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A SUMMARY OF THE FIRST-GUESS FIELDS USED FOR OPERATIONAL ANALYSES

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I. Introduction:

The NMC machine analysis procedures can be segmented into three portions: (1) the pre-analysis processing of the meteorological data (decoding, merging, sorting, checking, correcting, condensing, etc.); (2) the technique of obtaining first-guess fields of the parameters to analyzed; and (3) the "analysis" method itself, i.e., the procedure used to obtain values of a parameter at grid points by treatment of the data. Each of these portions is of much importance in determining the quality of the analyses obtained.

It appears certain that parts (1) and (3) are to remain permanent features of the operational analysis system. The use of first-guess fields has proved to be very successful at NMC, although this approach has not had universal acceptance. With sufficient data first-guess fields may be unnecessary; however, the value of guess fields for checking data is great and their use for this purpose should not be overlooked.

This paper concerns itself with the details of part (2) -- obtaining first-guess fields for analyses of constant-pressure height and temperature from 1000 to 100 mb.

The current procedures for obtaining the guess fields from 1000 to 500 mb are described in a memorandum by Gustafson and McDonell (1). In order to consolidate that material into this paper some of their work is reproduced here. For additional details and explanations, the reader should refer to the memorandum. Procedures for analyzing the 50, 30, and 10 mb levels are described in a publication by Finger, Woolf, and Anderson (2).

In the equations which appear later, D-values are in meters and temperatures (T) are in deg. C. A table of reference heights used to form the D-values is given in Appendix I. Subscripts are used to denote pressure in decibars. Superscripts which are numbers denote the forecast hour (e.g., ^{00} indicates an analysis). Primes are used to denote first-guesses. The first-guess fields are discussed in the order they are used.

II. First-Guess Height and Temperature Fields for Constant-Pressure Analyses, 1000 to 100 mb:

A. 1000 mb:

The 1000 mb D-field is not analyzed directly but is derived hydrostatically from objective sea-level pressure and surface temperature analyses by assuming the surface temperature to be the mean between sea-level and 1000 mb:

$$D_{10}^{00} = \frac{58.58\,(T_S^{00} + 273)\,(P_S^{00} - 1000)}{P_S^{00} + 1000} - 113, \qquad (1)$$

where P_S^{00} = analyzed sea-level pressure in mb, and T_S^{00} = analyzed surface temperature.

The first-guess sea-level pressure field for this analysis is a six-hour (or twelve-hour for backup) numerical forecast. To analyze the surface temperature field a crude first-guess is computed by assuming the 1000 mb temperature proportional to the (500/1000)-mb forecast thickness and isothermal from 1000 mb to the surface:

$$T_S' = .0526\,(D_5^6 - D_{10}^6) + 14.3\,. \qquad (2)$$

The above procedures are consistent with the manner in which sea-level pressure is calculated by the Reed 1000 mb forecast model. The only purpose for the temperature analysis is to have reasonable values for computing D_{10}^{00} and nothing more. In the absence of data, these procedures will not degrade the analysis/forecast cycle. The Shuman primitive equation forecasts currently are not used to obtain first-guess fields, but a consistency of methods should be provided when they are used.

B. 850 mb, 700 mb, and 500 mb:

The following information is taken from (1) and the reader is referred to this paper for the derivations and explanations.

1. 500 mb (Preliminary):

A preliminary 500 mb D-analysis (D_5^*) is made using a numerical forecast for the first-guess field:

$$D_5' = D_5^{12}\,. \qquad (3)$$

2. 700 mb:

The 700 mb D- and T-fields are analyzed next using the following first-guess equations:

$$D_7' = .539\,D_5^* + .461\,D_{10}^{00} + S_7'\,, \qquad (4)$$

where S_7' is a guess stability factor $(-70 < S_7' < +40)$.

$$T_7' = .0492 \, (D_5^* - D_{10}^{00}) - 4.6 . \quad (5)$$

3. <u>850 mb</u>:

The 850 mb D- and T-fields are analyzed next using the following first-guess equations:

$$D_{8.5}' = .468 \, D_7^{00} + .532 \, D_{10}^{00} + S_{8.5}' , \quad (6)$$

where $S_{8.5}'$ is a guess stability factor $(-25 < S_{8.5}' < +12)$.

$$T_{8.5}' = T_7^{00} + \gamma \, (D_7^{00} - D_{8.5}') + 1554 . \quad (7)$$

where γ is the mean lapse rate of the (500/1000)-mb layer, computed from

D_{10}^{00}, D_7^{00}, and D_5^*.

