphere	30 Apr 79
European satellite cloud-tracked winds	5 May 79

The winds reported by ASDAR-equipped aircraft, constant-level balloons, and by OMEGA-system dropsondes have been routinely introduced into the operational data base throughout this time.

A typical global data count partitioned into 6-hour blocks is given in Table 1.

VARIABLE: TEMPERATURE

Type	Time			
	00Z	06Z	12Z	18Z
RAOB	724	65	699	143
TIROS A	690	760	800	562
TIROS B	120	113	75	81
TIROS C	197	211	243	157

VARIABLE: WIND

RAOB	943	346	961	460
ASDAR	71	90	27	66
AIRCRAFT	740	704	657	741
OMEGA	-	2	3	3
SAT WINDS:				
United States	453	-	349	116
Japan	335	-	373	-
Europe	694	-	432	-
C.L.B.	-	-	48	12

VARIABLE: SURFACE PRESSURE

LAND	3941	4551	4550	4260
SHIP	653	425	647	448
BUOYS	23	21	174	21
BOGUS	188	0	225	0

Table 1. Global data available 20 May 1979.

The TIROS satellite observations are divided into three categories: A, B. C. The A category is for largely cloud-free regions; type C is for cloudy regions and uses microwave data; type B is for partly cloudy regions where corrections to IR channel data have been effective. The TIROS data are presently used only over ice-free bodies of water.

The wind data are not uniformly distributed in the vertical; the bulk of aircraft reports are for levels near 250 mb. The satellite winds are obtained by tracking cloud elements. These reports tend to be bimodally distributed in the vertical at the cumulus and cirrus levels. The ASDAR data are highly accurate measurements taken on specially equipped, commercial aircraft.

The surface pressure 'bogus' reports are subjective estimates of mean sea level pressure prepared by NMC's Forecast Division personnel to supplement other reports.

IV. ANALYSIS FIT TO OBSERVATIONS

It is useful to examine the average fit of the analysis to the observations, as long as one recognizes that a good analysis system must account for the variability in observations due to errors of various types. Table 2 displays the root-mean-square deviation of the analysis from the observations for a typical analysis time.

PARAMETER: LAYER MEAN TEMPERATURE (°K)

	Pressure at Layer Midpoint (mb)										
TYPE	928	777	600	450	350	275	225	175	125	85	60
RAOB	1.5	1.5	1.0	1.3	1.3	1.6	2.0	1.7	1.7	1.5	2.1
TIROS A	1.0	0.6	0.7	0.7	0.8	0.9	1.2	1.0	1.9	1.2	1.2
TIROS B	1.0	1.3	0.8	0.9	1.0	1.3	1.3	1.2	2.2	1.3	1.3
TIROS C	1.8	1.5	1.4	0.9	0.8	0.9	1.2	1.3	1.5	0.9	1.8

PARAMETER: VECTOR WIND (m/s)

	Pressure										
TYPE	1000	850	700	500	400	300	250	200	150	100	70
RAOB	4.1	3.9	4.0	4.2	5.2	6.5	6.9	6.2	5.1	4.5	3.7
ASDAR	-	-	3.9	-	-	5.6	-	-	-	-	-
AIRCRAFT	-	-	5.3	9.8	7.5	7.6	8.9	7.1	5.8	-	-
OMEGA	-	3.1	1.6	1.8	3.7	3.9	6.7	-	-	-	-

SAT WINDS:

United States	-	3.0	2.6	4.4	9.3	9.0	10.4	7.1	-	-	-
Japan	2.4	4.7	7.4	6.8	4.0	11.9	13.6	15.3	10.2	13.1	-
Europe	3.1	3.5	5.4	5.4	16.8	14.5	6.1	5.7	5.8	-	-
C.L.B.	-	-	-	-	-	-	-	-	6.0	-	-

PARAMETER: SURFACE PRESSURE (mb)

LAND	1.71
SHIPS	2.10
BUOYS	2.26
BOGUS	0.88

Table 2. RMS deviation of analysis from observations 12 GMT 20 May 79.

V. MONITORING OF THE PERFORMANCE OF THE SYSTEM

For the past 8 months the DAS has been operational at NMC. The performance of the system is routinedly monitored using five different networks of radiosonde stations. Both the analysis and the first-guess fields are compared with the station observations for a number of levels and parameters. Monthly summaries of the mean and rms deviations have been tabulated, and are documented in NMC Office Notes that are available in limited numbers on request.

The table below presents the results for 500-mb height and 250-mb wind speed for a North American and a Southern Hemispheric network. On the whole, the RMS deviation of the analyzed 500-mb heights is about 50% of the first guess value. The 250-mb RMS wind speed deviation of the guess is about 50% larger than that of the analysis.

110 STATION NORTH AMERICAN NETWORK:

	RMS 500-mb Height (m)		RMS 250-mb Wind Speed (m/s)	
	Analysis	Guess	Analysis	Guess
OCT 78	15.4	26.0	5.3	7.5
NOV 78	15.1	26.5	3.2	7.4
DEC 78	16.4	33.6	5.5	7.9
JAN 79	17.8	36.1	5.3	8.1
FEB 79	15.6	30.8	4.9	7.2
MAR 79	15.0	29.1	5.1	7.7
APR 79	14.7	25.7	4.9	7.4
MAY 79	14.8	24.6	5.1	7.5

31 STATION SOUTHERN HEMISPHERE NETWORK:

	RMS 500-mb Height (m)		RMS 250-mb Wind Speed (m/s)	
	Analysis	Guess	Analysis	Guess
OCT 78	23.0	42.8	5.2	9.3
NOV 78	22.1	43.4	4.8	9.0
DEC 78	19.5	38.5	5.1	8.3
JAN 79	19.0	42.0	4.8	8.1
FEB 79	19.1	34.4	5.0	7.9
MAR 79	17.5	36.8	4.7	8.3
APR 79	17.1	34.2	4.8	8.9
MAY 79	18.7	35.5	5.0	9.2

Table 3. Summary statistics for the NMC DAS' performnance. RMS deviation between observation and either analysis or first-guess of 500-mb height in meters and 250-mb wind speed in meters/second.

Future Plans. When the second TIROS satellite begins to provide operational data, the entire global atmospheric thermal field will be observed within any 6-hour window. An expanded set of satellite cloud-tracked winds and a greater number of ASDAR equipped aircraft will assist in defining the circulation. These observational systems are not restricted to operation during the GWE, but will continue to function indefinitely. Therefore, work in global data assimilation will continue to have high priority in operational numerical weather analysis and prediction.

Over the next year, our work at NMC will be directed toward improving the performance of the DAS by introducing a spectral initialization and prediction model into the system. Close attention will also be directed to the formulation of the nonadiabatic processes used in the assimilation model and to the generalization of the data selection step of the optimum analysis system.

References

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