4. <u>500 mb (Final)</u>:

The 500 mb D-field is reanalyzed at the same time the 500 T-field is being analyzed. The first-guess equations are given below:

$$D_5' = D_5^* + A , \quad (8)$$

where A is the adjustment required to make D_5' conform to D_{10}^{00}, D_7^{00}, and allowable limits for the stability factor S_7.

$$T_5' = .0984 \, (D_5' - D_7^{00}) - 21.2 . \quad (9)$$

C. <u>400 mb</u>:

The 400 mb first-guess D-field is obtained by using a family of regression equations developed by the Travelers Research Center (3). A smoothing technique (described in Appendix II) is performed on the coefficients of the equations so that discontinuities are not introduced into the field. The form of the equations is given below:

$$D_4' = a_0 + b_0 D_5^{00} + c_0 T_5^{00} . \quad (10)$$

The coefficients for the family of equations are given in Table 1.

The 400 mb first-guess temperature is obtained by assuming the 400 mb temperature to be proportional to the (400/500)-mb thickness:

$$T_4' = .1502\,(D_4' - D_5^{00}) - 31.7\,. \qquad (11)$$

D. <u>300 mb</u>:

The 300 mb first-guess D-field is formed by using a "corrected" 300 mb D-forecast. This correction is the error found in the 500 mb D-forecast and a layer stability test:

$$D_3' = D_3^{12} + (D_5^{00} - D_5^{12}) + B\,, \qquad (12)$$

where B is the adjustment required to make D_3' conform to D_5^{00}, D_4^{00}, and a reasonable stability factor for the (300/500)-mb layer ($-40 < S_4 < +20$).

The 300 mb first-guess temperature field is formed by using regression equations derived from observations available on NMC data tapes for the period March 1962 through February 1963. Reports from all stations were used and the sample was separated into four seasons: spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February). The equations are of the following form:

$$T_3' = a_1 + b_1 D_5^{00} + c_1 D_3' + d_1 T_7^{00} + e_1 T_5^{00}\,. \qquad (13)$$

Notice that the guess 300 mb D-value is used as one of the specifiors in the equation. The coefficients are given in Table 2.

E. <u>200 mb</u>:

The 200 mb first-guess D-field is obtained by using a "corrected" 200 mb D-forecast. The correction used is the error found in the 300 mb D-forecast:

$$D_2' = D_2^{12} + (D_3^{00} - D_3^{12})\,. \qquad (14)$$

A check on the stability factor for the (200/400)-mb layer (similar to what is done for 300 mb) has not yet been programmed.

The 200 mb first-guess temperature field is obtained in a like manner as for the 300 mb temperature field (and from the same data sample):

$$T_2' = a_1 + b_1 D_3^{00} + c_1 D_2' + d_1 T_5^{00} + e_1 T_3^{00}\,. \qquad (15)$$

The coefficients for this equation are listed in Table 3.

F. 250 mb:

Because 250 mb is not an international mandatory data level and therefore not transmitted in all messages, it is analyzed after the 300 and 200 mb levels. This procedure is followed so that the analyzed 200 mb fields can be used to influence the 250 mb first-guess fields. By assuming that temperature varies linearly with the logarithm of pressure, the following relationship may be used:

$$T'_{2.5} = .1684\,(D_2^{00} - D_3^{00}) - .55\,T_2^{00} - .45\,T_3^{00} - 104.4\ . \quad (16)$$

Using this guess 250 mb temperature, the (250/300)-mb guess thickness may be computed to obtain the 250 mb first-guess D-field:

$$D'_{2.5} = D_3^{00} + 2.67\,(T_3^{00} + T'_{2.5}) + 261\ . \quad (17)$$

For any station which reports height and temperature at 300 mb but only temperature at 250 mb, equation (17) is used to calculate a 250 mb D-value to be used as real data.

G. 100 mb:

Because of the availability of a family of regression equations for the 100 mb level prepared by the U. S. Navy (4), the 100 mb level is analyzed next. The coefficients are smoothed by the procedure described in Appendix II. The form of the equations is given by:

$$D'_1 = a_0 + b_0\,D_2^{00} + c_0\,T_2^{00}\ , \text{ and} \quad (18)$$

$$T'_1 = a_1 + b_1\,D_2^{00} + c_1\,T_2^{00}\ . \quad (19)$$

The coefficients for these equations are given in Table 4.

H. 150 mb:

The first-guess fields for the 150 mb level are obtained by using regression equations derived from the same data sample referred to in sections D and E. The form of these equations is given by:

$$D'_{1.5} = a_0 + b_0\,D_2^{00} + c_0\,D_1^{00} + d_0\,T_2^{00}\ , \text{ and} \quad (20)$$

$$T'_{1.5} = a_1 + b_1\,D_2^{00} + c_1\,D_1^{00} + d_1\,T_2^{00} + e_1\,T_1^{00}\ . \quad (21)$$

The coefficients for these equations are given in Table 5.

III. Remarks :

In the absence of data at any level, the current system will return as first-guess height fields the forecasts at 1000, 500, and 200 mb. The main emphasis has been placed on the height analyses for input to the three-level model. In its initialization section, the primitive equations model uses height and temperature analyses to interpolate to the "sigma" surfaces it requires. Even so, the height fields are more important than the temperature fields. Additional developmental effort directed toward obtaining first-guess fields using the forecast fields from the primitive equations model is needed. One of the most intriguing of the new items which will be available is the tropopause forecast.

The technique of analyzing height and temperature fields concurrently is a significant time saver. A temperature analysis consumes less than ten seconds of 7094-II time when appended to a height analysis; whereas, the same analysis done as an independent field requires about 50 seconds. In the regions of no data, there is no advantage whatever for doing one field before the other, since the first-guess fields will prevail in either case. The wind reports can be utilized in the height analyses, and this suggests doing the height analyses before the temperature analyses. The fact that the forecasts being used to form the first-guess fields are not without errors further complicates the problem of building three-dimensional first-guess height and temperature fields which will produce acceptable analyses.

It appears that the analysis system needs to allow manual control (monitoring), which can be exerted in a simple and speedy manner. The programmed procedures and manual procedures should be worked out in tandem, so that inconsistencies do not develop because of a poor "machine-man" mixture.

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APPENDIX I

Reference heights used to form NMC D values

Level (mb)	Ref. Ht.(meters)
1000	113
850	1457
700	3011
500	5572
400	7181
300	9159
250	10357
200	11784
150	13618
100	16206

APPENDIX II

Discontinuities are introduced into the first-guess fields if a family of regression equations which have been grouped by latitude bands is applied directly to an array of grid points. These irregularities manifest themselves at the grid points which straddle the latitude circle along which the grouping has been made. This procedure necessitates a need for smoothing the guess field before the analysis begins. The smoothing procedures usually remove some realistic details in order to get at the spurious irregularities.

A simple weighting procedure was devised and has been incorporated into the analysis procedures at NMC and is described below:

Let Φ_G = the latitude of the grid point in question,

Φ_N = the mean latitude of the group just to the north of the grid point, and

Φ_S = the mean latitude of the group just to the south of the grid point.

Two weights are computed by using linear interpolation in sine of latitude:

$$W_N = \frac{\sin \Phi_G - \sin \Phi_S}{\sin \Phi_N - \sin \Phi_S} , \text{ and}$$

$$W_S = 1 - W_N .$$

Coefficients to be used at the grid point are calculated by multiplying each coefficient to the north by W_N and each to the south by W_S and adding each of the two products.

These "weighted" coefficients could be computed once and for all, but storage space and input time required would be excessive. The procedure allows as much stratification of the coefficients as seems warranted; and while other weighting procedures could be considered, the one described gave very satisfying results when tested.

Table 1

400 mb

Coeff.		Latitude Band (deg.)					
		0-25	25-35	35-45	45-55	55-65	65-90
April	a_o	183.7	152.3	143.7	134.6	137.9	128.8
	b_o	.8756	.9700	.9773	.9874	.9864	.9785
	c_o	7.3768	7.0320	6.6940	6.3514	6.4886	6.2758
July	a_o	148.4	148.4	158.7	146.0	144.1	149.0
	b_o	.9701	.9701	.9602	.9869	.9954	.9843
	c_o	5.7897	5.789	7.2195	6.8312	6.7501	6.9528
October	a_o	167.0	151.9	147.8	140.5	138.6	133.6
	b_o	.9088	.9759	.9693	.9884	.9939	.9723
	c_o	5.9704	7.0010	6.7653	6.4886	6.4968	6.5264
January	a_o	158.6	149.0	139.2	130.8	131.2	132.3
	b_o	.9308	.9700	.9785	.9933	.9830	.9813
	c_o	6.2700	6.7407	6.4547	6.1692	6.2990	6.3408

Table 2

300 mb

Coeff.		Latitude Band (deg.) 0-90
Spring	a_1	-62.7
	b_1	-.112112
	c_1	.108651
	d_1	.096774
	e_1	-.838439
Summer	a_1	-51.9
	b_1	-.081466
	c_1	.078709
	d_1	.053320
	e_1	-.315959
Fall	a_1	-61.9
	b_1	-.107812
	c_1	.105860
	d_1	.100937
	e_1	-.811750
Winter	a_1	-62.4
	b_1	-.110036
	c_1	.107132
	d_1	.062144
	e_1	-.800966

Table 3

200 mb

Coeff.		Latitude Band (deg.) 0-90
Spring	a_1	-84.1
	b_1	-.119847
	c_1	.111832
	d_1	.163963
	e_1	-.693233
Summer	a_1	-77.6
	b_1	-.104692
	c_1	.094890
	d_1	.055254
	e_1	-.563950
Fall	a_1	-81.9
	b_1	-.113029
	c_1	.106708
	d_1	.149875
	e_1	-.641786
Winter	a_1	-88.1
	b_1	-.125736
	c_1	.121858
	d_1	.138774
	e_1	-.756461

Table 4

100 mb

Month	Coeff.	Latitude Band (deg.) 0-19	20-29	30-39	40-49	50-59	60-69	70-90
January	a_0	373.9	273.5	309.1	588.6	674.3	1133.8	1133.8
	b_0	.693	.701	.715	.890	.953	1.145	1.145
	c_0	7.968	5.966	6.319	10.922	11.985	18.900	18.900
	a_1	-72.7	-74.0	-66.1	-44.9	-27.0	2.6	2.6
	b_1	-.024	-.024	-.022	-.008	.002	.011	.011
	c_1	-.170	-.220	-.098	.243	.480	.948	.948
February	a_0	445.4	293.9	303.3	560.8	603.8	909.4	909.4
	b_0	.722	.716	.713	.859	.980	1.134	1.134
	c_0	9.747	6.589	6.149	10.118	9.543	14.100	14.100
	a_1	-67.8	-67.9	-66.5	-47.4	-36.0	-16.4	-16.4
	b_1	-.023	-.021	-.024	-.013	-.001	.009	.009
	c_1	-.070	-.071	-.101	.188	.274	.562	.562
March	a_0	469.1	368.1	362.6	554.3	629.8	811.9	811.9
	b_0	.696	.681	.704	.885	.919	.960	.960
	c_0	9.917	7.624	7.087	9.714	10.614	13.867	13.867
	a_1	-58.4	-65.1	-62.7	-46.1	-35.4	-34.6	-34.6
	b_1	-.027	-.024	-.023	-.011	-.007	-.004	-.004
	c_1	.055	-.063	-.052	.184	.330	.520	.520
April	a_0	508.7	338.9	355.3	447.1	505.0	624.0	726.4
	b_0	.765	.685	.658	.765	.850	.892	1.021
	c_0	11.495	7.103	6.667	8.140	8.704	10.636	11.455
	a_1	-57.8	-69.0	-65.2	-53.5	-44.3	-37.4	-22.6
	b_1	-.024	-.023	-.023	-.015	-.009	-.007	.004
	c_1	.092	-.146	-.127	.052	.175	.280	.475

Table 4 (Contd)

Coeff.		Latitude Band (deg.)						
		0-19	20-29	30-39	40-49	50-59	60-69	70-90
May	a_0	466.4	537.8	531.4	520.0	505.0	742.7	693.6
	b_0	.729	.614	.647	.718	.778	.986	.966
	c_0	10.159	9.639	9.216	8.881	8.229	12.103	10.784
	a_1	-65.0	-62.4	-58.4	-47.9	-42.6	-30.0	-30.6
	b_1	-.028	-.028	-.022	-.015	-.007	-.002	-.003
	c_1	-.108	-.115	-.056	.113	.171	.375	.339
June	a_0	82.6	592.2	542.8	478.0	557.0	640.1	669.2
	b_0	.849	.638	.563	.603	.799	.912	.949
	c_0	4.433	10.844	8.366	6.935	8.329	9.554	9.737
	a_1	-103.4	-72.3	-66.4	-52.0	-40.2	-32.5	-31.6
	b_1	-.017	-.026	-.029	-.024	-.008	-.002	-.004
	c_1	-.716	-.296	-.280	-.033	.171	.284	.267
July	a_0	-125.4	354.5	601.6	444.1	506.1	595.9	517.7
	b_0	.800	.715	.531	.503	.623	.925	.842
	c_0	-.050	7.009	8.750	4.981	6.294	8.368	6.175
	a_1	-104.0	-78.4	-54.9	-50.6	-40.7	-34.4	-36.2
	b_1	-.015	-.018	-.029	-.028	-.008	-.003	-.009
	c_1	-.719	-.354	-.107	-.070	.148	.231	.151
August	a_0	-103.3	577.8	605.4	477.8	461.8	582.2	569.4
	b_0	.826	.588	.507	.567	.700	.881	.972
	c_0	.698	9.719	8.671	6.407	6.172	8.528	7.947
	a_1	-107.5	-72.8	-57.3	-47.7	-43.8	-36.4	-34.2
	b_1	-.015	-.022	-.027	-.025	-.010	-.007	.000
	c_1	-.783	-.303	-.134	.013	.101	.214	.231

Table 4 (Contd)

Month	Coeff.	Latitude Band (deg.) 0-19	20-29	30-39	40-49	50-59	60-69	70-90
September	a_0	-103.0	491.4	450.8	432.2	398.6	522.1	424.6
	b_0	.850	.703	.600	.626	.698	.875	.969
	c_0	1.019	9.681	7.242	6.783	6.161	8.296	5.668
	a_1	-117.0	-75.2	-66.5	-56.4	-47.1	-38.9	-39.3
	b_1	-.007	-.022	-.028	-.023	-.013	-.006	.001
	c_1	-.852	-.310	-.266	-.078	.090	.221	.164
October	a_0	310.2	597.9	390.9	412.1	416.8	371.5	679.5
	b_0	.753	.684	.668	.706	.750	.839	.987
	c_0	7.769	11.870	7.278	7.600	7.613	6.596	11.665
	a_1	-93.5	-56.3	-65.6	-55.2	-49.8	-44.2	-33.1
	b_1	-.021	-.023	-.023	-.019	-.013	-.006	.002
	c_1	-.541	.074	-.149	.026	.102	.181	.346
November	a_0	336.5	543.4	457.8	458.1	270.0	763.2	789.6
	b_0	.789	.713	.690	.756	.689	.886	1.114
	c_0	8.619	11.244	9.146	8.997	5.740	13.998	12.440
	a_1	-79.0	-64.4	-62.6	-55.5	-50.3	-22.7	-11.1
	b_1	-.022	-.022	-.023	-.017	-.012	-.001	.016
	c_1	-.269	-.039	-.047	.068	.108	.551	.601
December	a_0	459.9	390.5	338.9	518.4	526.9	937.1	799.6
	b_0	.684	.664	.720	.832	.903	1.087	1.211
	c_0	9.584	7.913	7.031	9.976	9.633	15.822	12.363
	a_1	-63.6	-67.8	-65.9	-52.5	-38.3	-13.5	-15.2
	b_1	-.032	-.022	-.022	-.014	-.001	.010	.016
	c_1	-.098	-.096	-.087	.131	.290	.655	.593

Table 5

150 mb

Season	Coeff.	Latitude Band (deg.) 0-90	Season	Coeff.	Latitude Band (deg.) 0-90
Spring	a_o	238.9	Spring	a_1	-30.0
	b_o	.82001		b_1	-.02422
	c_o	.15471		c_1	.02221
	d_o	4.27940		d_1	.20422
				e_1	.24260
Summer	a_o	263.8	Summer	a_1	-20.9
	b_o	.81500		b_1	-.01947
	c_o	.13177		c_1	.01363
	d_o	4.53135		d_1	.18910
				e_1	.40437
Fall	a_o	249.2	Fall	a_1	-26.7
	b_o	.82267		b_1	-.02168
	c_o	.16039		c_1	.01939
	d_o	4.50013		d_1	.20661
				e_1	.30745
Winter	a_o	234.3	Winter	a_1	-39.3
	b_o	.78531		b_1	-.03380
	c_o	.21458		c_1	.03063
	d_o	4.15231		d_1	.14158
				e_1	.13465